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ASSESSING THE IMPACT OF THE LATERAL SWINGING OF THE TRAM TO ITS ELECTRICAL CURRENT COLLECTOR

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Abstract *– This article presents a study aimed at assessing the impact of the side to side swinging of the body of the tram over the electrical current collector, caused by the dip in the railroad and to research the reasons behind the failures of it. The rail track on which the research took place is made of grooved rails on top of panels. Due to the usage of the track, there are frequent asymmetrical collapses of the two rails which have different frequency and depth. The needed data for determining the side to side swinging of the body has been obtained with an inertial measuring system, which has been mounted on the roof of the carriage just under the electrical current collector. The values of acceleration, angular velocities and magnetic field in the three axes of the tram have been obtained from it. It has been found that the lateral swinging of the tram body causes high dynamic loads in the structure of the collector and this leads to damages and accidents.*

Keywords – tram, electrical current collector, railroad, accelerometer, gyroscope, magnetometer, Kalman filter.

1. INTRODUCTION

The current collectors are designed to be resistant to longitudinal and vertical forces during movement, ie. loads from accelerations when starting and stopping and from the pressure on the contact wire.

This gives the structure security at significantly lower loads in the transverse direction.

2. STATUS OF THE PROBLEM

In recent years, there has been an increase in the number of faults to the current collectors of tramways in the city of Sofia. The predominant damages are: appearance and development of cracks on the elements of the current collector, damages on the hinges, deformations of the thinner elements in the upper part, damages on the connecting elements and the mechanisms of the stand of the sliders. These faults are typical for the trams moving primarily on routes, which in some parts have sections with rail track in poor condition.

The tramways in the city of Sofia are equipped with different types and models of current collectors. Symmetrical are: Pf-80, KE28. Asymmetrical are: Fb500.54, Fb700.87 и ESgs 17-3100. Depending on their construction they have different faults.

3. MEASUREMENTS

Measurements were carried out along the route from The Triangle junction to the Iliyantsi turning ear. The route is built with stemless grooved rails on top of panels. Due to the long-term operation, there are frequent asymmetrical collapses of the two rails with different frequency and depth.

The sensors were placed in trams type T8M 700 M with inventory № 923 and type T6A2-BG with inventory № 3014. The measurements were made in operational mode with passengers.

4. PROCESSING OF THE DATA

An inertial measuring system was used to determine the angles at which the tram tilted during its movement relative to the local north-east-down

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coordinate system. In it are included triaxials: accelerometer, gyroscope and magnetometer. They are mounted on a single base, ensuring alignment between their axes. The system is fixed to the ceiling of the tram in the area where the pantograph is located, as shown in figure 1.

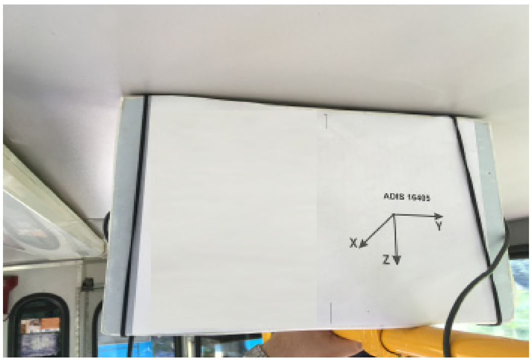

Fig.1. Inertial measuring system

The orientation of the axes of the sensors and the angles that describe the spatial position of the tram are shown in Figure 2.

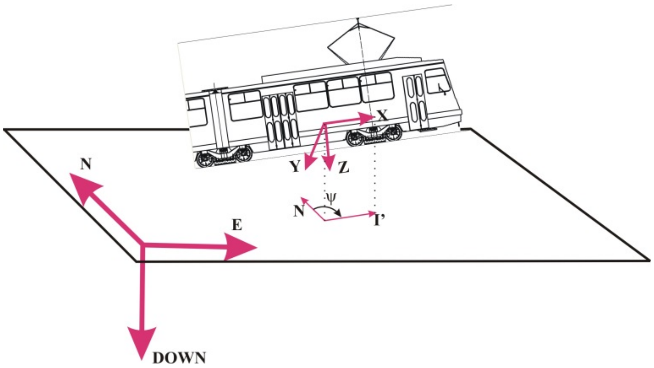

Fig.2. Orientation of the tram axes and the local coordinate system

The relationship between the coordinates of the sensors in the two systems is given by the expression (1)[1]:

$$V^{local} = \left(R_{local}^{body}\right)^T . V^{body} \tag{1}$$

In order to calculate the matrix R_{local}^{body}, it is necessary to determine the Euler angles Φ, Θ, ψ. The sequence of rotation around the axes, when converting coordinates, from the coordinate system of the tram to the local coordinate system, is shown in Figure 3.

