Diagnostics and reliability of current receivers

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Abstract. The most vulnerable element of modern electric buses, which are dynamically charged, are pantographs. The article describes the main reasons for the wear and tear of pantographs. The calculation of the probability of failure-free operation of the pantograph systems is made.

1. Introduction
A pantograph is an electrical device for creating a contact of electrical equipment of an electric rolling stock with a contact network. At present, the requirements for the operational characteristics of pantographs and, first of all, for their reliability and efficiency are constantly increasing [1]. The characteristics and parameters of pantographs must comply with the values established by the regulatory document [2].

In this regard, to ensure reliable and economical current collection, it is necessary to carefully monitor the state of the pantograph during operation, which is carried out by various diagnostic devices [3].

2. Materials and methods
To carry out instrumental diagnostics of the state of the pantograph, it is necessary to highlight the signs, the parameters of which can suddenly change during operation on the line, as well as those parameters that slowly change over time and are monitored during inspections and repair in the depot.

A generalized analysis of the main parameters of diagnostics of tram pantographs is presented in Table 1.

Analysis of failures of the main rolling stock units in several large tram and trolleybus facilities shows that the rolling stock response due to pantograph malfunctions is 5.3...11.8% of the total.

In percentage terms, the manifestation of typical malfunctions, based on statistical data, is given in Figure 1. As can be seen from the table, the largest number of faults is associated with the deformation or breakage of structural elements of current collectors [4].
### Table 1. Analysis of diagnostic parameters.

| Statistical depression characteristic | Spatial position of the pantograph | Presence of gouges on the contact insert |
|---------------------------------------|-----------------------------------|------------------------------------------|
| Deformation of the frame levers structures, jamming in the hinges due to impact, defective lifting springs, freezing greases in frame hinges | Deformation of the frame or contact insert, breakage of the base insulators | Hitting the clips and braces with breakage, tearing off the pantograph, leading to burnout, breakage on the special parts of the contact wire |
| Tear-off of the pantograph, leading to burnout of the contact wire, breakage of the contact wire clamps, increased wear | Increased pressure on the contact wire, jamming in the frame hinges, lack of lubrication in the contact insert | Breakage of the contact wire, breakdown of the pantograph |

### TOTAL NUMBER OF FAULTS

![Pie chart showing distribution of faults by type.]

**Figure 1.** Distribution of faults by type.

Reasons for deformation and breakage of pantograph frame structures [5, 13-15]:

- Constructive imperfection of the current collector unit of the pantograph;
  - A large decrease in static pressure on the contact wire with a significant increase in the height of the wire suspension; to improve the current collection, pressing is adjusted at the height of the contact insert near the upper limit of the working range of the pantograph, and this, in turn, in the absence of control over the change in the static characteristics of the pantograph during operation, entails a significant increase in pressing in places with a lower suspension of the contact wire, as well as complicating the passage of the pantograph special parts and fixing elements of the contact network.
- Poor-quality inspection and repair of pantographs due to the lack of instrumentation [16, 17].
The main criterion for the operation of the pantograph is a high-quality current collection [6]. The high-quality current collection is characterized by reliability, economy, and environmental friendliness. In addition, when collecting the current, it is necessary to take into account the possibility of energy saving [7, 8].

The main criteria for the current collection process include the wear of the contact pair, the separation of the pantographs from the wires, the swing of the runner and contact pressure, the coefficients of the contact reliability, and the efficiency of the current collection, as well as the minimum annual operating costs [9-12].

Let us dwell on reliability in more detail, since this criterion is one of the most important indicators of concomitant technology. Reliability directly affects quality, efficiency, reliability, risk, availability, survivability. The technique can only be effective if it is reliable [18-20].

The reliability of the current collection is determined by the indicators of the reliability of the interaction of the pantograph and the contact network. The transmission of current from the overhead wire to the engine of the electric rolling stock must be continuous - without destroying the pantograph, as well as without breaking or damaging the wires of the overhead catenary. The economic efficiency of the current collection is associated with the cost of replacing worn-out contact wires and collector plates, as well as eliminating failures in the operation of these technical means.

3. Results and discussion

Reliability calculation of the designed pantograph is carried out by the method of structural diagrams. From the point of view of the theory of reliability, the current collector should be considered as a system consisting of series and parallel connected simple elements, the combined effect of which provides optimal conditions for the current collection.

