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Life-Time of Vibration Insulators Made of Metal Rubber Material under Random Load

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Abstract: MR material (Metal Rubber) is manufactured by cold pressing of randomly placed wire spiral made of stainless steel. It has high strength, large energy dissipation coefficient, large working ability in aggressive environment, under high and low temperature. Vibration insulators with elastic-damping elements made of MR material are used widely. A research of life-time of vibration insulators made of MR material under random load is presented in this study. Dependencies of vibration insulator life-time on random load stress are obtained for different relative density, wire diameter, preliminary static deformation of MR material. Different types of MR material wearing are considered. Results of the present research are necessary for design of vibration protection systems with vibration insulators made of MR material.

Key words: Metal Rubber material, life-time, stress, random load, design

INTRODUCTION

MR material (Metal Rubber) is manufactured by cold pressing of randomly placed wire spiral made of stainless steel (Ponomarev, 2014; Troynikov and Moskalev, 2014). It has high strength, large energy dissipation coefficient, large working ability in aggressive environment, under high and low temperature. Properties of this material don't change during time of its storage. Vibration insulators with elastic-damping elements made of MR material are used widely in aerospace industry, railway, cars, etc. (Ao *et al*., 2005; Jiang *et al*., 2008; Troynikov *et al*., 2014; Xia *et al*., 2009). For example, it is used for reducing of resonant stress level in gas turbine engine (Popov *et al*., 2014). Damper made of MR material can work in combination with a hydrodynamic damper of shaft (Falaleev *et al*., 2014).

Load on transport system is random often. Thus for design of vibration protection system with vibration insulators made of MR material it is necessary to know a life-time of these vibration insulators under random load. However, this question is not researched till the present time. Researches of life-time of vibration insulators made of MR material for harmonic vibration load exist only (Ao *et al*., 2006; Ulanov and Ponomarev, 2008; Yan *et al*., 2013). These researches consider MR as anisotropic quasi-continuous media and use for calculation of its life-time the same parameters as for usual structure materials: fatigue limits for normal and tangential stress σ_{-1} and τ_{-1}, respectively (Ao *et al*., 2006; Timoshenko and Goodier, 1951). Consideration of MR as anisotropic quasi-continuous media is used for its calculation by finite element method (Ulanov and Ponomarev, 2009; Ulanov, 2014) and gives good results. Thus, it is possible to apply this approach for research of life-time of MR material under random load.

RESEARCH

For research of life-time of MR vibration isolators under random load sleeve-type vibration isolator (Fig. 1) were used. An outer diameter of sleeves is D_1 = 16 mm, inner diameter is D_2 = 6.5 mm, height of sleeves in free condition was from H = 4.7 mm till 5.3 mm, height of sleeves into vibration isolator is H_1 = 4.4 mm.

Direction of load was in direction of pressing during MR material manufacturing. This direction is more usual

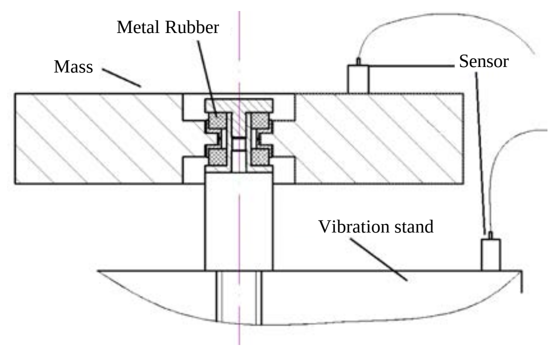

Fig. 1: Loading of sleeve-type vibration isolator for life-time test in direction of MR material pressing

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Fig. 2: Sleeves of different wire diameter after wearing; Left: d_w = 0.2 mm; middle: d_w = 0.15 mm and right: d_w = 0.1 mm

for MR vibration isolator work. Frequency range of random load changed from [5...200] to [5...2000] Hz. Parameters of MR material depend on its relative density:

$$\bar{\rho} = \frac{\rho_{MR}}{\rho_s}$$

Here:

ρ_{MR} = density of MR material

ρ_s = density of steel

wire diameter d_w and preliminary static relative deformation is $\varepsilon_Q = Q/H$ (here, $Q = H-H_1$ is absolute static deformation). Ranges of researched parameters of MR material were: $\bar{\rho} \in [0.2...0.28]$, $d_w \in [0.1...0.2]$ mm, $\varepsilon_Q \in [0.06...0.17]$. Mass is m = 2.08 kg.

