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The analysis of modern diagnostic and monitoring devices for the traction power supply system

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ABSTRACT While developing a new modern device for diagnostics and monitoring of the grounding system in real time, the existing modern devices for diagnostics and monitoring of the railway traction network have been analyzed and specific features of high-speed rail traffic development have been studied. The paper presents the existing devices and methods for diagnostics and monitoring of the power supply elements of railway traction. The basic principles of operation of the devices used are given and their advantages and disadvantages are analyzed. The presented analysis makes it possible to estimate the new tendencies in diagnostics and monitoring system development and to summarize further prospects of their implementation and improvement.

KEYWORDS: monitoring; grounding; diagnostics; grounding system of contact line poles; traction power supply; high-speed transport; low-maintenance system.

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Научная статья

Анализ современных устройств диагностики тяговой сети высокоскоростного железнодорожного транспорта

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АННОТАЦИЯ В процессе разработки нового современного прибора диагностики и мониторинга в режиме реального времени системы заземления для учета существующих особенностей развития высокоскоростного движения проведен анализ современных устройств диагностики тяговой сети железнодорожного транспорта. Представлены имеющиеся устройства, методы диагностики и мониторинга элементов тягового электроснабжения железных дорог. Отражены основные принципы работы применяемых устройств, а также проанализированы их преимущества и недостатки. Выполненный анализ позволяет судить не только о тенденциях развития систем диагностики и мониторинга, но и сделать выводы о дальнейших перспективах их внедрения и доработки.

КЛЮЧЕВЫЕ СЛОВА: мониторинг; заземление; диагностика; система заземления опор контактной сети; тяговое электроснабжение; высокоскоростной транспорт; малообслуживаемая система

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INTRODUCTION

Based on the “Strategy for the Development of Rail Transport in the Russian Federation up to 2030”, Russian railways have been concentrating their efforts on the extension of high-speed traffic, increase of train weights and improvement of reliability of the current collection system. The risks of traction network failures increase with the increase in speeds; train traffic disruptions lead to significant economic losses. Repair works take a considerable amount of time, as the damaged sections become more extensive. The standard way of ensuring high reliability factors is providing redundancy and increasing 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 speeds, the 30 % wear is allowed. A similar situation is with the tension of contact wires and cables in the catenary suspension system. Despite the positive effect of increased wire tension on the quality of current collection, it is limited to about 50 % of the yield strength of the material.

The factors described above have led to the situations when the contact wires have to be replaced long before reaching their critical wear and tear nowadays, thus, leading to a decrease in the dynamic performance of the current collection system. The problems related to the increase of permissible speeds and service life of contact wires in conditions of high-speed traffic are acute and should be taken into consideration when designing high-speed lines.

In operation, the contact line adjustment characteristics specified by the project are capable of exceeding the permissible values due to the electric rolling stock impact (ERS), climatic conditions and current loads and all this can lead 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 systems helps to reduce the need for JSCo “Russian Railways” in traction network elements with increased strength characteristics as well as to increase their life service and allow high-speed train movement on conventional rail sections.

Under the “Strategy for Scientific and Technological Development of the Russian Railways Holding Company for the period up to 2025 and for the perspective until 2030”, one of the most important tasks in rail transport is to improve the quality of the traction network maintenance through the use of software and hardware complexes. They will enable the monitoring and diagnostics of traction network elements in an autonomous mode.

Autonomous diagnostic and monitoring devices integrated into the whole 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).

MATERIALS AND METHODS

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

Mobile Diagnostic Devices

The problem with using mobile devices is that they have to perform diagnostics on operating lines with electric trains constantly running. In addition, manual measurements aren’t sufficiently effective since they require patrolling of the monitored sections of different lengths and do not give accurate data.

One of the most effective mobile devices is an automated control system of contact line parameters. They are installed in a diagnostic laboratory wagon, on the