The formula for calculating the probability of failure-free operation of a system is the product of all probabilities of failure-free operation of units and parts that make up the system. The general formula for calculating the reliability of a pantograph:

\[ P_{\text{pant}}(t) = P(t)_{\text{carr}} \cdot P(t)_{\text{lift-low}} \cdot P(t)_{\text{base}} \cdot P(t)_{\text{insul}}, \]

where \( t \) is the estimated time, \( t = 8760 \) hours (the time \( t \) is selected based on the calculation method);
\( P_{\text{pant}}(t) \) is the probability of failure-free operation of the pantograph;
\( P_{\text{carr}}(t) \) is the probability of failure-free operation of the “carriage” subsystem;
\( P_{\text{lift-low}}(t) \) is the probability of failure-free operation of the “lifting-lowering mechanism” subsystem;
\( P_{\text{base}}(t) \) is the probability of failure-free operation of the “base” subsystem;
\( P_{\text{insul}}(t) \) is the probability of failure-free operation of the insulator;

The object of the research is a pantograph intended for use on lines with a modernized current collection system infrastructure.

To calculate the reliability indicators of the pantograph, it is necessary to calculate the reliability indicators of all subsystems. Thus, it is necessary to separately consider each subsystem and build a structural diagram for it.

When calculating the probability of a no-failure operation, we use the formula for a sudden failure:

\[ P(t) = e^{-\lambda t}, \]

where \( \lambda \) is the failure rate, \( 10^{-6} \) 1/h.
To take into account the influence of the dynamics of rolling stock and climatic influences, we introduce the coefficients $k_d$ and $k_t$ into formula (1). For all systems, we take the coefficient of influence of the dynamics of the rolling stock $k_d$ = 1.54 and the coefficient of climatic influences $k_t$ = 2.

We get a refined formula:

\[ P(t) = e^{-\lambda(t-k_d-k_t)t} \]

\[ P(t) = e^{-0.00510^{-6}0.00510^{-6}0.00510^{-6}0.00510^{-6}2} = 0.999865105 \]

Next, we calculate the probability of a no-failure operation of sequential connection of the elements: shaft – upper arm of the carriage – lower arm of the carriage – shaft. According to the formula:

\[ P_1(t) = P_{\text{shaft}}(t) \cdot P_{\text{uca}}(t) \cdot P_{\text{lca}}(t) \cdot P_{\text{shaft}}(t), \]

where $P_1(t)$ – is the probability of a no-failure operation of sequential connection of the elements: shaft – upper arm of the carriage – lower arm of the carriage – shaft;

$P_{\text{shaft}}(t)$ – is the probability of a no-failure operation of shaft;

$P_{\text{uca}}(t)$ – is the probability of a no-failure operation of upper arm of the carriage;

$P_{\text{lca}}(t)$ – is the probability of a no-failure operation of lower arm of the carriage.

$P_1(t) = 0.998705758$

We calculate (2) the sequential connection of the elements: shaft – spring – shaft – lower arm of the carriage – shaft.

\[ P_2(t) = P_{\text{shaft}}(t) \cdot P_{\text{spring}}(t) \cdot P_{\text{shaft}}(t) \cdot P_{\text{lca}}(t) \cdot P_{\text{shaft}}(t), \]

(2)

where $P_1(t)$ – is the probability of a no-failure operation of sequential connection of the elements: shaft – spring – shaft – lower arm of the carriage – shaft;

$P_{\text{spring}}(t)$ – is the probability of a no-failure operation of lower arm of the carriage.

$P_2(t) = 0.997951557$

The formula for calculating the probability of no-failure operation of $n$ parallel-connected elements:
\[ P(t) = 1 - \prod_{i=1}^{n} \left(1 - P_i(t)\right) \]

where \( P_i(t) \) is the probability of failure-free operation of parallel-connected elements; \( n \) is the number of parallel-connected elements.