Changes of resonance frequency f_0 and transfer ratio at resonance $\eta_0 = a_{sin}/A_{sin}$ (here, A_{sin} and a_{sin} are input and output vibration acceleration for sine vibration) controlled periodically during the test by sine vibration. If one of these parameters was deviate >20% of its initial value, vibration isolator is considered as disabled. Amplitude of sine vibration was A_{sin} = 10...30 m/sec^2.

Process of wearing is significantly depending of wire diameter. At Fig. 2, sleeves which parameters are out of 20% limit are shown.

Left sleeve made of wire d_w = 0.2 mm is completely broken. Middle sleeve made of wire d_w = 0.15 mm has many black dust (of worn-out wire) and broken pieces of wire. Right sleeve made of wire d_w = 0.1 mm only changed its initial height and has very few dust. Its parameters are out of 20% limit, however if this limit will be wider, it is able to work at least twice more.

It is possible to explain this difference that for the same density MR material made of wire which diameter is little has more contact points. Wires of little diameter are more flexible. Wires of large diameter are not so flexible, stress in a few contact points is more and wires cut each other much more quickly.

Usually wearing leads to decreasing of resonance frequency. Wires cut each other, stiffness of vibration isolator decreases. Transfer ratio at resonance changes insignificantly for little wire diameter (d_w = 0.1 mm), little static deformation (ε_Q = 0.06) and little relative density ($\bar{\rho} = 0.2$). For large wire diameter (d_w = 0.15...0.2 mm) transfer ratio at resonance hardly decreases for large static deformation (ε_Q = 0.12...0.17) transfer ratio at resonance hardly increases. For large relative density ($\bar{\rho} = 0.289$) resonance frequency during life-time is almost stabile, however transfer ratio at resonance hardly increases. If relative density ($\bar{\rho} = 0.236$) is less this effect is less too (frequency decreases, transfer ratio at resonance slightly decreases). It means a different type of wearing for different parameters of MR material.

A stress was chosen as a load parameter for life-time research. Advantage of this parameter for load is that is includes load of random vibration (spectral density), mass load and size of vibration isolator. It is well-known an equation for calculation of middle value of acceleration under random load (Biderman, 1980):

$$a = \sqrt{\frac{\pi A f_0 \eta_0}{2}} \tag{1}$$

Here, A is spectral density of random load [(m/sec^2)/Hz] is resonance frequency of system, η_0 is transfer ratio on resonance. Thus, middle value of dynamic stress for random load in vibration isolator is:

$$\sigma_A = \frac{ma}{S} = \frac{m}{S}\sqrt{\frac{\pi A f_0 \eta_0}{2}} \tag{2}$$

Here:

m = Mass of system

S = Area of vibration isolator section

Vibration isolator has static preload too. Static stress in vibration isolator is (Ulanov, 2014):

$$\sigma_Q \approx (0.61 + 1.77\varepsilon_Q - 20.4\varepsilon_Q^2 + 160\varepsilon_Q^3)\varepsilon_Q\left(\frac{\bar{\rho}}{0.18}\right)^{1.7} (-47.1d_w^2 + 16.5d_w - 0.174) \tag{3}$$

Common stress in vibration isolator is:

$$\sigma = \sigma_A + \sigma_Q \tag{4}$$

Life-time of vibration isolator depends on middle value of its deformation x, however, it depends on middle value of random acceleration a:

$$x = \frac{a}{4\pi^2 f_0^2} \tag{5}$$

Thus, dynamic stress includes the amplitude of vibration isolator deformation too. The dependency of life-time on frequency range of random load in the present experiments didn't find out.

