DESIGN OF AN ELECTRIC LOCOMOTIVE WITH A ROTATING FRAME

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ABSTRACT

The authors consider problems of reducing travel time and energy saving in the operation of rolling stock. The developed design makes it possible for an electric locomotive to move to an adjacent track and to move in the opposite direction on a parallel track to the point of formation. This saves time of locomotive stay on the track, the amount of electricity needed to go to a nearby station and back, and also minimizes the duration of overlapping of the section of the track for maintenance work, because after the completion of works an electric locomotive moves to the adjacent track and the section becomes open for traffic.

ENGLISH SUMMARY

Background. *In this paper the authors consider the problem of reducing travel time and energy saving. Currently some electric locomotives are used to repair catenary; after delivery of workers, equipment and troubleshooting process they are sent either to a nearby station and then return, or move on the wrong track to a formation station, thereby occupying a track and delaying trains. Because of this schedule shifts, and there are delays in passenger trains, and increased travel time for freight trains. Due to the developed design delays will be minimized, because the track will be released immediately after completion of works.*

Reduction in travel time and energy savings are, of course, only parts of the tasks of defining interest in improving rotating frame of electromotives. However, only their presence would not reduce the relevance of the proposed technical solutions, structural innovation, appearing in the current journal publication.

Objective. *The objective of the authors is development of an electromotive design with rotating frame, making it possible for an electromotive to move to an adjacent track and to move in the opposite direction on the right track to the point of formation.*

To achieve this goal, the following tasks are set and solved in the work:

1) patent and literature search, the development of a new design of an electric locomotive with rotating frame;

2) durability calculation of electromotive rotating frame model in the program Solid Works;

3) loading evaluation of a rotary element of a frame by considering it as a spatial system consisting of rods, the axes of which pass through the centers of gravity of areas;

4) evaluation of the safety margin in the dangerous section of the frame under the most unfavorable combinations of loads.

Methods. *To solve the set tasks, the authors used the method of mathematical modeling of mechanical systems. Geometric model of a rotating frame design was simulated in the package Solid Works. For the calculations the authors used a package of SolidWorks Simulation.*

Results.

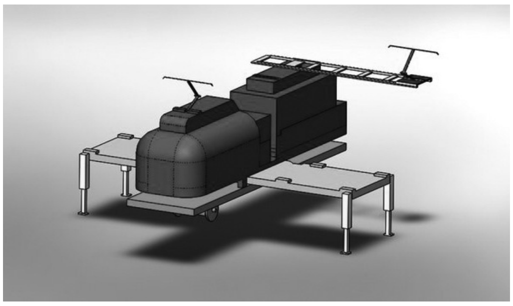
Description of a design

Electromotive design (Pic. 1) was developed on the basis of a railcar 1ADM 1.3, it has a length of 13 m, width – 3,25 m, height under the contact wire – 5520 cm. On a rooftop two pantographs are mounted: one directly above the cab, the other – on rotary skids on a moving platform, oriented perpendicularly to the contact wire [3].

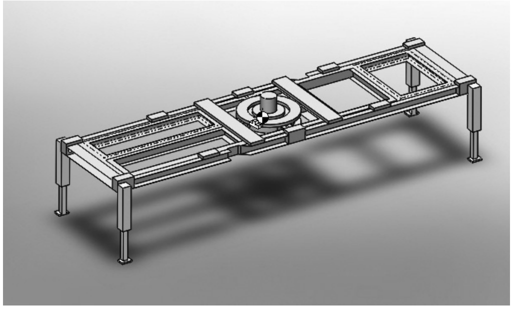
Rotating frame (Pic. 2) is located between body frame and above framed constructions. It is proposed to make it of carbon steel. On the frame there are four pillars with sliding rods. The length of each is 1,5 m, rods slide by 1 m, which allows lifting up an electromotive above the track bed to 35–40 cm maximum. Inside the frame there are channels for electrical cables, pipeline of a braking main line and pipeline for air delivery on sliding bearing supports.

On the frame along the sides of the center tooth group is installed, the length of their bed is 1 m from each side of the frame. Teeth move out of the frame for 2 cm and are moved away by a pneumatic assembly. Air is pumped into a small cylinder, and it lifts up the bed with a tooth group.

