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METHODS FOR DETERMINING THE STIFFNESS OF A RUBBER-METALLIC SHOCK ABSORBER OF A PENDULUM SUSPENSION OF A TRACTION ELECTRIC MOTOR OF AN ELECTRIC LOCOMOTIVE

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ABSTRACT

The article presents a new technique for determining the stiffness of the rubber-metal shock absorber of the pendulum suspension of the locomotive traction electric motor.

The article presents new methods for determining the stiffness of the rubber-metal shock absorber of the pendulum suspension of the locomotive traction electric motor (TEM).

To calculate the dynamic force factors acting on the elements of the pendulum suspension of the traction electric motor of an electric locomotive, all the necessary parameters are set, except for the stiffness of the shock absorber of the traction motor suspension.

In the accepted design scheme (Figure 1) [1, 2, 03], the shock absorber of the pendulum suspension of the traction motor of an electric locomotive is the only elastic element, and its parameters, to a great extent, determine the run of the oscillatory process. Stiffness *Stif* and inelastic resistance β of rubber elements depend on the brand of rubber, ambient temperature and shock absorber design. Parameter β is set, and the stiffness of the shock absorber must be determined by calculating it according to the initial data [4].

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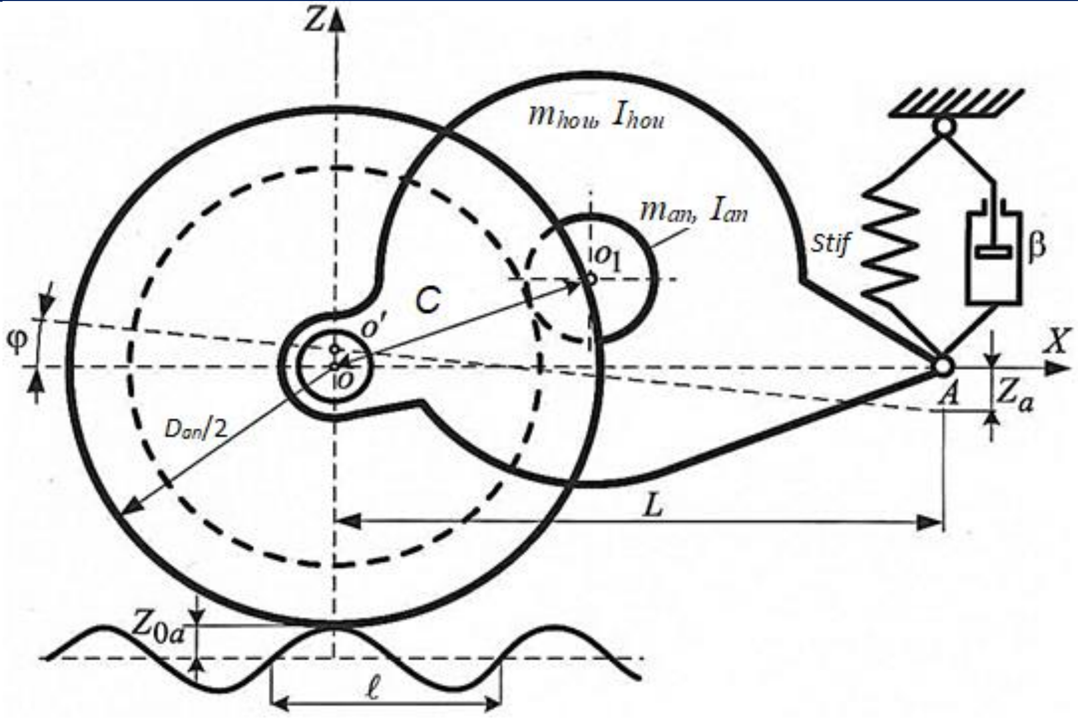

Figure 1. Design scheme of the system “railway track – wheelset – traction transmission – traction electric motor – supports – cross (pivot) beam of the trolley frame” with axial suspension.

To calculate the dynamic force factors acting on the elements of the traction transmission, all the necessary parameters are set, except for the stiffness of the shock absorber of the traction motor suspension.

