The Analysis of Modern Diagnostic and Monitoring Devices for the Traction Power Supply System

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Abstract. In the process of a new modern device developing for diagnostics and real-time monitoring of the ground system, in order to take into account, the existing features of high-speed traffic development, the present modern diagnostic devices for the traction network of high-speed railway transport were investigated. The existing devices and methods of diagnostics and monitoring of the traction power supply elements of railways are discussed in the article. The basic operation principles of the used devices have been analyzed and the analysis of their advantages and disadvantages are considered in the present paper. The presented analysis allows us to studied not only the trends in the development of diagnostics and monitoring systems, but also to make a conclusion about the future prospects for their implementation and refinement.

1 INTRODUCTION

Based on the Strategy for the Development of Rail Transport in the Russian Federation through 2030, an increase in the range of high-speed and high-speed traffic, the weight of trains and the reliability of the current system are being implemented. The risks of traction network failures increase with the increase in speed; train traffic disruptions lead to significant economic losses. Restoration work takes a considerable amount of time, as the damaged sections become more extensive. The classical way to ensure high reliability indicators is to provide redundancy and increase the safety margin. So, at speeds over 160 km/h, it is forbidden to operate the contact wire with wear and tear exceeding 20 % of the nominal cross section. At the same time, on the lines with low speed it is allowed to wear out 30 %. There is a similar situation with the tension of contact wires and cables that are part of the contact suspension system. Despite the positive effect of increasing the tension on the quality of current collection, it is limited to about 50 % of the yield strength of the material.

The reasons described above have led to the fact that the operation of the contact line nowadays involves the replacement of contact wires much earlier than reaching their critical wear and tear, and also leads to a decrease in the dynamic performance of the current collection system. Problems related to the increase of permissible speeds and service life of contact wires in conditions of transition to high-speed traffic, when designing high-speed lines, are extremely topical.

During operation, the contact line regulation characteristics specified by the project are capable of exceeding the permissible values as a result for the effects of electric rolling stock (ERS), climatic conditions and current loads, which leads to failures. To ensure quality and reliable current collection, it is necessary to constantly monitor the state of the contact line and traction network as a whole. Improvement of contact line operation technologies using the permanent diagnostics and monitoring system helps to reduce the need for JSCo "Russian Railways" in traction network elements with increased strength characteristics and increase it’s replacement periods and will ensure the possibility of high-speed traffic on the sections with standard design solutions.

According to the "Strategy for Scientific and Technological Development of Russian Railways Holding Company for the period until 2025 and for the perspective until 2030," one of the most important tasks in rail transport is to improve the quality of traction network maintenance through the use of software and hardware complexes that can allow monitoring and diagnostics of traction network elements in autonomous mode. Autonomous

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diagnostic and monitoring devices combined into the system will improve the quality of diagnostics and monitoring, as well as reduce the need for highly qualified personnel and virtually eliminate the human factor (Burkov, 2021).

2 MATERIALS AND METHODS

Traction network monitoring and diagnostic devices form a set of special equipment that can be divided into mobile and stationary. Mobile devices are the laboratory wagon and various manual devices for control of traction power supply system elements. Stationary devices are used for continuous real-time monitoring of certain parameters. Information from stationary devices is transmitted via various communication channels, such as: optoelectronic, radio channels, mechanical (via insulating element) and optical. Processing and analysis of output signals from sensors installed on traction network elements are performed according to specially developed algorithms for each of them, as well as the program responsible for combining, storing and transmitting these signals.

2.1 Mobile Diagnostic Devices

The problem of mobile devices is that they have to perform diagnostics on functioning lines, along which the ERS movement is carried out stable. In addition, manual measurements aren’t sufficiently effective, since they require several bypass of diagnosed sections of different lengths, and give insufficiently accurate results.

One of the most effective mobile devices is a complex of automated control of contact line parameters. Them equipped with a diagnostic laboratory wagon, on the roof for which a measuring current collector and an observation tower with measuring equipment are installed. Apart from determining voltage to the type and magnitude in contact line, special devices make it possible to measure and register the deviations of the contact line parameters that go beyond the set norms for all the contact line objects, and on this basis they automatically generate a report on the assessment of the technical condition of the contact line on the track section under diagnosis. The design of the observation tower provides a wide and sufficient view for the measuring and control systems installed on it for video and thermal monitoring as well as ultraviolet diagnostics.

The system of speed control of contact wire is also known (Contact network control systems, tvema.ru) Fig. 1 - one of modern developments. Sensors perform all measurements in a non-contact manner, and the recorded parameters are processed by the information-computer equipment of the complex. Parameters are measured in relation to the level of top of rail heads and their position in the plot plan. At the same time, the hardware complex registers the reduction of contact wire on aerial frog and the height of registration fitting set relative to it, measures the force of current collector pressing on the contact wire, as well as registers hits on the current collector, tension of contact wire and breaking loose of current collector. Diagnostic results, including registered deviations from the required standard parameters of the contact line, are displayed in the form to graphs on the monitors of the operator's hardware complex and saved to electronic storage devices. Measurement results for the thermal imaging and ultraviolet camera are recorded separately. All recorded readings are linked to the recorded parameters of speed sensors and the distance travelled, as well as to the points of contact wire fixation.