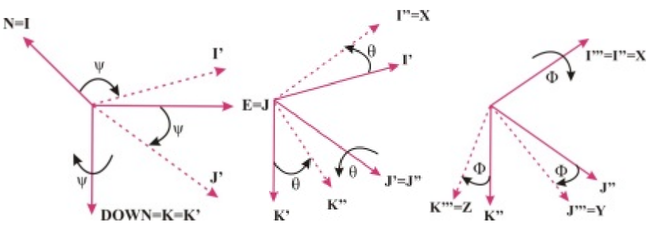

Fig. 3. Sequence of rotation of the axes

The data from the various sensors were processed using an algorithm in which a Kalman filter was used to obtain the required angles [2]. The way the data from the different sensors are combined is shown in Figure 4.

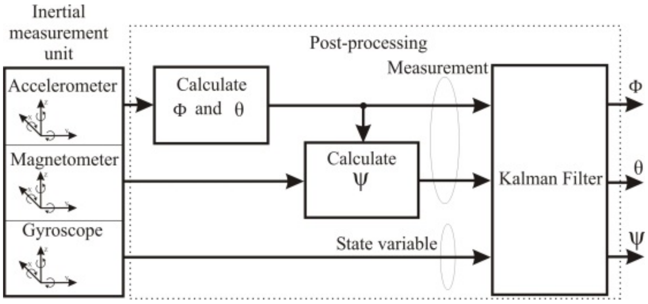

Fig.4. Calculation of the angles

5. RESULTS.

To determine the influence of the rocking of the body of the tram on the pantograph, the following parameters are taken into account: the accelerations along the transverse axis $\vec{a}_y$, the angular speed of rotation relative to the longitudinal axis ω_x and the angle of inclination of the body of the tram in the transverse plane Φ_x.

For the tram with inventory № 923 the measured maximum values of the parameters are:
$\vec{a}_{y\max,923} = 1,7\ m.s^{-2}$; $\omega_{x\max,923} = 3,5\ \deg.\sec^{-1}$,
$\sphericalangle\Phi_{x\max,923} = 15\ \deg$.

For the tram with inventory № 3014 the measured maximum values of the parameters are:
$\vec{a}_{y\max,3014} = 0,95\ m.s^{-2}$; $\omega_{x\max,3014} = 3,0\ \deg.\sec^{-1}$,
$\sphericalangle\Phi_{x\max,3014} = 7\ \deg$.

It is noteworthy that the values for the tram with inventory № 923 are higher. This is due to the type of suspension of the chassis. The tramways type T8M 700 M have a two-stage spring suspension made of sets of cylindrical coil springs. While trams type T6A2-BG have a fixed guide of the axles and cylindrical coil springs in the central spring.

6. INFLUENCE ON THE CURRENT COLLECTOR

The design of the current collectors (Figure 5.a) is a mechanism designed to work in one plane [3]. This is a plane defined by the X and Z axes. While in the transverse plane it can be considered as a singe body (Figure 5.b).

When shaking the basket, the entire current collector has the same deviation. This leads to a load in the hinge joints of the structure. The loads are different according to the type of construction, at what height they are and what masses are above them.

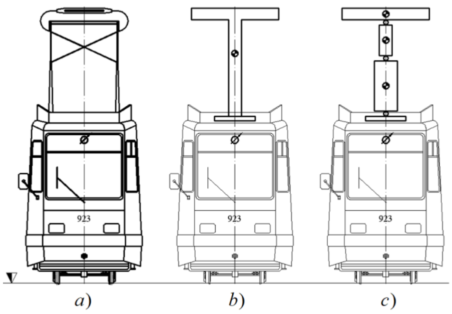

Fig.5. Schemes of the current collector as one body and as a composite body

Due to their immobility in the transverse direction, hinged connections are considered to be thinner places in the structure (Figure 5.c).

The pantograph can be divided into four levels:

- base – firmly attached to the roof of the basket by insulating elements;
- lower level – the elements below the middle hinges;
- upper level – the elements above the middle hinges;
- head – stand of sliders with sliders.

For each of the levels, no matter how many elements it consists of, we assume that its mass m_i is concentrated in the center of gravity. The same goes for the hinges - regardless of their number, they are considered one. These points of the structure are chosen as characteristic and the calculations for the loads are made in regards to them. The points of the center of gravity of each of the bodies of the pantograph are marked with B_i, the centers of the hinges – with S_i. The point where the sensor is located is marked with C.

Figure 6 shows the pantograph as a single body.

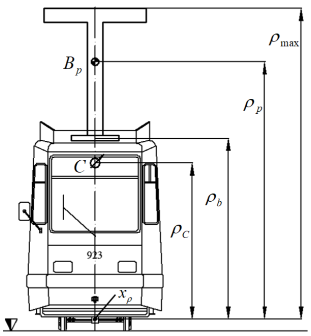

Fig.6. Location of the characteristic points in case the current collector is considered as one body

Figure 7 shows the pantograph as a component body. Its levels are separated into separate bodies.

