SOFTWARE TOOLS FOR MONITORING CONTACT SUSPENSION

Sedykh, Dmitry V., *St. Petersburg State Transport University (PSTU), St. Petersburg, Russia.*
Efanov, Dmitry V., *St. Petersburg State Transport University (PSTU), St. Petersburg, Russia.*
Osadchy, German V., *STC Bridge monitoring, St. Petersburg, Russia.*

ABSTRACT

Methods for constructing software for the system of continuous monitoring of railway contact suspension, implemented on the St. Petersburg–Moscow high-speed line are shown. The technical features of the software of the lower and upper levels of the system are highlighted. The technological process of output of monitoring results to automated workplaces of dispatchers of electrification and power supply distances, service of power supply and technologists of situational centers is shown.

Keywords: railway, contact suspension, continuous monitoring, automation, software tools, AWP monitoring.

Background. *An important step towards improving the technology of servicing rail infrastructure devices is the organization of continuous monitoring systems and functional diagnostics of their constituent elements. Due to the use of such systems, it becomes possible to predict the technical state, as well as to fix the non-destructive states of diagnostic objects in the process of directly performing their functions.*

Among the first systems of continuous monitoring and functional diagnostics on the country's railways, the hardware and software of the dispatch control of railway automation and telemechanics devices became known [1–3]. Such systems arose in the late 90-ies of the last century. The level of automation of data analysis and technical condition forecasting proved to be quite high [4, 5].

The case with systems for the continuous monitoring of other railway infrastructure facilities–track economy and power supply, is much worse. Unlike the monitoring systems for railway automation facilities, where electrical parameters of devices are mainly controlled, less uniform parameters are used for the objects of track, electrification and power supply as diagnostic parameters: temperature, pressure, mechanical force, acceleration, etc. In addition, it should be noted that the diagnosed automatic devices are usually either centralized (located in the same post), or they are located «point-by-point», at a certain distance from each other (for example, railway crossing automatics or through-pass traffic lights of automatic blocking). This simplifies the procedure of their monitoring. And the objects of track superstructure and contact suspension belong to the geographically distributed objects, reaching large lengths. And from here there are objective difficulties.

Let's pay attention to the railway contact suspension [6]. This facility operates in difficult climatic conditions, is subject to wind loads, snowfalls, temperature changes, and also directly perceives the pressure of the pantograph during the movement of an electric locomotive. The share of the contact suspension accounts for more than 75 % of the failures of the objects of the contact network [7]. The first real operating systems for continuous monitoring of the contact suspension appeared in Russia only towards the end of the first decade of the 21st century. In particular, several anchor sections in the alignment on St. Petersburg–Moscow high-speed line were equipped with this system [14]. By the beginning of 2016, extensive statistics were collected, containing the results of vibration diagnostics, tensometric measurements and temperatures, which allows to rank events, including to highlight some failures and pre-stresses of elements of the contact suspension [15–17].

Objective. *The objective of the authors is to consider different software tools for contact suspension monitoring.*

Methods. *The authors use general scientific and engineering methods, graph construction, comparative analysis.*

Results.

1. Block diagram of the system

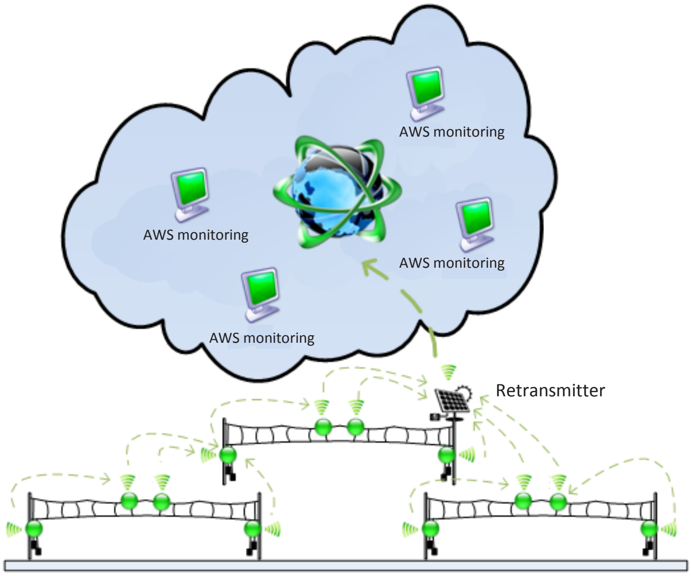
The system of continuous monitoring of railway contact suspension has a hierarchical structure, formed by several functional levels (Pic. 1) [19].