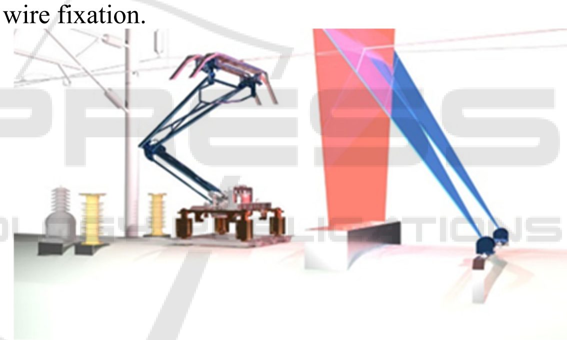

Figure 1: System for speed control of contact wire.

2.2 Stationary Diagnostic Devices

Currently on the JSCo «Russian Railways» range, the most widespread stationary diagnostic and remote monitoring system (SDRM) of the contact line contains various sensors for recording parameters for the technical condition of the contact line elements, which include the carrying cable (CC), contact wire (CW), consoles, strings, load-compensating devices placed on the anchored poles of the contact line. Stationary data acquisition and transmission devices are installed along the entire length for the contact line section on the CC and CW behind the rollers of the load-compensating units and/or above the load of the load-compensating unit placed on the anchored poles of the contact line, Fig. 2. Each device for transmitting and collecting information contains a certain list of sensors for measuring parameters to the technical condition of the contact line elements, a microprocessor device for analog-digital processing an information from the sensors, an autonomous power supply, a device for wireless communication between the device and an intermediate information storage device SDRM placed at the nearest station, which is connected by a wire and/or wireless communication with a single information storage device on the condition of the contact line elements of the railway network (Nepomnyashchij, RU2444449C1).

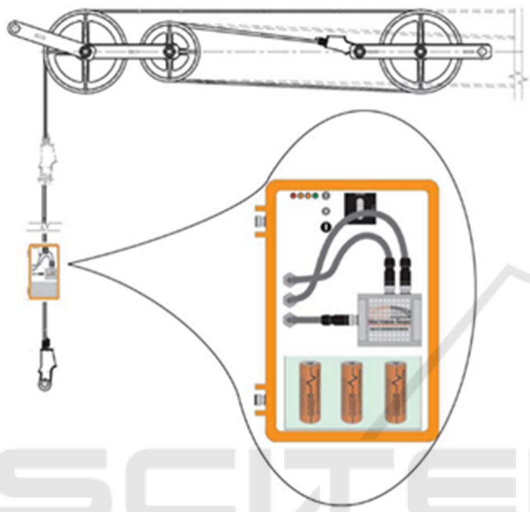

Figure 2: Information collection and transfer device SDRM.

However, a complete transition to stationary devices has not yet been organized and is difficult. In order to control the parameters of the contact line with detection of pre-fault conditions, it is planned to use a

combined monitoring and diagnostic system consisting of mobile diagnostic devices (laboratory wagons), diagnostic tools on the ERS, stationary monitoring devices installed along the entire line area, as well as a unitary system for data collection and analysis. Stationary devices provide diagnostics and monitoring for a number to certain parameters, including movement of compensating device weights, tension of contact suspension wires, temperature of contact wires, conditions of ice formation, vibration and inclination of contact line poles, etc (Eurasia news, eav.ru).

3 RESULTS AND DISCUSSION

The main disadvantage of the existing systems for monitoring the state of the contact line with the help for mobile diagnostic devices is that these measurements are carried out periodically, and the observation time is short enough, which does not provide an opportunity to monitor the stress and strain state of the components to the contact line. Also, the presence of optical devices has a negative impact on all the above, as it significantly reduces the reliability of the described method.

Table 1: Frequency of inspections, checks and measurements of grounding devices.

Name of work on the scope of maintenance for grounding devices	**Periodicity**
1. Inspection of all visible elements for the grounding device, checking the contacts strength, the correctness of installation, no mechanical damage; tightening loose bolted contacts, elimination of detected faults	Twice a year (spring and autumn)
2. Selective opening of the ground to inspect the elements of the grounding device in the ground	once every 5 years
3. Measuring the resistance of the grounding device (if it's value is normalized)	After installation, no later than 6 months after commissioning, and thereafter at least once every 3 years
4. Measuring the grounding resistance of structures and devices connected to the rail circuits (if necessary to control their values in the condition of the influence on the operation of the rail circuits for signals and interlocks and protection against electrical corrosion)	At commissioning and thereafter at least once every 5 years (direct current) and at least once every 10 years (alternating current)
5. Checking serviceability of protective devices of the grounding circuit: airgap diode, diode-spark grounders airgap type IPV-CNII	 once every 3 months twice a year once a year
6. Checking the serviceability of the grounding circuits by electrical measurement	once a year

Continuous monitoring systems that are used do not allow you to properly assess the tension of wires and cables traction network in the online mode, or require changes in the construction of the control object.

