THE CALCULATION OF THE VIBROINSULATORS' FAILURE RATE

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The questions of an assessment of reliability of the vibroinsulators which are applied to protection of radio-electronic means from vibration influences were considered. The calculations of intensity of refusals of springs for various techniques were given. It is shown that application of the technique, which considers influence of features of constructive and technological execution, allows to solve not only calculation problems, but also providing demanded level of characteristics of reliability of vibroinsulators.
Keywords: reliability, radio-electronic means, reliability, vibroinsulators, springs, failure rate

This study (research grant № 14-05-0038) supported by The National Research University - Higher School of Economics' Academic Fund Program in 2014. In the process of exploration of the majority of types of radio-electronic means (REM) are subjected to the vibration. The frequency and acceleration of vibration influences can be quite various depending on the sources of influence and their arrangement concerning REM constructions, so the design of REM, that operating in the conditions of vibration influences, have to meet the requirements of durability and stability.

One of the more effective measures to struggle against vibration is the vibroprotection of REM by various vibroinsulation systems, the essence of which is that between the REM and the object of installation are placed devices – vibroinsulators which weaken vibration impacts on the design.

The shock-absorber (vibroinsulator) is a structure uniting an elastic and damping element. The elastic forces in the shock-absorber are created by steel springs, the elastic component hardness of rubber or polymer componentrs, elasticity of metalrubber or a cable. Forces of resistance (damping) in the design of the shock-absorber is formed as a result of dry friction in the material of elastic and damping elements and viscous friction.

Depending on the type of the elastic element and the way of damping vibroinsulators are divided into the following groups: the rubber-metal; spring-loaded with air damping; spring-loaded with frictional damping; all-metal with structural damping [1].

Figure 1 shows the form of insulator type DO.

Figure 1 – Vibroinsulator

Figure 2 shows the sketch of the design of vibroinsulator type DO.

The material of the spring is the steel 65 [2]. Main technical characteristics of vibroinsulators type DO are given in tables 1 and 2.

Table 1 - Characteristics of vibroinsulators type DO

Brand	Load P,	Vertical	Height in	Sediment of the	The	Weight,

	N		rigidity , N/cm	the free state	spring under load, mm		number of working coils	kg
	Work.	Prev.			Work.	Prev.		
DO-38	122	152	45	72	27	33,7	5,6	0,3
DO-39	219	273	61	92,5	36	45	5,6	0,4
DO-40	339	424	81	113	41,7	52	5,6	1
DO-41	540	674	124	129	43,4	54	5,6	1
DO-42	942	1177	165	170	57,2	72	5,6	1,8
DO-43	1648	2060	294,3	192	56	70	5,6	2,4
DO-44	2384	2979	357	226	66,5	83	5,6	3,65
DO-45	3728	4660	441,5	281	84,5	106	5,6	6,45

Table 2 - Characteristics of vibroinsulators type DO

Brand	Sizes, mm						
	A	A_1	B	D_{cp}	d	d_1	d_2
DO-38	100	70	60	30	3	12	8,5
DO-39	110	80	70	40	4	12	8,5
DO-40	130	100	90	50	5	12	8,9
DO-41	130	100	90	54	6	14	10,5
DO-42	150	120	110	72	8	14	10,5
DO-43	160	130	120	80	10	14	10,5
DO-44	180	150	140	96	12	14	10,5
DO-45	220	180	170	120	15	16	12,5

Note:

1. The Deformation (sludge spring) under the load, which is different from that indicated in the table, changes in proportion to load.

2. For vibroinsulators of all types the total number of rounds of a spring is 6,5.

3. For the vibroinsulators DO-38, DO-39 S = 2 mm, for other vibroinsulators S = 3 mm, S1 is respectively 5 and 10 mm. In the rubber gaskets in all cases d1 = d2 + 3,5 mm.