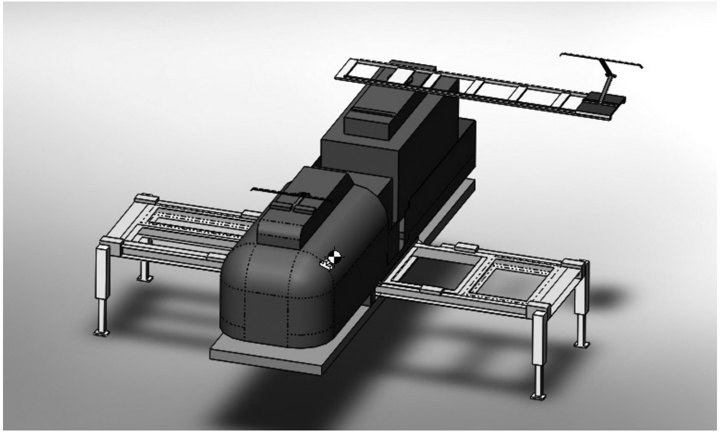
In the center of the frame there is a set of rollers mounted around a rotative axis of the frame, there are only 8 of them. They are required for better sliding of electromotive frame and underframe (mechanical) part on the rotating frame. The same set of rollers is mounted on the underside of the rotating frame (underneath). Rollers are mounted fixedly, without further movement on some directions. Fixed mounting increases stability when turning and sliding on the rotating frame. Moreover, along its entire length, there are five sliding plates at each side for softer movement



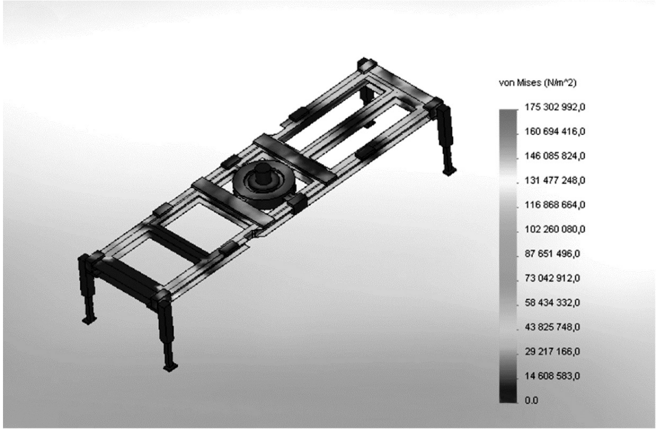
Pic. 1. General view of a design.



Pic. 2. Rotating frame.



Pic. 3. Operating status of the locomotive.



Pic. 4. Stress diagram on the rotating frame.

of an electromotive along the frame. Sizes of plates: 30 cm – length, 15 – cm width, 5 cm – thickness.

The frame is turned by a center pin, passing through the center of the electromotive and attached to the rotating frame by spur gearing. When the frame rotates, a center pin falls on it; it gears to it and turns the entire structure strictly through 90 ˚. The center pin moves with the help of a simple gearbox and electromotor, it is connected by chain gear to the rotary mechanism by skids, which have an additional pantograph. After turning of the frame, the center pin moves up back in order not to impede the movement of the electromotive on the frame. Beds of the teeth, rising above the frame, enter the chains on the electromotive body, the motors turn on and begin to slowly rotate the chains in the right direction. Upon reaching the required distances they turn off.

Then the compressor turns on and pumps air into the cylinder of a pressure line, and then it is delivered on the sliding bearing supports on the ends of the rotating frame, the bearing supports move down by 90 ˚. In each of them there is a sliding rod with a platform designed to provide greater contact with the ground (Pic. 3).

Once the bearing support has moved down, the air enters the cylinder with the rod and pushes it down to the necessary distance, or to the bottom of the piston distance. In this case the electromotive will be above the track bed at a height of up to 50–60 cm

In the next step the motor turns on, thus pulling the chain, and moves the electromotive on the rotating frame to the desired distance (adjacent track).

For a precise mounting of the electromotive above the track bed, sensors can be used, or it is necessary to determine visually when the wheels are just above the rails, but it is less efficient. Therefore it is better to use sensors.

Moving down of the electromotive is carried out as follows (Pic. 3 – service position).

The air is discharged gradually out of the lifting bearing supports, and the rod returns to its original position. The electromotive moves down smoothly on the track and stands up on the rails.

After that bearing supports are raised to their original position and get back into the plane of the rotating frame. Chain gear turns on again and the rotating frame moves to its initial position that is exactly in the middle of the electromotive. Upon reaching the center motors with the chain turn off, beds with the tooth group move down in the rotating frame. The center pin connects to it by the electric motor, which turns the frame, and it stands up under the underframe constructions of the electromotive. The center pin rises. The electromotive is ready for movement on a nearby track.

Application field

When checking out the scene at large hauls (10 km or more) the electromotive will be irreplaceable.