Both versions of diagnostic and monitoring systems have the ability to control only one parameter - the force in wires and cables. In addition, the described systems do not provide the possibility of continuous diagnosis and monitoring of the state of traction network elements, but most importantly, they do not provide the possibility of rapid prediction of pre-fault and failure situations. At the moment, many of these disadvantages have been solved in the developments (Efanov, RU2701887C1; Navik, 2016). However, even before it’s final and full-fledged implementation, certain improvements are needed. Along with the development of the optimal system for diagnostics and monitoring of the contact suspension elements, the issue of diagnostics and monitoring of other elements in the traction network, in particular, such an important element of traction power supply as the grounding system, remains unresolved.

According to (Ministry of Railways of Russia, 1993) (Table 1) it can be concluded that the frequency of checking the grounding system devices is not great and consists mainly of visual inspections, which, combined with the human factor, creates a high probability of untimely detection of faults in the grounding system.

This maintenance procedure inevitably leads to high labor costs for it’s implementation, and often misses the real pre-fault states of the grounding system elements. This leads to failures and, as a consequence, to disruptions in train traffic, and in the worst cases can lead to disasters.

One of the important and problematic nuances is the resistance of the contact line poles groups, which affects the operation of the relay protection.

Operational information about the technical condition of the traction network elements, including the grounding system, will allow technicians to eliminate pre-fault conditions in time.

Means of continuous diagnostics and monitoring are currently sufficiently equipped only facilities of railway automation and telemechanic, the fault of which is registered less than 3% of failures that caused violations of train traffic and safety of people (Efanov, 2016). However, it’s mainly necessary to provide means of continuous diagnostics and monitoring of the following objects: traction network and track railway line, which aren't redundant.

For quite a long time there has been a need to introduce continuous monitoring and diagnostic systems of the traction network on railways, because it's elemention failures lead to disruption of train traffic, threaten the safety of passengers and maintenance personnel, and also have a negative effect on adjacent objects.

It should be noted that, according to a preliminary estimate, the cost of implementing the monitoring and diagnostics system will be less than 10-15 % of the cost of capital building of the traction network. The costs of the diagnostics and continuous monitoring system can be divided into two components: the cost of technological equipment: sensors, accumulators, autonomous power supplies, etc. and the hardware complex of centralization: data transmission channels, automated workplaces, servers, etc. Application of the continuous monitoring and diagnostics system will contribute to almost complete elimination of critical damage for traction network elements, leading to a threat to human safety and disruption of train traffic.

Obviously, the quality and safe operation of electrified railways directly depends on the reliable operation of all components of railway infrastructure and ERS. Thus, an effective means of ensuring high reliability as well as preventing pre-failure states are systems for continuous monitoring and diagnostics of railway infrastructure facilities, including grounding systems.

On the Department "Electrical Power Supply of Railways" of the Emperor Alexander I St. Petersburg State Transport University is working on a modern diagnostic and real-time monitoring device for the grounding system, which in combination with the traction power supply system without grounding the contact line poles on the traction rail will create a low-maintenance grounding system and allow for control within the digital substation.

4 CONCLUSION

Development of the real-time diagnostics and monitoring system for the railway traction network is associated with the improvement of monitoring technologies, reduction in the cost of hardware and equipment and increase in the established level to the quality of system operation. At the same time, equipping railways with continuous monitoring systems creates favorable conditions for the development of digital railway space (digital railway) (Rozenberg, 2016).

The development of data transmission networks at signal transmitting elements, which include diagnostic devices of the permanent monitoring system of the traction network, on long railway sections is accompanied by the creation of a system of wireless transmission of diagnostic information in real time. Any diagnostic and monitoring devices for the railway infrastructure, including grounding systems equipped with radio transmitters, can be connected to such a system. At the same time, there will be no need to provide the services of contractors in terms of communication (Ivanov, 2016). At the same time, a real-time digital diagnostic data transmission system will allow the use of cloud-based storage and transmission technologies in the railway transport, for example, diagnostic and monitoring results can be transmitted on the portable devices of the nearest service personnel to the diagnostic and monitoring object. Stationary workstations with a large number of hardware and computers can be eliminated, and monitoring results can be displayed in a separate module of the automatic train control system. The reduction in equipment will reduce the cost of diagnostic and monitoring systems for various railway infrastructure facilities.

However, scientists engaged in the development of continuous monitoring systems for railway infrastructure facilities have not yet been able to solve the problem associated with the use of diagnostic data not only for maintenance tasks, but also to transfer information about deviations from established standards onboard devices for ERS, which would allow in conditions of critical violations of train safety to make different decisions to counteract dangerous situations: from lowering the pantograph in dangerous areas to a complete train stop.

The development of the continuous monitoring and diagnostics system for railway traction network elements allows to judge about the prospects of it's widespread implementation, as well as to conclude that with it's help the transition to Smart grid technology - smart power supply networks - is possible (Madrigal, 2017).

The development of continuous traction network monitoring technology, as well as the creation of low-maintenance technical diagnostic tools, will enable the optimization of all electrified railways in the future.

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