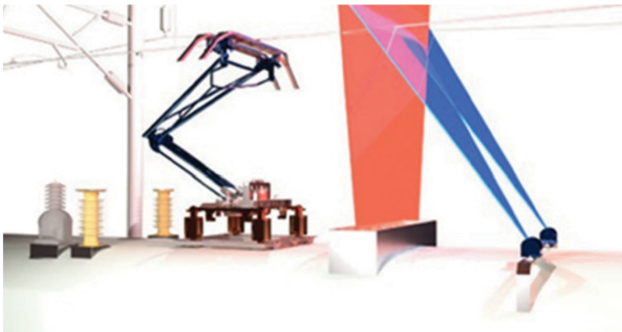

Fig. 1. System for speed control of contact wire

roof of which a measuring current collector and an observation tower with measuring equipment are mounted. Besides determining the type and magnitude of the voltage used in a contact line, the special devices make it possible to measure and register the deviations of the contact line parameters beyond normal for all the contact line facilities. Thus, they automatically generate a report on the assessment of the technical condition of the contact line on the monitored track section. 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 fast control of the contact wire[1] [1] (*Fig. 1*) is one of the modern developments. The sensors take all measurements in a non-contact manner, and the measurements are taken at the level of railhead top in relation to their location in the section. Simultaneously, the computer system devices register the lowered position of the contact wire on aerial frogs and the height of the clips set relative to it. They also measure the force of current collector pressure on the contact wire as well as register shocks to the current collector, contact wire tension and current collector skid breaks off. The diagnostics data with the registered deviations from the required standard parameters of the contact line are displayed in the form of graphs on the monitors of the operator's computer system that are saved on the computer storage devices. The measurements from the thermal imaging and UV camera are recorded separately. All recorded readings are integrated with the recorded parameters of train speeds and the distance travelled in the sensors as well as in the points of contact wire fixation.

Stationary Diagnostic Devices

The JSCo "Russian Railways" testing ground railway has been widely using the stationary diagnostic and remote monitoring system (SDRM) of the contact line. It includes various sensors for recording the parameters of the technical condition of the contact line elements consisting of a carrying cable (CC), contact wires (CW), consoles, strings, and load-compensating devices placed on the anchored poles of the contact line. The stationary data acquisition and transmission devices are installed along the entire length of the contact line section on the CC and CW behind the rollers of the load-compensating units and/or above the load-compensating unit placed on the anchored poles of the contact line (*Fig. 2*). Each device for collecting and transmitting information has a set of sensors for measuring the parameters of the technical condition of the contact line elements, a microprocessor device for analog-digital processing of the sensors' information, an autonomous power supply, a device for wireless communication between the device and an intermediate information storage device SDRM placed at the nearest station. The latter is connected with a single storage device collecting information about the contact line elements of the railway network by wire and/or wirelessly [2].

However, the stationary devices have not been installed yet due to certain difficulties. In order to control the parameters of the contact line for detecting pre-failure conditions, it is planned to use a combined monitoring and diagnostic system consisting of mobile diagnostic devices (laboratory wagons), diagnostic tools on the ERS, and stationary monitoring devices installed along the entire line section as well as a single system for data collection and analysis. The stationary devices provide diagnostics and monitoring of a number of pa-

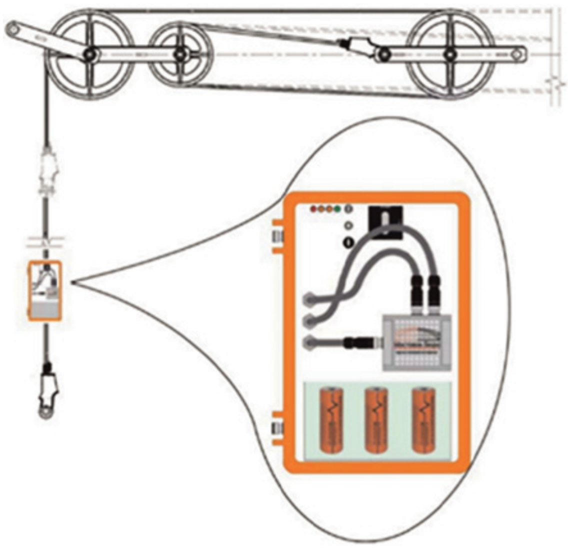

Fig. 2. Information collection and transfer device SDRM

[1] Contact Network Control Systems. URL: https://tvema.ru/625 (In Russ.).

rameters, for example, the displacement of compensating weights, tension of contact suspension wires, temperature of contact wires, ice formation, vibration, and inclination of contact line poles, etc.[2].

Results and discussion

The main disadvantage of the existing systems for monitoring the contact line condition with the help of mobile diagnostic devices is that these measurements are carried out periodically, and the monitoring time is short enough, which does not provide a constant control of the stress-strain behaviour of the contact line elements. In addition, the optical devices do not provide very reliable data.

The continuous monitoring systems that are used do not allow assessing the tension of wires and cables of the traction network in online mode; otherwise, they require corrections in the construction of the monitored facilities.