Upon completion of work, it moves to the adjacent track and then moves toward its depot (depot of formation).

Advantages:

– There is no need to go to the nearest station and then back on its track;

– Energy is saved as the electromotive does not overcome the distance to the nearest station and does not go back N km, and moves to the adjacent track and from this point returns to the station of formation;

– In some cases, decisions are made to return an electromotive on the track in the opposite direction, in this case the track remains occupied until the electromotive arrives at the station of formation – the new design allows moving to the adjacent track and moving on it back to the station, leaving lines for free passage of passenger and freight trains;

– Thanks to the mentioned factors energy is saved, the time of its turnaround from the starting point is reduced, troubleshooting becomes possible without returning to the station of formation;

– The electromotive will be especially useful at hauls from 15 to 30 km, since at such long distances power consumption for a complete turnaround of the locomotive between stations and turnaround of the locomotive from fault point and back will be the greatest.

Calculations of the rotating frame

All operations were carried out using Solid Works.

Key features:

Density – 7858 kg / cu. m.

Weight – 8800 kg.

Volume – 3.96 cu. m.

Surface area – 114,54 sq.m.

Calculation of the safety margin

1. Simplified scheme

The frame is presented as a spatial system consisting of rods whose axes pass through the centers of gravity of areas [1,5] (Pic. 6).

The frame is a spatial statically indeterminate system with two closed contours. The calculation is associated with bringing such systems to statically determinable systems by cutting «unnecessary» rods. In cut places three unknown forces and three moments must be applied [2].

The frame is considered as a statically determinate system, if we neglect the influence of the end beams. Since the contours are open, the calculation can be carried out for a quarter of the frame. The dropped part is replaced by the rigid support, and maximum bending moment will act in it, that is in joint place of side to center pin bolster. This cross section will be dangerous. It is thoroughly tested for strength with account of feed data.

Frame length is set as 2l=13 m. Frame width is set as 2b=3,25 m. The base is 2a=7 m.

Distance from the axis of the frame center pin bolster to the suspension axis of the traction motor is found as

$$x_Д = \frac{2a - 2\cdot 1,2}{2} = \frac{7-2,4}{2} = 2,3\ m. \qquad (1)$$

Distance to hinges of spring riggings:

$$x_{p1} = \frac{2a - 1,4}{2} = \frac{7-1,4}{2} = 2,8\ m; \qquad (2)$$

$$x_{p2} = \frac{2a + 1,4}{2} = \frac{7+1,4}{2} = 4,2\ m. \qquad (3)$$

Distance to the hinge axis of locking dogs of axle-bearing:

$$x_{n1} = \frac{2a - 0,95}{2} = \frac{7-0,95}{2} = 3,025\ m. \qquad (4)$$

$$x_{n2} = \frac{2a + 0,95}{2} = \frac{3,0+0,95}{2} = 3,975\,m. \qquad (5)$$

Distance from calculated plane of the frame to the underframe structure:

zП1 = 0,4 m;

zП2 = 0,4 m.

Distance to the center of the spherical hinge of the center pin:

zШ = 0,4 m.

2. Weight load

Frame weight:

P = mg =31113,17·9,81=305220,198 N = 305,220 kN (6)

Weight of overframe part, acting on the frame:

P1 = m1g = 18000·9,81 = 176580 N = 176,58 kN. (7)

The magnitude of the reaction is determined in kN from the condition:

$$R = \frac{P' - P_1'}{4},\ kN, \qquad (8)$$

R = 32,16 kN

q is an intensity of uniformly distributed load from weight of side and center pin bolster is determined by the expression:

$$q = 2,2 + 120\cdot\sum F_i =$$
$$= 2,2 + 120\cdot 0,0516670 = 8,4\ kN/m. \qquad (9)$$

3. Stress in the dangerous section from weight load

Computational scheme is reduced to the simple bending of a bolster, fully-fixed by one end Xk = 0,874 m.