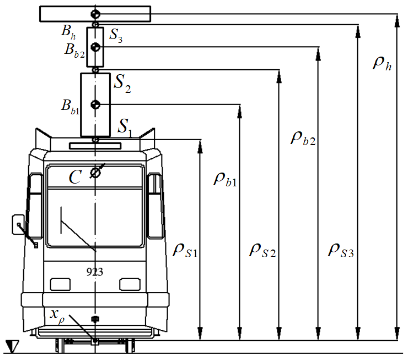

Fig.7. Location of the characteristic points in case the current collector is considered as a composite body

It is assumed that the rocking of the basket is a partial rotation around an axis x_ρ parallel to the longitudinal axis of the basket – X, at a height around the axes of the wheelset, depending on the design of the spring suspension. From the measurements made, the values of the angular velocity ω_x when rotating around the axis x_ρ, the angle of rotation - Φ_x and the accelerations along the Y axis - $\vec{a}_y$ were obtained. The distance from the axis x_ρ to each of the characteristic points is ρ_i, and to the sensor ρ_C.

The angular velocity ω_x and angular acceleration ε_x, which are derivatives of the angle of inclination of the body Φ_x, are the same for all points of the pantograph. The measured effective values of the acceleration due to the small angle of deviation can be considered as values of the tangential acceleration.

The following dependences are used to calculate the loads at the accepted characteristic points of the current collector [4]:

- for the angular acceleration: $\varepsilon_x = \dfrac{\vec{a}_y}{\rho_C}$;
- for the tangential acceleration at the characteristic points: $\vec{a}_\tau = \varepsilon_x . \rho_i$;
- for the force at the center of gravity of each of the levels: $F_i = m_i . \vec{a}_\tau$;
- for the bending moment in the hinges: $M_i = F_i . \rho_i$;
- for the linear velocity at the characteristic points: $v_i = \omega_x . \rho_i$.

If we consider the scheme, which accepts the current collector as one body (Figure 6.), then the entire load from the swing is taken by the connection between the base and the roof of the tram. After replacement and conversion for the bending moment in the base of the pantograph is obtained:

$$M_b = m_p . \varepsilon_x . \rho_p . \left(\rho_p - \rho_b \right) \tag{2}$$

When considering the scheme, which accepts the current collector as a composite body of its levels (Figure 7.) for the bending moment in the hinged connections connecting the levels after replacement and conversion, separate dependences are derived.

For the hinges connecting the pantograph head to the upper stage:

$$M_{S3} = m_h.\varepsilon_x.\rho_h\left(\rho_h - \rho_{S3}\right) \quad (3)$$

For the middle hinges the parameters are in accordance with the specific construction and the bending moment is calculated by:

$$M_{S2} = \left(m_h + m_{b2}\right).\varepsilon_x.\rho_{(h+b2)}.\left(\rho_{(h+b2)} - \rho_{S2}\right) \quad (4)$$

where: $\left(m_h + m_{b2}\right)$ - the sum of the masses of the head and the upper level; $\rho_{(h+b2)}$ - distance of the center of gravity of the masses above the middle hinge to the axis of rotation of the body.

For the main hinges, the parameters are taken into account with the specific construction and the bending moment is calculated by:

$$M_{S1} = \left(m_h + m_{b2} + m_{b1}\right).\varepsilon_x. \\ .\rho_{(h+b2+b1)}.\left(\rho_{(h+b2+b1)} - \rho_{S1}\right) \quad (5)$$

where: $\left(m_h + m_{b2} + m_{b1}\right)$ - the sum of the masses above the main hinge; $\rho_{(h+b2+b1)}$ - distance of the center of gravity of the masses above the main hinge to the axis of rotation of the body.

The details and assemblies of railway vehicles are mostly endangered by tired destruction, which occurs years after the production and commissioning of large batches and series, usually of a mass nature, and is associated with huge material damage [5, 6, 7].

Fatigue strength is affected by two groups of loads - resistances and loads. The current collectors are subjected to loads of constant and random nature. The constant loads are from the static load and have relatively low values. The dynamic loads from the road have significantly higher values and reach the zone of plastic deformations of the material [7].

From the described experiment, information can be derived about the behavior of the pantograph and the accelerations of its elements when passing through the collapse of one rail.

The results show that the dynamic load is random and depends on the condition of the track. When driving on a route with poor road condition, at some points the stresses are in the dragging zone or above it. Periods of low and high loads alternate. Meaning that it is difficult to determine whether there is low-cycle or multi-cycle fatigue.

7. CONCLUSION

The assumption that the cause of damage and emergency switch is the influence of the track is confirmed. The current collectors are subjected to a large number of alternating cycles of a random nature, which leads to a strong decrease in the fatigue strength of the material.

The article analyzes the influence of the lateral rocking of the tram body on the pantograph caused by the collapse of the rail. On this basis, mathematical dependences are proposed for determining the loads in the elements of the different structures of the pantograph. A methodology for measuring the parameters of the lateral swing has been proposed. The replacement of the obtained data from the measurement in the mathematical dependences will make it possible to obtain the actual loads in certain elements and on this basis to develop a plan for their maintenance, in order to avoid their frequent failures.

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