Apparently from figure 1 the main element of vibroinsulator of the type DO is the spring, so its characteristics of reliability are defined by the reliability exactly this element. According to the classification of GOST 27.003 [3] springs relate to the products of general purpose type I (highly reliable accessory intersectoral application), continuous and long application, nonrestorable, unattended, transition which transition to the limit state does not lead to catastrophic consequences, worn out, growing during storage. For such products the following indicators of reliability are normalized:

- failure rate - λ
- average resource - $T_{P.Cp}$
- medium term persistence - $T_{C.Cp}$

Let required value λ of the vibroinsulator DO-38 is $5 \cdot 10^{-7}$ 1/h^{-1}

Consider the calculation of the failure rate of the vibroinsulator's DO-38 spring under the following conditions:

- Amplitude of acceleration of vibration: 40 m / c2;
- Range of frequencies: from 1 to 300 Hz;
- Working temperature: 50 °C;
- Limit temperature: 70 °C,

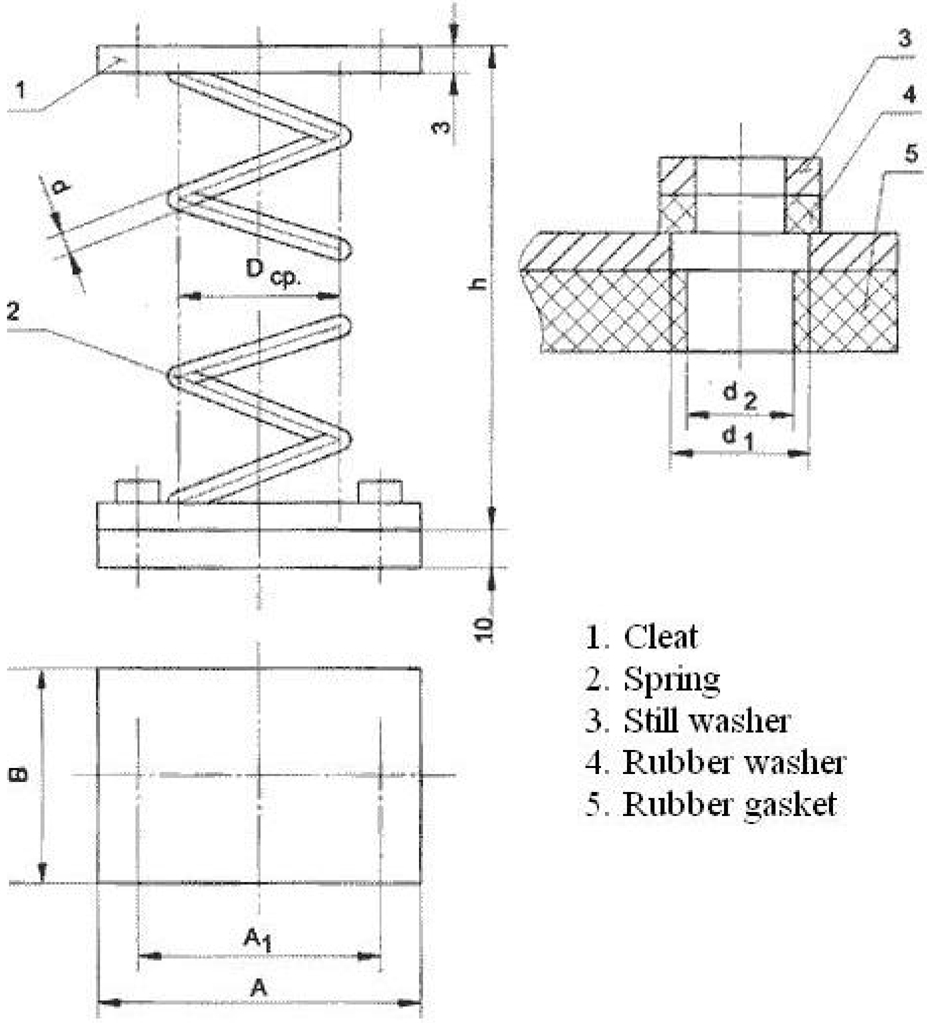

Figure 2 – The design of vibroinsulator

Which corresponds to class 1, group 1.9 «Equipment based on railway platforms,» on the classification of GOST RV 20.39.304 [4].

