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Determining the elasticity of the contact suspension of electrified railways

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Abstract: In electrified railways, the reliability and efficiency of the power supply system are directly dependent on the condition of the contact suspension. Determining the elasticity of the contact suspension is one of the most critical issues, as it impacts the following: stable operation of the current collector – if the contact suspension lacks sufficient elasticity, the stable connection with the pantograph may be disrupted, leading to interruptions in the transmission of electrical energy; reliability and long service life – excessive rigidity or flexibility of the contact suspension can result in rapid wear and tear, increasing maintenance costs; adaptation to high-speed requirements – for trains operating at high speeds, the optimal elasticity of the contact suspension is crucial; otherwise, strong vibrations and contact interruptions may occur; energy efficiency – optimal elasticity helps distribute the load evenly, reduces energy losses, and improves overall efficiency. Therefore, determining and optimizing the elasticity of the contact suspension is of great importance for enhancing the efficiency and safety of railway transport. The digitization of contact suspension elasticity is a modern necessity. Digitization can be implemented through the following methods: sensors and IT devices – smart sensors capable of measuring pressure, vibrations, and bending angles can be installed to monitor the elasticity of the contact suspension in real time; laser and video analysis – high-resolution cameras and laser scanning technologies enable continuous monitoring of the deformation and condition of the contact suspension; artificial intelligence and machine learning – based on collected data, it is possible to create performance forecasts for the contact suspension and predict wear and tear processes in advance; database systems – storing the collected data on central servers and analyzing it in real time allows for the optimization of maintenance schedules. As a result of digitization, maintenance costs are reduced, potential failures are prevented, and the efficiency of electrified railways is significantly improved

Keywords: contact suspension, elasticity, rigidity, current collector, electric rolling stock, rigid points.

1. Introduction

It is known that the contact suspension has an elastic design, so during the movement of the pantograph, the contact wire rises. The value of this rise varies at different intermediate lengths, which depends on the elasticity of the chain-type contact suspension.

When determining the elasticity of the contact suspension, we consider the characteristic value of the rise of the contact wire at different points of the intermediate length under the influence of a 1 N force. This value is called the elasticity coefficient, or simply the elasticity of the contact suspension, denoted as "э", for example, $э = 0{,}5 mm/N$. This value represents the rise of the contact wire by 0.5 mm under the influence of a 1 N vertical force on the contact wire in the chain-type suspension [1].

The opposite characteristic of the elasticity of the contact suspension is called the rigidity of the suspension: $ж = 1/Э$.

The rigidity of the contact suspension is the necessary force required to lift the contact wire by 1 mm at different points of the suspension along the intermediate length. For example, $ж = 2\ N/mm$, a force of 2 N is needed to lift the contact wire by 1 mm.

2. Research methodology

Let's consider the elasticity of a simple contact suspension with fixed support points (freely suspended wire).

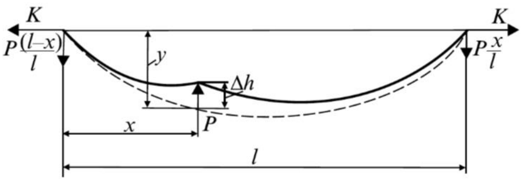

Fig. 1. A diagram to determine the rise of a simple contact suspension with fixed support points: *P* - vertical force, *x* - the distance from the support to the point of rise, Δ*h* - the rise in the wire due to the applied force

Under the influence of the force P, the algebraic sum of the changes in the positions of the wire relative to the fixed points along the intermediate length must be equal to zero.

$$K\Delta h - P(l-x)x/l = 0 \quad (1)$$

where: $P(l-x)$ - the reduction of the left support reaction caused by the force P; K – the tension in the wire.