The lower level is formed by diagnostic devices placed in the area of compensator cables on insulating inserts, as well as in the middle anchorage area. Since diagnostic devices are located in the open air, they are subjected to stringent operational requirements, including a subsystem of autonomous power supply based on solar batteries and lithium batteries. The subsystem is unique and allows the device to be supplied with energy for up to 10 years without changing the batteries, while, unlike continuous monitoring systems, the automation does not require power wires.

In the diagnostic tool, made in a rigid hull, the microcontroller is located on the printed circuit board; here a number of sensors (vibration diagnostics and temperatures) are mounted; external boards (for example, a mechanical force sensor) are connected to the card via dedicated connectors. The microcontroller performs the primary processing of diagnostic information and transmits it over the radio channel with a dedicated frequency of 868,7 MHz to the line-hub concentrator located at a nearby station. The communication layer is the second in the hierarchy, and its own data transfer protocol is used. A similar channel for continuous monitoring facilities is used for the first time by JSC Russian Railways. Features of the data transmission network are described in [20].

The upper level of the hierarchy is the line-hub concentrator, as well as the concentrators of the central posts and situational monitoring centers. At this level there are automated work places (AWP) for dispatchers of electrification and power supply distances, as well as technologists of monitoring centers and management personnel. Here, the diagnostic information in a processed and user-friendly form is transmitted to the end user.

An important component of the system of continuous monitoring of the contact suspension is unique software, which is its intellectual basis and performs the functions of processing diagnostic information, its transmission and output to the end user. Without software, the system would be a set of diagnostic devices, channel-forming equipment and computer equipment.



Pic. 1. Structural diagram of the system of continuous monitoring of the contact suspension.

2. Software tools

2.1. Modular levels

The software of the subsystem for transmitting messages and the upper level of processing and displaying the results of monitoring are the core of the system of continuous monitoring and functional diagnostics.

All developed software does not use special commercial platforms and modules that require separate licensing. Server software can be deployed on most distributions of the free operating system Linux, including those collected and certified in Russia. As a database, both commercial software products and freely distributed MySQL or PostgreSQL of the Russian assembly are possible.

The software part of the monitoring system is built on client-server technology and consists of a set of software modules that are conditionally divided into two categories:

1. Lower-level software for collecting and transmitting diagnostic information and controlling system devices.

2. Upper-level software for secure storage of information and data access for external users.

The lower level software includes information concentrator software for collecting messages from sensors via radio or wired channels and a server for receiving and processing messages from information concentrators.

The lower-level server system provides transmission of industry data to JSC Russian Railways, as well as storage of the information received on dedicated servers. The data transfer protocol itself was specially designed for monitoring system tasks, allows organizing a transmission network with an automatically reconfigurable topology, solves the problem of optimizing the monitoring system, including minimizing the energy consumption of sensors and maximizing the speed of message transmission without disconnecting subscribers [20]. This is its key difference from the well-known industrial networks «LoRaWAN» and «Strizh» [21, 22].

The server directly supports interaction with all devices in the monitoring system, and also performs a self-diagnostic procedure (monitors all connected devices), remote configuration and control of devices.

Let's highlight the features of the developed software of the lower level:

– a specialized protocol for interaction with all components of the system, including devices using the radio channel;

– subsystem for logging all data;

– subsystem of data export to external databases;

– an integrated software update system for connected devices.

The upper-level software includes an SQL database and automated work places for dispatchers of the electrification and power supply service (AWS monitoring system). The SQL database, which is a secure repository of all information about the system itself, as well as the status of monitored devices at any one time. The server with the database provides storage and access to information for users of the system: dispatchers, mechanics, managers of various levels. Currently, interaction with two widely used databases is implemented: MS SQL Server and MySQL, the system also adapts to the PostgreSQL database if necessary. AWS exist locally or are accessible through the cloud. AWS monitoring provides access to data for the standby distance of electrification and power supply, as well as the dispatcher of the monitoring and diagnostic center. Automated workstations provide a full set of functions that facilitate the work not only for energy workers, but also for computer administrators. The functions of AWS for a particular user may differ depending on his rights and tasks. A typical technological window of the user of the program is shown in Pic. 2.