.

$$\begin{aligned}
&M_y = R\cdot(X_{p1} + X_{p2}) - 0,5\cdot 1^2\cdot q -\\
&-0,2\cdot q\cdot b\cdot 1 - 0,25\cdot P_k\cdot X_k =\\
&= 32,16\cdot(2,8+2,4)\ -0,5\cdot 3,5^2\cdot 8,4 -\\
&-0,2\cdot 8,4\cdot 1,167\cdot 3,5 - 0,25\cdot 176,8\cdot 0,874 =\\
&= 65,59\ kN/m.
\end{aligned} \qquad (10)$$

Computed bending moment

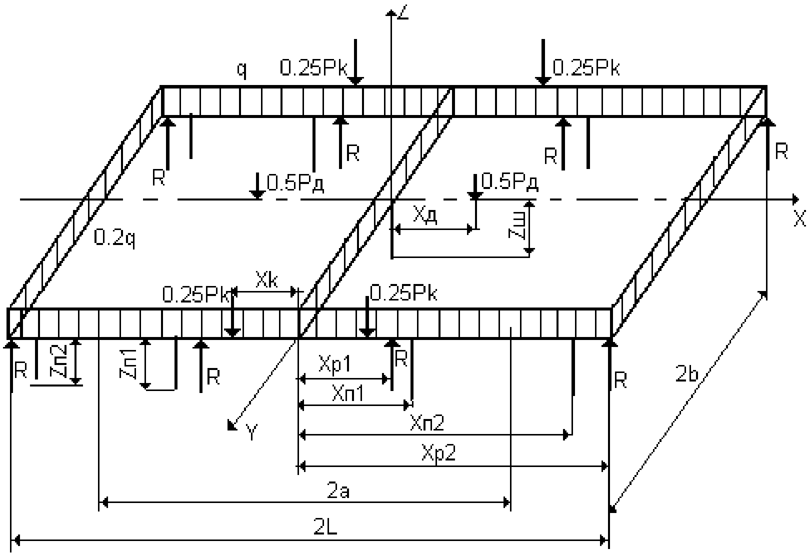
Voltage from the weight load from side of the frame:

$$G_{вi} = \frac{M_y}{W_{y1}} = \frac{123,48}{-0,021}\cdot 0,001 = -58,8\ MPa, \qquad (11)$$

since 1 H/mm2 = 1 MPa.

Value of the moments in some points of the computational scheme:

$$\begin{aligned}
&M_{y1} = 0;\\
&M_{y2} = M_{y3} = -0,2\cdot q\cdot b\cdot(1 - X_{p2}) -\\
&-0,5\cdot q\cdot(1 - X_{p2})^2 = -0,34003\,kNM;\\
&M_{y4} = M_{y5} = R\cdot(X_{p2} - X_{p1}) - 0,2\cdot q\cdot b\cdot(1 - X_{p1}) -\\
&-0,5\cdot q\cdot(1 - X_{p1})^2 = 11,0208\,kNm;\\
&M_{y6} = M_{y7} = -0,2\cdot q\cdot b\cdot(1 - X_k) +\\
&+R\cdot(X_{p1} - X_k) + R\cdot(X_{p2} - X_k) = 18,54kNm;\\
&M_{y8} = M_y = 65,59\,kNm.
\end{aligned} \qquad (12)$$



Pic. 6. Simplified computational scheme of the frame: xK – distance from center pin bolster to suspension; xP1, xP2 – distance from center pin bolster to bearing supports of the frame; xП1, xП2 – distances from center pin bolster to sliding plates; xД – distance from center pin bolster to axis of the central sliding plates; PK – weight of the body.

The most unfavorable load combinations

We take the simultaneous action of various loads in their possible combination and produce algebraic summation of voltages for the 6th point of the section. Safety margin is determined by the maximum magnitude and it is concluded that the bogie frame is suitable for use. The frame is considered to be suitable if a margin safety coefficient is not less than 1,28 and not more than 2. As for the metal flow:

1,28<пм<2;

$\sigma_{\max}^{рез} = 131,47$ *MPa;*

$$n_m = \frac{\sigma_{\max}}{\sigma_{\max}^{рез}} = \frac{700}{131,47} = 5,32, \qquad (13)$$

where σ max = 700 MPa and steel flow point is 1,4028 (for steel of quality X30Cr13).

The frame has overrated margin safety (5,32 instead of required 2), increased weight. Reduction of side cross-section parameters may lead to weight-saving of the frame and loss of endurance strength margin. In this situation metal with a minimum flow from 162,5 to 450 will be suitable. It will provide necessary strength factor margin and reduce cost and weight of the entire structure.

Conclusions. *1. Analysis of calculation results shows that under a given load equivalent stresses in the structural elements of the frame do not exceed the yield strength of the used materials, that is, the necessary strength is provided.*

2. Maximum deflections of the frame structure, arising from the external loads, do not exceed the allowable margin – the necessary rigidity of the frame is provided.

3. Stress level in the significant part of the frame structure is very low. This means that it will retain certain safety margin and has the prerequisites to a reduction of metal intensity.

Keywords: *electromotive, rotating frame, railcar, new design, durability, movement between tracks.*

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