From equation (1), we can find Δh:

$$\Delta h = Px(l-x)/(lK). \quad (2)$$

According to the expression for determining elasticity:

$$э = \Delta h/P. \quad (3)$$

The elasticity value at the points of the contact suspension (in freely suspended wires), at a distance x from the left support, can be determined using the following formula:

$$э_{x,n} = \Delta h_{x,n}/P = x(l-x)/(lK). \quad (5)$$

For the condition between the intermediate length under the influence of the force P (when x=0,5l is given):

$$э_{0,5l,n} = l(4K). \quad (6)$$

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Consider the suspension of wires in different conditions or the elasticity of a contact suspension with a non-elastic design (Figure 2, a). The rise of the wires under the influence of the force P is expressed as follows:

$\Delta h_s = g_K s^2/(8K)$. (7)

where: g_K - the weight load of 1 meter of wire.

The necessary force P to lift (or suspend) the contact wire at a distance S can be determined from the following equation when $g_K s = P$ is given [2]:

$\Delta h_s = P^2/(8 g_K K)$. (8)

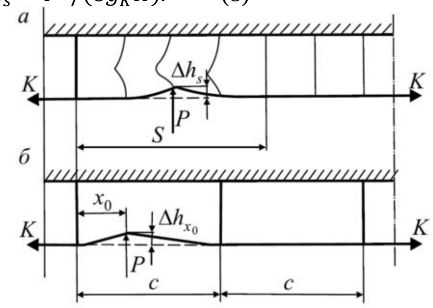

Fig. 2. The distribution diagram of the rise of a rigidly constructed contact wire in a multi- dropper (a) and single dropper (b) contact suspension

The elasticity of the wires does not remain constant in this case; it changes proportionally under the influence of force P:

$\text{э}_s = \Delta h/P = P/(8 g_K K)$. (9)

Consider the elasticity of the dropper contact wire suspension. In various dropper suspensions, the elasticity will differ at the intermediate points (Figure 2, a). In this case, the force P in the narrow interval and its value depend on the elasticity of the wire:

$\Delta h_{x_0} = P x_0 (c - x_0)/(cK)$, (10)

elasticity:

$\text{э}_{x_0} = \Delta h x_0/P = x_0(c - x_0)/(cK)$, (11)

where: x_0 – the distance from the wire under the left load to the point of the contact wire where the force *P* is applied; *c* – the length of the dropper interval.

The effect of the force P between the dropper intervals ($x_0 = 0.5c$):

$\Delta h_{0.5c} = Pc/(4K)$, (12)

$\text{э}_{0.5c} = c/(4K)$. (13)

The contact wire will rise in this case under the dropper ($x_0 = 0$) when the force P exceeds the weight of the wire by g_Kc, and the load in the dropper will be greater by ($P > g_K c$).

Until the moment of the dropper's release (when the load decreases), the elasticity of the wire ($P \leq g_K c$) will be equal to zero [3].

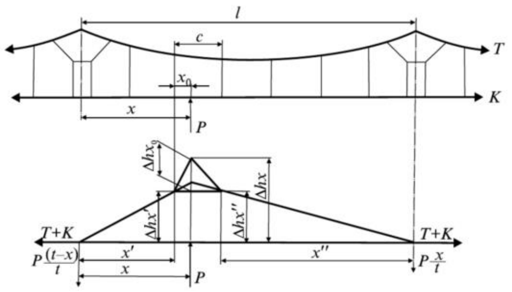

Fig. 3. A computational scheme for determining the elasticity of a single-chain suspension in the middle of the span

Contact wire uplift after the dropper release:

$\Delta h_{2c,K} = (P - g_K c)c/(2K)$. (14)

Elasticity of the contact wire after the dropper release:

$\text{э}_{2c,K} = c/(2K)$. (15)

In catenary spans, the elasticity of the contact wire is the sum of the elasticity of the "supporting cable and contact wire" system and the elasticity of a single-chain suspension (Figure 3). To determine the elasticity of the single-chain suspension at any arbitrary point in the span, the computational formula can be written in the following general form:

$\text{э}_x = \frac{\Delta h_x}{P} = \frac{1}{P}(\Delta h_{x'}\frac{c-x_0}{c} + \Delta h_{x''}\frac{x_0}{c} + \Delta h_{x_0}$ (16)

where: Δh_x - the total uplift of the contact wire at a point located at a distance *x* from the left support under the influence of force *P*; $\Delta h_{x'}$ - the uplift of the contact wire on the left side at a distance x' under the influence of force *P*, near the loaded catenary wires; $\Delta h_{x''}$ - the uplift of the contact wire on the right side at a distance x'' under the influence of force *P*, near the loaded catenary wires; $\Delta h x_0$- the uplift of the contact wire in catenary spans (between two loaded catenary wires); *c* – the length of the catenary span (the distance between two loaded catenary wires, either in the unloaded state or under the influence of force *P*). x_0 - the distance from the left loaded catenary wire to the force *P*. Δh_{x_0} the value is determined using the formula mentioned above.