Results of experiments are given in Fig. 3-5. Life-time T is in minutes. Equations of lines for dependency of life-time on wire diameter are:

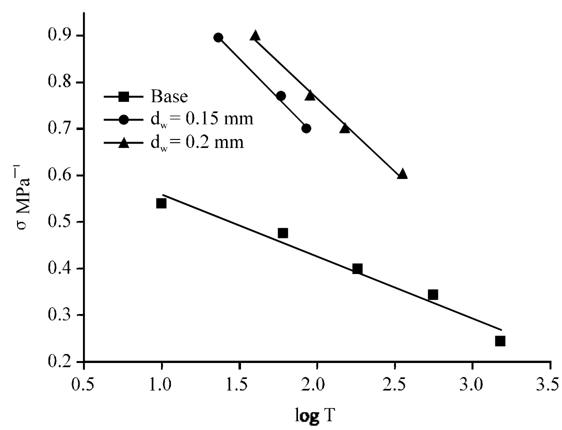

Fig. 3: Dependency of life-time on wire diameter; $\bar{\rho} = 0.2$, $\varepsilon_Q = 0.06$; squares: base line ($d_w = 0.1$ mm), circles: $d_w = 0.15$ mm, triangles: $d_w = 0.2$ mm

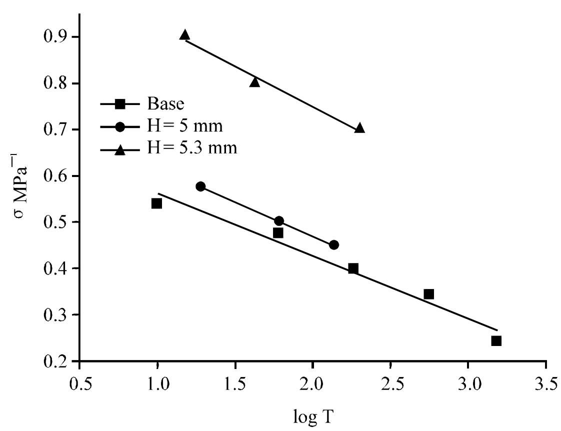

Fig. 4: Dependency of life-time on static deformation; $\bar{\rho} = 0.2$, $d_w = 0.1$ mm. Squares: base line ($\varepsilon_Q = 0.06$), circles: $\varepsilon_Q = 0.12$, triangles: $\varepsilon_Q = 0.17$

- $\sigma = 0.69\text{-}0.13 \log T$ (for $d_w = 0.1$ mm)
- $\sigma = 1.37\text{-}0.35 \log T$ (for $d_w = 0.15$ mm)
- $\sigma = 1.40\text{-}0.32 \log T$ (for $d_w = 0.2$ mm)

To obtain common equation for this lines one can divide coefficients of second and third equations by the same coefficients of first base equations. If first relative coefficient is α_1 and second one is α_2 result will be presented in a Table 1.

It is possible to describe the dependency of these coefficients on d_w by equations:

$$\alpha_1(d_w) = -3.78 + 66.6d_w - 188d_w^2 \tag{6}$$

$$\alpha_2(d_w) = -7.54 + 121.6d_w - 350d_w^2 \tag{7}$$

Thus, common equation will be $\sigma = 0.69\alpha_1(d_w)\text{-}0.13\alpha_2(d_w)\log T$. Equations of lines for dependency of life-time on static deformation are:

- $\sigma = 0.69\text{-}0.13 \log T$ (for $\varepsilon_Q = 0.06$)
- $\sigma = 0.76\text{-}0.15 \log T$ (for $\varepsilon_Q = 0.12$)
- $\sigma = 1.10\text{-}0.18 \log T$ (for $\varepsilon_Q = 0.17$)

Relative coefficients are presented in a Table 2. It is possible to describe the dependency of these coefficients on ε_Q by equations:

$$\alpha_1(\varepsilon_Q) = 1.43 - 11.94\varepsilon_Q + 73.9\varepsilon_Q^2 \tag{8}$$