Then we determine (3) the probability of failure-free operation of two parallel branches: shaft – upper carriage arm – lower carriage arm – shaft and shaft – spring – shaft – lower carriage arm – shaft.

\[ P_{1-2}(t) = 1 - (1 - P_1(t)) \cdot (1 - P_2(t)) \]  
\[ P_{1-2} = 0.999997348 \]

Since the carriage has a symmetrical structure, the probability of failure-free operation for two parallel branches \( P_{1-2}(t) \) is calculated as:

\[ P_{1-2H}(t) = 1 - (1 - P_{1-2}(t)) \cdot (1 - P_{1-2}(t)) \]
\[ P_{1-2H} = 0.99999999 \]

The probability of failure-free operation of the carriage is calculated by the formula:

\[ P_{corr}(t) = P_{1-2}(t) \cdot P_{1-2H}(t) = 0.999865104 \]

The pantograph design includes two carriages. The calculation is made taking into account the parallel connection.

**Table 3.** Calculated parameters of pantograph elements.

| Element          | Failure rate, \( \lambda_i \), \( 10^{-6} \) | Probability of no-failure operation, \( P \) | MTBF, \( T \), h |
|------------------|---------------------------------------------|---------------------------------------------|------------------|
| Insert           | 1.110                                       | 0.97049533                                  | 900900           |
| Overlay          | 0.001                                       | 0.999973019                                  | \( 10^9 \)       |
| Frame            | 0.025                                       | 0.999325707                                  | \( 4 \cdot 10^7 \) |
| Shunt            | 2.200                                       | 0.942369566                                  | 454454           |
| Shaft            | 0.020                                       | 0.999460529                                  | \( 5 \cdot 10^7 \) |
| Bearing          | 0.875                                       | 0.976668293                                  | 1142857          |
| EEC              | 9.000                                       | 0.784407047                                  | 111111           |
| Damper           | 0.030                                       | 0.999190903                                  | 33333333         |
| Insulator        | 0.050                                       | 0.998651869                                  | \( 2 \cdot 10^7 \) |
| Base             | 0.005                                       | 0.999865105                                  | \( 2 \cdot 10^8 \) |
| Lever arm        | 0.004                                       | 0.999892082                                  | \( 250 \cdot 10^6 \) |
| Spring           | 0.012                                       | 0.999676282                                  | 83333333         |
| Frame            | 0.005                                       | 0.99865105                                  | \( 2 \cdot 10^8 \) |
| Chain lane       | 2.175                                       | 0.999993301                                  | 459770           |
| Air filter       | 0.200                                       | 0.994618373                                  | \( 5 \cdot 10^6 \) |
| Pneumatic regulator | 2.100                        | 0.944915588                                   | 476190           |
| Electro-pneumatic | 0.900                      | 0.976009733                                   | 11111111         |
| Pneumatic choke  | 0.800                                       | 0.978646641                                  | \( 1.25 \cdot 10^6 \) |
| Speed sensor     | 0.040                                       | 0.989265708                                  | \( 2.5 \cdot 10^6 \) |
| Spark sensor     | 0.100                                       | 0.997305556                                  | \( 1 \cdot 10^7 \) |
| Control block    | 0.800                                       | 0.978646641                                  | \( 1.25 \cdot 10^6 \) |

Similarly, calculated reliability indicators for all elements and subsystems of the pantograph are given in Table 4.
Table 4. Calculated parameters of pantograph subsystems.

| Subsystem                      | Probability of no-failure operation, P | MTBF, T, h |
|-------------------------------|----------------------------------------|------------|
| Carriages                     | 0.9999999981                           | 1.4 \times 10^{12} |
| Moving frame system           | 0.996526765                            | 2517762    |
| Lifting and lowering mechanism| 0.780906458                            | 109102     |
| Control devices               | 0.967495305                            | 816327     |
| Automatic control system      | 0.968113656                            | 832592     |

As a result of calculations carried out for all elements and subsystems of the pantograph (Table 5), we determine the probability of failure-free operation of the pantograph:

\[
P_{\text{pant}}(t) = 0.950398136
\]

4. Conclusion
When analyzing the malfunctions of the pantograph, it turned out that the direct deformation of the pantograph is the most frequent of them. According to the results of calculations, it was determined that the mean time between failures of the considered pantograph is 10,000 hours with the probability of failure-free operation of the pantograph more than 90%. This value meets the technical requirements for pantographs.

The elements with the shortest MTBF are a rubber-cord element, chain transmission, and pneumatic regulator. Thus, these elements require the most frequent and increased supervision over them.

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