Both versions of diagnostic and monitoring systems can control only one parameter — the strain in wires and cables. In addition, the described systems do not provide continuous diagnostics and monitoring of the behaviour of traction network elements. Most importantly, they do not provide real-time prediction of pre-failure and failure situations. Currently, many of these disadvantages have been solved in the recent developments [3, 4]. However, further improvements are required before the new system can be installed. 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*), it can be concluded that the frequency of checking the grounding system devices is not as required and consists mainly of visual inspections. That combined with the human factor creates a high probability of not detecting the faults in the grounding system beforehand.

This maintenance procedure inevitably involves high labor costs of its implementation, and often does not detect the real pre-failure states of the grounding system elements. This leads to failures and, consequently, to disruptions in train traffic, and in the worst cases, can lead to disasters.

One of the important and problematic issues 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-failure conditions in time.

Currently, only the railway automation and telemechanic facilities are equipped with the devices of continuous diagnostics and monitoring as less than 3 % of failures leading to disruption of train traffic and risking safety of people registered are caused by them [5, 6]. However, the traction network and railway track facilities are to be equipped by continuous diagnostics and monitoring devices as they are not redundant.

It has been a long-time necessity to introduce continuous monitoring and diagnostic systems of the traction network on railways as failures of traction network elements lead to disruption of train traffic, threaten the safety of passengers and maintenance personnel, and have a negative effect on adjacent facilities.

It should be noted that the cost of implementing the monitoring and diagnostics system is supposed to be less than 10–15 % of the cost of capital construction of the traction network according to a preliminary estimate. The cost of the diagnostics and continuous monitoring system can be divided into two components: the cost of technological equipment such as sensors, accumulators, autonomous power supplies, etc. and the computer centre of the complex including data transmission channels, automated workplaces, servers, etc. Application of the continuous monitoring and diagnostics system will contribute to almost complete elimination of critical damage of 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, the system of continuous monitoring and diagnostics of railway infrastructure facilities including grounding systems is an effective means of ensuring high reliability as well as forecasting pre-failure conditions.

The specialists of the "Electric Power Supply of Railways" Department at the Emperor Alexander I St. Petersburg State Transport University are working on the development of a new diagnostic and monitoring device for the grounding system in real time. In combination with the traction power supply system without grounding the contact line poles on the traction rail, this device will create a low-maintenance grounding system and allow for control within the digital substation.

[2] Innovative Contact Network Solutions for High-Speed Lines. URL: http://eav.ru/publ1.php?publid=2017-11a04 (In Russ.).

Table

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 grounding system elements, checking tightness of contacts, the integrity of the installation, absence of mechanical damage; tightening of loose bolted contacts, elimination of detected faults	Twice a year (spring and autumn)
2. Selective opening of the ground to inspect grounding elements in the ground	once every 5 years
3. Measuring the resistance of the grounding device (if it's value is rated)	After installation, not 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 monitor their values with regard to their influence on the operation of signalling circuits and protection against electrical corrosion)	During commissioning and thereafter at least once every 5 years (for direct current) and at least once every 10 years (for 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

CONCLUSION

Development of the real-time diagnostics and monitoring system for the railway traction network goes hand in hand with the improvement of monitoring technologies, reduction in the computer system cost and an increased level of the system operation quality. Additionally, the equipment of railways with continuous monitoring systems creates favorable conditions for the development of digital railway space or digital railway [7].

The development of data transmission networks with signal-transmitting elements included in the diagnostic devices of the permanent traction network monitoring system on long railway sections boosts the development of diagnostic information wireless transmission system 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. This would not require the provision of counterpart services in terms of communication [8]. At the same time, a real-time digital diagnostic data transmission system will allow the use of cloud-based storage and transmission technologies on the railway transport. For example, the nearest service personnel can transmit the diagnostic and monitoring data by means of portable devices to the diagnostic and monitoring facility. Stationary workplaces with a large number of hardware and computers will not be required, and the monitoring data can be integrated into a separate module of the automatic train control system. The reduced equipment will cut the cost of diagnostics 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 for transferring information about deviations from the standard indicators on the on-board units of the EPS. This would allow taking the right decisions in conditions of critical violations of train safety to counteract dangerous situations, from a lowered pantograph in dangerous areas to a complete train stop.

The development of the continuous monitoring and diagnostics system for controlling railway traction network elements have shown the prospects of its widespread implementation as well as the possibility of using Smart grid technology, that is smart power supply networks [9].

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

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