Table 1: Relative coefficients for wire diameter

d_w	α_1	α_2
0.1	1.00	1.00
0.15	1.99	2.69
0.2	2.02	2.46

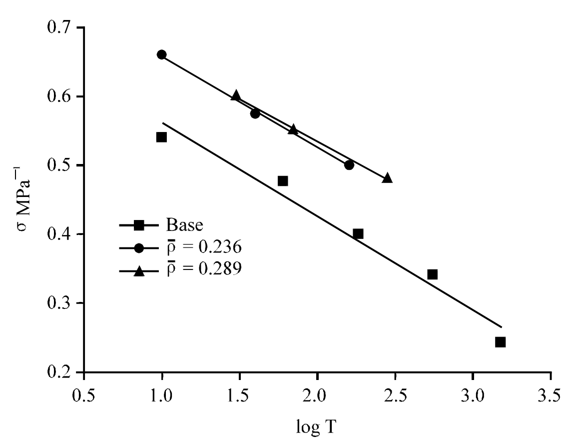

Fig. 5: Dependency of life-time on relative density; $d_w = 0.1$ mm, $\varepsilon_Q = 0.06$; squares: base line ($\bar{\rho} = 0.2$); circles: $\bar{\rho} = 0.236$ and triangles: $\bar{\rho} = 0.289$

Table 2: Relative coefficients for static deformation

ε_Q	α_1	α_2
0.06	1.00	1.00
0.12	1.10	1.15
0.17	1.59	1.38

Table 3: Relative coefficients for relative density

$\bar{\rho}$	α_1	α_2
0.2	1.00	1.00
0.236	1.14	0.98
0.289	1.12	0.91

$$\alpha_2(\varepsilon_Q) = 0.99 - 0.94\varepsilon_Q + 19.1\varepsilon_Q^2 \tag{9}$$

Thus, common equation will be $\sigma = 0.69\alpha_1(\varepsilon_Q)$-$0.13\alpha_2(\varepsilon_Q)$ log T. Equations of lines for dependency of life-time on relative density are:

- σ = 0.69-0.13 log T (for $\bar{\rho}$ = 0.2)
- σ = 0.79-0.135 log T (for $\bar{\rho}$ = 0.236)
- σ = 0.78-0.12 log T (for $\bar{\rho}$ = 0.289)

Relative coefficients are presented in a Table 3. It is possible to describe the dependency of these coefficients on ε_Q by equations:

$$\alpha_1(\bar{\rho}) = -2.04 + 24.8\bar{\rho} - 47.9\bar{\rho}^2 \tag{10}$$

$$\alpha_2(\bar{\rho}) = 0.71 + 3.19\bar{\rho} - 8.60\bar{\rho}^2 \tag{11}$$

Thus common equation will be $\sigma = 0.69\alpha_1(\bar{\rho})$-$0.13\alpha_2(\bar{\rho})$ log T. Common equation of all lines is:

$$\sigma = 0.69\alpha_1(d_w)\alpha_1(\varepsilon_Q)\alpha_1(\bar{\rho}) - 0.13\alpha_2(d_w)\alpha_2(\varepsilon_Q)\alpha_2(\bar{\rho}) \log T$$

Thus, equation for life-time calculation is:

$$T = 10^{\frac{0.69\alpha_1(d_w)\alpha_1(\varepsilon_Q)\alpha_1(\bar{\rho}) - \sigma}{0.13\alpha_2(d_w)\alpha_2(\varepsilon_Q)\alpha_2(\bar{\rho})}} \tag{12}$$

where coefficients are from Eq. 6-11, stress is from Eq. 2-4 and life-time is in minutes. Dependencies of life-time on d_w, ε_Q and $\bar{\rho}$ are approximately linear in the range of experiment. However, it is impossible that all these lines cross any coordinate axis (it would mean negative stress or life-time). It means that out of the range of experiment these dependencies have non-linear parts, approach to the axis. Left parts of these dependencies are not interesting for practical use, because life-time for them is >10 min. Right parts require very long experiment (>2000 min). This problem needs future research.

CONCLUSION

Random load changes structure of MR material. It is enough only a few minutes of random load (2 min in the present experiments) for it. If MR has large preliminary static deformation, there is large stress in wire contacts. Random load disturbs these contacts, some of them slip, and stiffness of MR reduces. Resonance frequency of vibration isolator becomes less. For relative static deformation <0.12 this effect is insignificant (<4%) if relative static deformation is 0.17, initial resonance frequency reduces about 16% (for d_w = 0.1 mm). Large wire diameter (0.15...0.2 mm) reduces this effect approximately twice (to 8%), influence of relative density didn't find out. Random load changes a friction in MR material too. Transfer ratio at resonance after 2 min under random vibration becomes less. For relative static deformation <0.12 this effect is insignificant (<6%) if relative static deformation is 0.17, initial transfer ratio at resonance reduces about 33% (for d_w = 0.1 mm). Large wire diameter (0.15...0.2 mm) reduces this effect approximately twice (to 17%), influence of relative density didn't find out too. This changing of structure should depend on a level of random load, thus this question needs future research too. It is necessary to take into account these effects for calculation of vibration protection system under random load.