The features of the developed software of the upper level include:

1) For administrators:

– automatic system for software deployment;

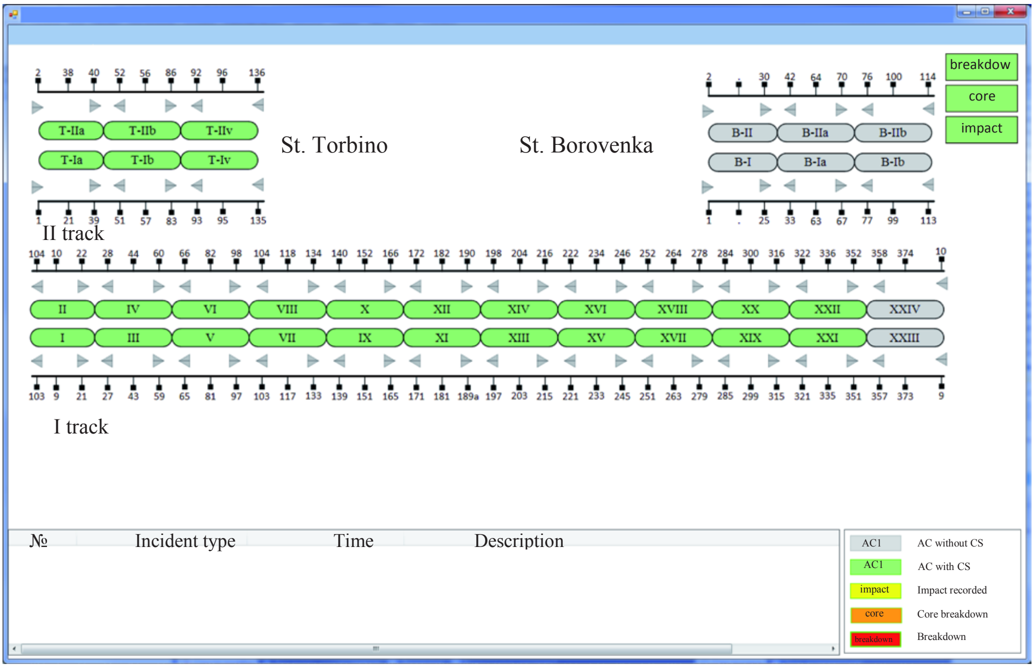
– automated software update system;

– administration of system users;

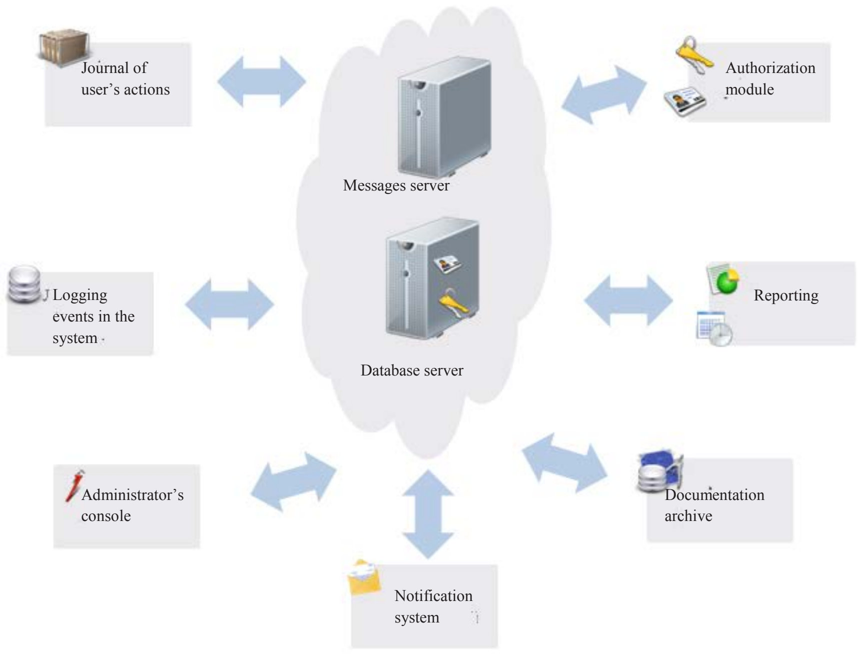
– administration of thresholds for system operation for various classes of events (access only to special persons, changes only in coordination with the railway authorities);

– monitoring of user actions in the system.

2) For users:



Pic. 2. The main technological window of AWS monitoring.



Pic. 3. Structure of software modules of the upper level.