The choice of methods of calculation of indicators of reliability of the mechanical and electromechanical elements applied in practice is rather limited [5-7].

For the calculation we will use the technique given in [8] according to which the mathematical model of the failure rate of the spring is the following:

$$\lambda_e = \lambda_0 \cdot a_1 \quad (1)$$

where: λ_0 - failure rate of a spring in the nominal mode and normal conditions (ambient temperature 20±10 ºC, relative humidity of air is 30-70%; atmospheric pressure 0,825...1,06•10^5 PA; lack of vibration and blows); a_1 – the coefficient taking into account the design features of the spring, the conditions of production and spring operation.

The value of the coefficient a_i is calculated by the formula:

$$a_1 = K_{11} \cdot K_{12} \cdot K_{13} \cdot K_{14} \cdot K_{15} \quad (2)$$

where: K_{11} - the coefficient taking into account the of vibration; K_{12} - the coefficient taking into account the influence of blows; K_{13} - the coefficient taking into account the influence of climate; K_{14} - the coefficient taking into account the influence of quality of service; K_{15} - the coefficient taking into account the influence of quality of production.

The values of coefficients K_{11} - K_{14}, received according to the tables provided in [8], are presented in table 3.

Table 3 – The values of correction coefficients of a formula (2)

The coefficient	The classification characteristic	The value
K_{11}	Enterprises of metallurgical heavy machinery. Railway transport. (unamortized equipment)	8.0
K_{12}		4.0
K_{13}	Climate is temperate, midland (not heated, unpackaged room)	1.3
K_{14}	The transport	1.5
K_{15}		0.5

The value given in [8] for the class of «Spring» is $0.05 \cdot 10^{-6}$ 1/h.

Then, operational failure rate of the spring of the vibroinsulator DO-38 is:

$$\lambda_e = 1.56 \cdot 10^{-6} \text{ 1/h.}$$

As follows from the received result, the calculated value exceeds demanded that requires the adoption of measures to increase reliability.

The analysis of the table 3 shows that coefficients K_{11} and K_{11} (see table 3) have the greatest impact on value λ.

However, to reduce their values by the use of vibroinsulator DO other denomination is not possible, since when using this technique, the values of the coefficients K_{11} and K_{11} will not change, as they depend on the characteristic «Railway transport» (see table 3).

Therefore we will use the technique given in the standard [9]. Mathematical model for the class «Spring» has the following form:

$$\lambda_s = \lambda_{sp,b} \cdot C_G \cdot C_{DW} \cdot C_{DC} \cdot C_N \cdot C_Y \cdot C_L \cdot C_K \cdot C_{CS} \cdot C_R \cdot C_M \tag{3}$$

where: $\lambda_{SP,B}$ - basic failure rate of the spring; C_G, C_{DW}, C_N, C_Y, C_L, C_K, C_{CS}, C_R, C_M - correction coefficients.

The value of the coefficient C_G, taking into account the size of the module of rigidity of a material, calculated by the formula:

$$C_G = \left(\frac{G_M}{11.5 \cdot 10^6} \right)^3, \tag{4}$$

where: G_M is the module of rigidity of a material of a spring.

The value of the coefficient C_{DW} taking into account the value of the thread diameter is calculated by the formula:

$$C_{DW} = \left(\frac{D_w}{0.085} \right)^3, \tag{5}$$

where: D_W - diameter of the thread.

The value of the coefficient C_{DC} taking into account the value of the diameter of the coil is calculated by the formula:

$$C_{DC} = \left(\frac{0.58}{D_C}\right)^6, \qquad (6)$$

where: D_C - the average diameter of a spring.

The value of the coefficient C_N taking into account the number of active coils calculated by the formula:

$$C_N = \left(\frac{14}{N_A}\right)^3, \qquad (7)$$

where: N_A - number of active coils.