There are other damping wire materials beside MR for example "Spring Cushion" manufactured by Stop-Choc Company (Germany). Comparison of vibration insulators made of this material and MR material is presented by Lazutkin *et al.* (2014). Problem of life-time is important for all types of pressed wire vibration insulators. Thus, it is possible to use a method developed in the present study for obtaining its life-time characteristics under random load too.

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REFERENCES

Ao, H.R., H.Y. Jiang and A.M. Ulanov, 2005. Dry friction damping characteristics of a metallic rubber isolator under two-dimensional loading processes. Modell. Simul. Mater. Sci. Eng., 13: 609-620.

Ao, H.R., H.Y. Jiang and A.M. Ulanov, 2006. Estimation of the fatigue lifetime of metal rubber isolator with dry friction damping. Key Eng. Mater., 326: 949-952.

Biderman, V.L., 1980. Theory of Mechanical Vibration. Vysshaya Shkola, Moscow, Russia, pp: 408 (In Russian).

Falaleev, S.V., K.N. Chaadaev and D.S. Diligenskiy, 2014. Selection of the hydrodynamic damper type for the turbomachine rotor. Life Sci. J., 11: 502-505.

Jiang, H.Y., D.G. Hao, Y.H. Xia, A.M. Ulanov and Y.K. Ponomarev, 2008. Damping characteristics calculation method of metal dry friction isolators. J. Beijing Instit. Technol. (English Edn.), 17: 173-177.

Lazutkin, G.V., A.M. Ulanov and K.V. Boyarov, 2014. Comparison of mechanical characteristics of vibration isolators made of wire pressed materials. Int. J. Eng. Technol., 6: 2201-2208.

Ponomarev, Y.K., 2014. On transformation of hysteresis in damper rings made of metal rubber pressure-tested wire material under precessional loading conditions. ARPN J. Eng. Applied Sci., 9: 1866-1872.

Popov, G.M., A.O. Shklovets, A.I. Ermakov and D.A. Kolmakova, 2014. Methods to reduce the resonant stresses level of gas turbine engines compressor rotor wheels. Proceedings of the 4th International Conference on Simulation and Modeling Methodologies, Technologies and Applications, August 28-30, 2014, Vienna, Austria, pp: 619-624.

Timoshenko, S.P. and J.N. Goodier, 1951. Theory of Elasticity. 2nd Edn., McGraw-Hill, New York, pp: 506.

Troynikov, A.A. and Y.A. Moskalev, 2014. Elastic and strength properties of metal rubber material. Int. J. Eng. Technol., 6: 2276-2282.

Troynikov, A.A., A.I. Ermakov and T.V. Volkova, 2014. Maintainable isolator based on MR material. Int. J. Eng. Technol., 6: 2322-2325.

Ulanov, A.M. and Y.K. Ponomarev, 2008. A fatigue limit of MR material for different load condition. Proc. Samara Sci. Center Russian Acad. Sci., 10: 849-852, (In Russian).

Ulanov, A.M. and Y.K. Ponomarev, 2009. Finite element analysis of elastic-hysteretic systems with regard to damping. Russian Aeronaut., 52: 264-270.

Ulanov, A.M., 2014. Constants of metal rubber material. Modern Applied Sci., 8: 216-223.

Xia, Y.H., H.Y. Jiang, H.D. Wei, H. Yan and A.M. Ulanov, 2009. Shock protection characteristics of metal rubber isolators. J. Vibr. Shock, 28: 72-75.

Yan, H., W.J. Zhang, H.Y. Jiang and L. Chen, 2013. Experimental study on fatigue of metal rubber vibration isolator under pulsating cyclic stress. Applied Mech. Mater., 385: 180-183.