– authorization;

– display of events in real time mode;

– displaying data in tabular or graphical form;

– reporting on the order of the user;

– viewing the contents of the event archive in any time interval;

– diagnosis of the components of the system itself;

– sound and graphic notifications;

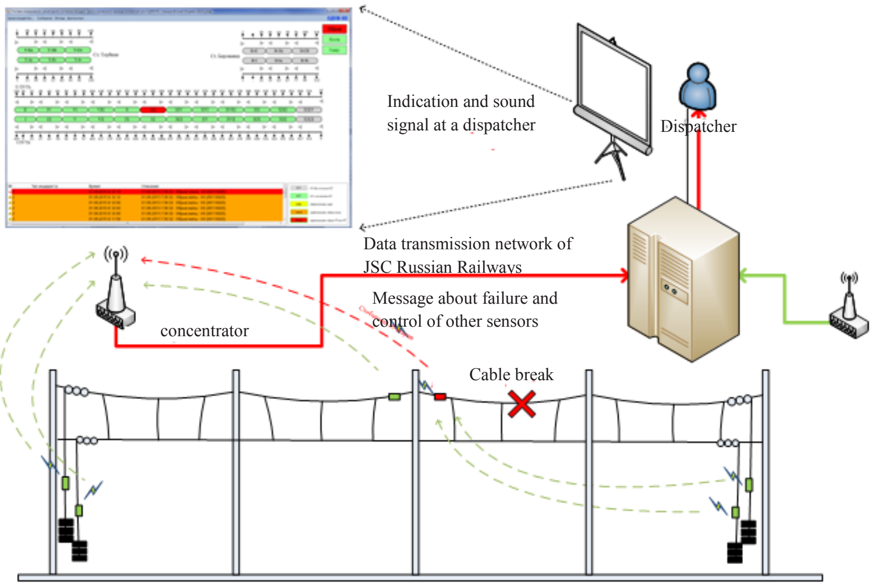
– logging of user actions;

– access to technical documentation of control areas with built-in software.

The general scheme of upper-level software modules is shown in Pic. 3.

2.2. The main technological window of the software shell

Let's consider the typical mode of operation of the program shell of the AWS monitoring system. All devices operate in normal mode, no critical events. The monitoring objects in the order of consolidation



Pic. 4. The main technological window of AWS monitoring system when a wire strand break is detected.

are: a support, an anchor section, a service area (ECHK), a distance of electrification and power supply (ECH), a road (Pic. 2).

To enable the output of diagnostic information, we have developed our own notation system. The lines show the entire section of the contact suspension equipped with a continuous monitoring system. In the form of black squares connected by lines to the main site of the diagnostic object, the contact network supports and their numbers are shown along each of the paths in close proximity to which diagnostic devices are installed. Each anchorage is depicted in the form of an oval with the corresponding Roman numeral. Black squares, referring to the supports, are evenly distributed between all the anchorage areas: in three supports. Two extreme supports of the site and support in the middle anchorage area.

Thus, the system is equipped with a section of the railway line, which includes 36 anchor sections with six diagnostic devices on each. The diagnostic devices themselves are not indicated on the diagram; in case of event occurence, only the objects of the contact network are exposed, which are affected: it can be the anchor section itself and the effects on the compensating devices. In the diagram they are shown by conventionally gray triangles, divided in half (the upper part corresponds to the weights of the compensator on the supporting cable, and the lower one to the contact wire).

All types of messages in the monitoring system are fixed in the zone of their output (the lower part of the screen on the technological window of Pic. 2). New messages are always added to the top of the list, while the list itself is shifted down.

The basic and operational information is output directly to the mnemonic diagram, that is, when an event occurs, the object where it occurred is highlighted with the specified color (default is yellow or red, depending on the level of danger – yellow corresponds to the pre-fault state, and red – to failure). Highlighting occurs at all visible levels of the hierarchy. Also, when an alarm event (failure or pre-failure) occurs, a second beep sounds. Above the flashing block of the event, its time and date are indicated. If there are several events, then the date and time of the last one are indicated. Until the user confirms viewing the event, it will continue to flash the color set for it. The user can make a note about viewing the event, but before acknowledging it, it will continue to be highlighted in the corresponding color. An event is considered fully resolved when the user confirms that it has been viewed and acted on.

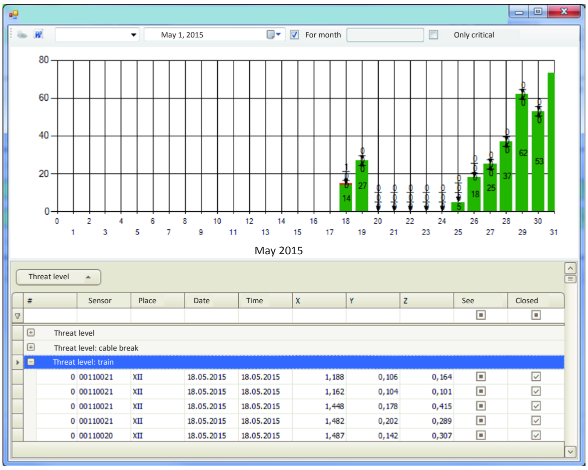
Depending on the system settings, various actions take place according to the parameters of the events output to the user when they occur.