Unlike steel springs, rubber elements have a non-linear elastic characteristic. Their stiffness depends on the value of pre-compression. The TEM suspension shock absorber consists of two rubber washers 6 compressed between steel washers - disks - lower 7 and upper 5 ones (Figure 2).

The washers (disks) of the TEM rubber-metal shock absorber, in addition to the dynamic load, perceive the weight of half the engine $\frac{P_m}{2}$, the reaction of the traction moment P_t and the preload P_p. The preload is necessary to eliminate the “absorber opening” (reducing the load on one of the washers to zero and the appearance of a gap clearance). This position is possible for the top washer if the reaction to the traction torque is directed downwards and acts in conjunction with the weight of the engine, and the preload is insufficient. To deliberately exclude such a possibility, we take the following value of the preload [4]

$$P_p = \frac{P_m}{2} + P_t \,. \qquad (1)$$

The reaction on the suspension under the traction moment can be determined from the moment equilibrium equation for forces acting on the engine in the traction mode

$$P_t = \frac{F_T \; D_K}{2\,L}. \qquad (2)$$

The calculated traction force is taken as the maximum one from the traction constraint condition. For the VL-80s electric locomotive, it can be calculated by the following formula

$$F_T = \psi 2\Pi_{CT} = \left(0{,}28 + \frac{4}{50+6V} - 0.0006\,V\right) 2\Pi_{CT}\,, \quad (3)$$

where – V is the speed of movement, km/h. At the moment of starting V=0 and ψ=0.36 we have

$$F_T = \psi 2\Pi_{CT} = 0{,}36 \cdot 2\Pi_{CT}\,. \quad (4)$$

The free height of the rubber washer is taken within h_0 = 0.06 ... 0.09 m.

The dimensions of the cross-section of the washer are determined from the strength condition, i.e., the acting stress should not exceed the allowable one, which is $[\sigma] = (3 \ldots 5)\, 10^3$ kPa.

The area of the working section of the washer can be approximately calculated by the following formula

$$S = \frac{P_p + \frac{P_m}{2} + P_t}{[\sigma]} \cdot (1 - \varepsilon)\ . \quad (5)$$

Coefficient (1-ε) takes into account the change in the cross-sectional area when the washer is compressed. Relative strain ε under the limit compression value Δh_{max} is in the range

$$\varepsilon = \frac{\Delta h_{max}}{h_0} = 0{,}1 \ldots 0{,}25\,. \quad (6)$$

If the force is measured in kilonewtons (kN), and the stress is measured in kilopascals (kPa), then the area is obtained in square meters (m^2).

Washer inner diameter is $d_{in} = 0{,}075 + (2 \ldots 5)\, 10^{-3}$ m.

Then the outer diameter of the washer, taking into account the cross-sectional area, is

$$d_{ou} = \sqrt{\frac{4S}{\pi} + d_{in}{}^2}. \quad (7)$$

Next, we perform a calculation *to determine the stiffness and check the strength of the rubber-metal shock absorber of the TEM.*

Characteristic of the rubber washer, i.e. the relationship between the force P and the deformation Δh, is determined by the following expression

$$P = Ee\frac{\pi}{4}(d_{ou}^2 - d_{in}^2)\frac{\Delta h}{h_0 - \Delta h} = E\,e\,S\frac{\Delta h}{h_0 - \Delta h}\,, \quad (8)$$

where $E = 5 \cdot 10^3$ kPa is the elastic modulus of rubber; e is the shape factor for a rubber washer under axial compression and full adhesion of the ends of the rubber washer with metal washers. The form factor is determined by the following formula

$$e = 1 + 4{,}67\,\frac{d_{ou} - d_{in}}{4\,h_0}. \quad (9)$$

The characteristic of one rubber washer for the rubber-metal shock absorber of the TEM suspension P(Δh) is shown in Figure 2.