The value of the coefficient C_Y taking into account the resistance to stretching the material of spring is calculated by the formula:

$$C_Y = \left(\frac{190}{T_S}\right)^3, \qquad (8)$$

where: T_S - strength of a material at the gap.

The value of the coefficient C_L taking into account the impact of precipitation coil springs is calculated by the formula:

$$C_L = \left(\frac{L_1 - L_2}{1.07}\right)^3, \qquad (9)$$

where: L_1-L_2 - draught spring.

The value of the coefficient CK taking into account the impact of compression is calculated by the formula:

$$C_K = \left(\frac{K_W}{1.219}\right)^3, \qquad (10)$$

where: $K_w = \frac{4 \cdot r - 1}{4 \cdot r - 4} + \frac{0.616}{r}$, , $r = \frac{D_C}{D_W}$.

The value of the coefficient CCS, taking into account the impact of the frequency of loading coil, calculated by the formula:

$$C_{CS} = \frac{CR}{300}, \qquad (11)$$

where: CR - the frequency of loading of a spring.

The numerical values of the parameters necessary for calculation of the coefficients of C_G, C_{DW}, C_N, C_Y, C_L, C_K, C_{CS}, C_R and C_M, are given in table 4.

Table 4 – The values of the parameters used in formulas (4)-(11)

Sign	Name	Value	Unit	Note
G_m	Module of rigidity	$8.0 \cdot 10^3$	kgf/mm2	GOST 14959
D_w	Diameter of a thread	3	mm	See table 2
D_c	Diameter of a spring	30	mm	See table 2
N_a	The number of active coils	5.6	PCs	See table 2
T_s	Tensile of strength	80	kgf/mm2	GOST 14959
L_1-L_2	Deposit of spring	27	mm	See table 1
K_w	Compression of spring	1.145	-	-
CR	Frequency of the load	300	Hz	GOST RB

				20.39.304
C_R	Corrosion influence	1	-	-
C_M	Quality of the production process	1	-	-

The numerical values of coefficients of model (3) received as a result of calculation are summarized in table 5.

Table 5 – The values of the model's coefficients (3)

Sign	Value
C_G	0.949
C_{DW}	2.658
C_{DC}	0.014
C_N	15.625
C_Y	4.657
C_L	0.99
C_K	0.829
C_{CS}	1

The basic failure rate for this group that given in the standard [9] is $23.8 \cdot 10^{-6}$ 1/h.

Then, operational failure rate of a spring of the vibroinsulator DO-38, is:

$$\lambda_{sp} = 5.128 \cdot 10^{-5} \text{ 1/h.}$$

As follows from the received result, the calculated value λ also exceeds the demanded that requires the adoption of measures to increase reliability. So for providing demanded level it is necessary to choose vibroinsulator DO other denomination.

The analysis of table 5 shows that the greatest impact on magnitude λ has C_{DW}, C_N and C_Y coefficients.

Find in how many time you need to reduce λ_{sp} for providing demanded level of failure rate:

$$\frac{\lambda_{sp}}{\lambda} = 98.94.$$

However it is impossible to reduce value of coefficients of C_N and C_Y because for production of springs of all face values of vibroinsulators DO the same brand of steel is used and they have an identical quantity of working rounds (see table 1). Besides, with increasing $d(D_w)$ (see table 2) the value of coefficient of C_{DW} according to (5) also increases.

The analysis of mathematical models of failure rate of the class "Springs" of the standard [9]that was given in works [10-12] has shown that the greatest impact on λ_{sp} has a parameter $D_C(D_{cp})$. Changing this value (see table 2) leads to change the value D_w that, according to (5), (6) and (10) leads to a change in the coefficients C_{DW} and C_{DC} and C_K.

For the vibroinsulators DO-42 the values of these coefficients are:

$C_{DW} = 50.412$;

$C_{DC} = 7.474 \cdot 10^{-5}$;

$C_K = 0.867$.