To determine $\Delta h_{x'}$ and $\Delta h_{x''}$ the elasticity of the spring-loaded catenary suspension will vary at different points in the spans. The computational formula is divided into three groups: for the spring cable catenaries (A), for the simple cables in the first installation area from the support (Б), for the middle section of the span length (B) (Figure 4).

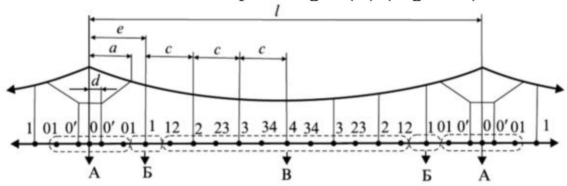

Fig. 4. A spring-loaded diagram with a working zone for calculating elasticity at various points of the interval

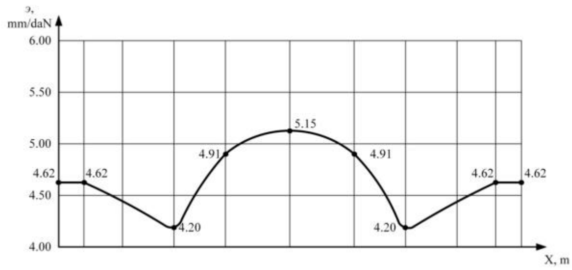

Fig. 5. Graph of the elasticity change of the contact suspension within the interval

We will conduct an experimental study for the conclusion of the calculation formula for the elasticity and contact wire uplift in the middle part (B) of the interval for a simple suspension cable and a single spring suspension (Figure 3, part b). We can use the above calculation diagram, so the contact wire uplift (holding rope) $\Delta h_{x'}$ and $\Delta h_{x''}$ can be determined from the equation.

$\Delta h_{x'} = \frac{P_{x'}(l-x)}{l(T+K)}$; (17)

$\Delta h_{x''} = \frac{P_{x''}x}{l(T+K)}$; (18)

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where: l – anchor span length; T – holding wire tension; K– contact wire tension.

The general formula to determine the elasticity of the chain contact suspension in the middle section of the span:

$$Э_x = \frac{\Delta h_x}{P} = \frac{x(l-x)}{l(T+K)} + \frac{x_0 T(c-x_0)}{cK(T+K)}. \quad (19)$$

If a force of ($x_0 = 0$) P acts under the dropper:

$$Э_{x,c} = \frac{\Delta h_{x,c}}{P} = \frac{x(l-x)}{l(T+K)}. \quad (20)$$

The elasticity of the chain suspension in the middle of the span under the influence of a force of ($x = 0.5l$, $x_0 = 0.5c$) P between the droppers:

$$Э_{0.5l} = \frac{\Delta h_{0.5l}}{P} = \frac{lK+cT}{4K(T+K)}. \quad (21)$$

If the force P acts in the middle of the span in the same way, but corresponds directly under the dropper ($x = 0.5l$, $x_0 = 0$):

$$Э_{0.5l,c} = \frac{\Delta h_{0.5l,c}}{P} = \frac{l}{4(T+K)}. \quad (22)$$

From this formula, we can determine the elasticity of the chain suspension only in the middle section of the span ($P_c$contact wire lift) until the moment of slackening. Also, currently $P \leq P_c$, slackening is observed under the influence of force 22 [4].

In the case where there is no force P on the droppers in the middle section of the span, the effect of the load.

$$R_{cK} = (g_K + g_c)c - \frac{8 f_K K_c}{l_K^2}, \quad (23)$$

where: g_K - 1 m of the contact wire weight load; g_c - the load of the dropper's cable weight per 1 m of the contact wire; l_K - span length section, the part where the sagging is present $l_K = l - 2e$.