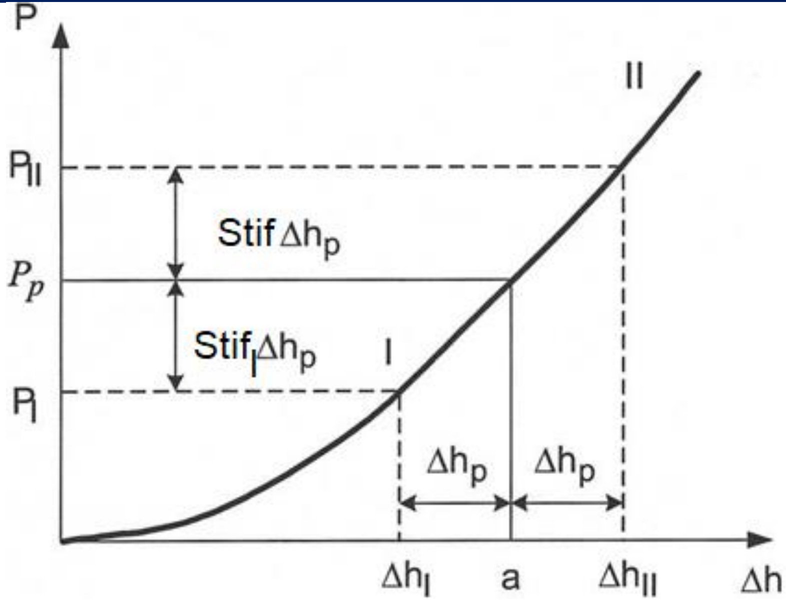

Figure 2. Characteristics of one rubber washer for the rubber-metal shock absorber of the TEM suspension $P(\Delta h)$.

When assuming the linearity of the elastic characteristic of the shock absorber in the range of working loads, it is possible to perform the calculation as follows. Let us take the stiffness of each washer in the entire range of loads the same as under the action of one preload $P = P_p$. Then, from expression (8) it is possible to determine the value of pre-compression $\Delta h = a$

$$a = \frac{h_0 P_{ou}}{E\ e\ S + P_p}. \qquad (10)$$

Considering the pre-compression of the washers, the stiffness of each of them, N/m, is

$$Stif_I = Stif_{II} = \frac{P_p}{a}. \qquad (11)$$

When the load on the suspension changes, the total height of the set of washers remains unchanged, and the increase in the height of one washer is equal to the decrease in the height of the other, i.e., the deformations of the washers are the same. Two washers work as elastic elements connected in parallel, and the stiffness of the shock absorber as a whole is equal to twice the stiffness of one washer

$$Stif = 2Stif_I. \qquad (12)$$

When applying working external load $P_P = P_e$,

$$P_p = \frac{P_m}{2} + P_t, \qquad (13)$$

the lower rubber washer is compressed, and the upper one is stretched by the following value

$$\Delta h_P = \frac{P_P}{Stif}. \qquad (14)$$

Then the value of the total deformation of the upper I and lower II washers is

$$\Delta h_I = a - \Delta h_P; \qquad (15)$$

$$\Delta h_{II} = a + \Delta h_P, \qquad (16)$$

and the loads are, respectively

$$P_P = P_e - P_I; \qquad (17)$$

$$P_I = P_e - Stif_I \Delta h_P; \qquad (18)$$

$$P_{II} = P_e + Stif_I \Delta h_P. \quad (19)$$

The following condition must be met for the rubber-metal shock absorber of the TEM not to open,

$$\Delta h_I \geq 0\,. \quad (20)$$

With the accepted value of the preload, this condition must be met.

To ensure the strength of the washers, the following condition must be satisfied

$$\sigma_{II} \leq [\sigma]\,, \quad (21)$$

or in expanded form

$$\sigma_{II} = Ee\frac{\Delta h_0 \Delta h_{II}}{(\Delta h_0 - \Delta h_{II})^2} \leq (3\ldots5)\cdot 10^3\text{ , kPa.} \quad (22)$$

If this condition is not met, it is necessary to reduce the preload within acceptable limits or increase the outer diameter of the washers. The operating points of the upper and lower washers corresponding to the external load P_P are shown by points *I* and *II* on the characteristic of one rubber washer for the rubber-metal shock absorber of the TEM suspension P(Δh) (Figure 2).

Then, a numerical calculation was performed on a computer using the *Mathcad 15 programming environment* according to the methods developed in the article using the iteration method [6].

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