Besides, since value of load of a vibroinsulator remains invariable, so L_1-L_2 = 7.435 mm, and the value C_L will be 0.021.

In this case operational failure rate of a spring of the vibroinsulator DO-42 is:

$$\lambda_{sp} = 1.111 \cdot 10^{-7} \text{ 1/h,}$$

that meets the set requirements.

Thus, it can be concluded that the technique given in [8], is more simple than technique standard [9].However, if the results received with its help are not satisfactory, it is necessary to apply a technique standard [9] in which at calculation of failure rate are considered both constructive and technological features of springs, and mechanical characteristics of materials.

References

1. Il'inskiy, V.S. Zaschita REA i pretsizionnogo oborudovaniya ot dinamicheskih vozdeystviy. / V.S. Il'inskiy - M.: Radio i svyaz', 1982. - 296 s.

2. GOST 14959-79. Prokat iz ressorno-pruzhinnoy uglerodistoy i legirovannoy stali.

3. GOST 27.003-90. Nadezhnost' v tehnike. Sostav i obschie pravila zadaniya trebovaniy po nadezhnosti.

4. GOST RV 20.39.304-98. KSOTT. Apparatura, pribory, ustroystva i oborudovanie voennogo naznacheniya. Trebovaniya stoykosti k vneshnim vozdeystvuyuschim faktoram.

5. Zhadnov, V.V. Metody i sredstva ocenki pokazatelej nadezhnosti mehanicheskih i e'lektromehanicheskih e'lementov priborov i sistem. / V.V. Zhadnov. // Datchiki i sistemy. - 2013. - № 4. - s. 15-20.

6. Zhadnov, V. Methods and means of the estimation of indicators of reliability of mechanical and electromechanical elements of devices and systems. / V. Zhadnov. // Reliability: Theory & Applications: e-journal. - 2011. - Vol. 2, No 4. - p. 94-102.

7. Markin, A.V. Metody oczenki nadyozhnosti elementov mexaniki i elektromexaniki elektronnyx sredstv na rannix etapax proektirovaniya. / A.V. Markin, S.N. Polesskij, V.V. Zhadnov. // Nadyozhnost'. - 2010. - № 2. - s. 63-70.

8. Shavykin, N.A. Otsenka pokazateley bezotkaznosti mehanicheskih elementov produktsii priborostroeniya. / N.A. Shavykin, B.P. Petruhin. // Datchiki i sistemy, № 6, 2006. - s. 28-35.

9. NSWC-11 Handbook of reliability prediction procedures for mechanical equipment.

10. Lushpa, I.L. Issledovanie modeli intensivnosti otkazov mehanicheskih elementov klassa «Pruzhiny». / I.L. Lushpa, M.A. Monahov, V.M. Fokin. // Innovatsionnye informatsionnye tehnologii: Materialy mezhdunarodnoy nauchno-prakticheskoy konferentsii. Tom 3. - M.:MIEM NIU VShE, 2013. - s. 443-446.

11. Lushpa, I.L. Issledovanie modeli intensivnosti otkazov volnoobraznyh kol'tsevyh pruzhin. / I.L. Lushpa, M.A. Monahov, V.M. Fokin. // XXI Mezhdunarodnaya studencheskaya konferentsiya-shkola-seminar «Novye informatsionnye tehnologii»: tez. dokl. - M.: MIEM NIU VShE, 2013. - s. 122-123.

12. Lushpa, I.L. Issledovanie modeli intensivnosti otkazov izognutyh kol'tsevyh pruzhin / I.L. Lushpa, M.A. Monahov, V.M. Fokin. // X Vserossiyskaya nauchno-tehnicheskaya konferentsiya «Nauchnye chteniya po aviatsii posvyaschennye pamyati N.E. Zhukovskogo»: sb. tez. dokl. - M.: Izdatel'skiy dom Akademii im. N.E. Zhukovskogo, 2013. - s. 415-419.