The chain suspension has the elasticity of several holding wires, and the lifting of the contact wire under the dropper is observed under the influence of force P. Therefore, under the influence of force P, the lifting of the contact wire under the chain suspension will be greater compared to the lifting in the span between the wires. For this reason, in these wires, in addition to the vertical tension of the contact wire and the loading of R_{cK}, the effect of compression is influenced by force P.

$$R'_{cK} = \frac{K}{T+K} P_C. \quad (24)$$

Therefore, a change in the position of the droppers occurs at the moment of their release. The following equation: $P_c = P_{cK} + \frac{K}{T+K} P_c$; its solution is related to P_c. We find the unknown:

$$P_c = R_{cK} \frac{T+K}{T}. \quad (25)$$

When the force P is applied to the intermediate section between the contact wire droppers, it results in the release of two droppers. The required magnitude of force P in this case is given in [5]:

$$P_{2c} = 2R_{cK} \frac{T+K}{T} 2P_c. \quad (26)$$

The uplift of the contact wire after the release of a single dropper under the action of force P:

$$\Delta h_c = Э_{x,c} P + \frac{cT(P-P_c)}{2K(T+K)}. \quad (27)$$

The lifting of the contact wire after the release of two droppers at the middle of the interval under the action of force P:

$$\Delta h_{2c} = 2Э_x P_c + \left[Э_{x,c} + \frac{3cT}{2K(T+K)}\right](P - 2P_c). \quad (28)$$

The elasticity of the chain suspension in the middle section of the interval after the release of a single dropper:

$$Э_c = Э_{x,c} + \frac{cT}{2K(T+K)}. \quad (29)$$

In the area (A), during the release of the spring dropper, the elasticity of the chain suspension at the support points O and O' (see Fig. 4) can be determined using the following formula:

$$Э_0 = \frac{\Delta h_0}{P} = \frac{1}{2\frac{T-H_p}{a}\gamma + 2\frac{K+H_p}{l}}. \quad (30)$$

where: H_p - the tension of the spring dropper, coefficient: $\gamma = 0.6\sqrt{\frac{a}{e}\frac{K}{T}}$

To determine the elasticity of the suspension at the point 01, we can use the following empirical formula:

Until the neighboring droppers are released $Э_{01} = 1{,}1Э_0$ and after their release $Э_{01} = 1{,}25Э_0$.

The placement of the droppers at the point 01 in a chessboard arrangement and the placement of the droppers in the two contact wire suspensions are as follows. At this point, the suspension elasticity can be assumed to be the same as at the points 0 and 01.

The elasticity of the spring suspension at point 1, before the release of the droppers in the area B (see Fig. 4), can be determined using the following formula:

$$Э_1 = \frac{\Delta h_1}{P} = \frac{e(l-e)}{l[T+K-(K+H_p)\beta]}, \quad (31)$$

where: $\beta = \frac{a}{e}(1 - 0.05a)$.

The coefficient $\beta = 0$ for the standard support droppers $\alpha = 0$ will have the following form for formula (32):

$$Э_{1.x} = \frac{e(l-e)}{l(T+K)}, \quad (33)$$

From this, it becomes clear that formula (33) is an analogous form of formula (31).

For the contact suspension with KC-200 construction used in railways, the uneven elasticity coefficient should not exceed 1.2. For the contact suspension with KC-160 construction, it should not exceed 1.35 [6].

3. Conclusion

For the contact suspension with KC-250-25-UZ (with reinforced concrete supports) construction, used for electrification of railways in Uzbekistan, the uneven elasticity coefficient:

- Should not exceed 1.226 for the length of the support interval *l = 60* m on straight tracks;
- Should not exceed 1.199 for the length of the support interval *l = 52* m on curved tracks.

For the contact suspension with KC-250-25-UZ (with steel supports) construction, the uneven elasticity coefficient:

- Should not exceed 1.2117 for the length of the support interval *l = 60* m on straight tracks;
- Should not exceed 1.15 for the length of the support interval *l = 52* m on curved tracks.

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