<u>The first event</u> is conditionally called «no events». This is the normal mode of the monitoring system when all the sensors of the diagnostic devices are in good order (Pic. 2). On the mnemonic diagram, green objects denote diagnostic objects that are equipped with a monitoring system. The display circuit itself can contain an arbitrary number of levels and be detailed to each sensor, if necessary.

<u>The second event</u> is «failure detection». It is fixed in the presence of events with a critical load level on the contact suspension (breakage of the carrier or contact cables). The background color of the monitoring object changes to red. In the technological cell, the text «break» appears instead of the object name. Information about the event automatically pops up on the monitor of the workstation: it is added to the top of the list of events, and also displayed on the graphic diagram of the monitored area. Through the speaker, a sound is played to attract the attention of the user (Pic. 4).

<u>The third event</u> of the system is «detection of wire breakage» (in fact this is not a break, but an increase in load, for example, a strong impact of a current collector). The information, as well as the event of the previous view, is added to the top of the list of events, and a sound is played through the speaker to attract the user's attention. The background color of the monitoring object changes to orange. In the cell, instead of the name of the object, the text «vein» will be written.

<u>The fourth event</u> is connected with «detection of a strong impact on the contact suspension» (in fact this is also not a break of the cable or veins, but an increase in load, for example, a strong impact from a current



Pic. 5. Technological window of the archive of events.

collector). Similarly, information of this type is added to the top of the list of events, and an audio signal is sent through the speaker. The background color of the monitoring object changes to yellow. In the cell, instead of the name of the object, an «impact» is recorded.

Any event message contains the following information:

– the identifier of the event in the system (its unique number), enclosed in square brackets;

– time of occurrence of the event;

– type of event (train passage, critical loads, etc.);

– name of the activated sensor;

– location of the sensor (for example, the support number).

After the occurrence of events with levels above the normal (normal mode of operation of the devices), the user needs to work out the event, check the event data, record the actions taken, and then the sound and light indication in this section can be turned off. After acknowledging the event, the color mode will return to the «default» colors until the next critical events occur in the system.

2.3. Working with archive data

The AWP contains built-in functions for generating reports on the events that occurred. For this purpose the section «Events archive» is intended. When it is activated, a special module is launched. The report can be printed and exported to Microsoft Excel by built-in tools. It contains the following fields:

– «#» event level, by default from zero to three (the larger is the number, the greater is the «anxiety» of the event);

– «Alarm level» (text field with description of the type of event);

– «Sensor» (the name from which the signal was received);

– «Place» (where the sensor was installed, as a rule, the place coincides with the number of the support of the contact network);

– «Date» (occurrence of an event according to the clock of the database server);

– «Time» (the occurrence of an event, accurate to thousandths of a second according to the clock of the database server);

– «Duration» (of impact on contact suspension in seconds);

– «X» (the maximum acceleration value of the vibration sensor movement along the X axis);

– «Y» (the maximum acceleration value of the vibration sensor movement along the Y axis);

– «Z» (maximum acceleration value of the vibration sensor movement along the Z axis).

The reporting module includes standard mechanisms for filtering and grouping data, similar to standard spreadsheet tools. For example, all events can be grouped by date and only events from a specific contact network support can be shown. To do this, to drag the header of the column to which you want to group the data into the table header, and when during filtering, to move the mouse cursor over the desired column or activate the filter from the data selection (Pic. 5).

For a more detailed study of the causes of events, a special viewing mode is used for all data, for diagnostic objects and devices. The report itself has built-in print output and export tools to all common data formats.

In connection with the expansion of the system's functionality, the lower and upper level software is being upgraded to support work with new monitoring tasks:

– continuous monitoring of tension force of the cables of contact suspension;

– continuous monitoring of the angle of installation of the contact network supports.

In addition, the diagnostic functions and methods for displaying data for new areas of monitoring are being modernized. A special language and means of describing mnemonic diagrams for displaying data both on the screen of a personal computer and on video walls of monitoring centers have been developed. The storage subsystems, the mnemonic display subsystem, and event displays are constructed in such a way that they allow to give any monitoring information for both power supply tasks and tasks of other economies.

Conclusion. *It is not enough just to get diagnostic information, it is important to perform its initial processing, to transfer data to a central post, and to bring it in a user-friendly and understandable form. It is such important properties that the developed software shell of the lower and upper levels of the system of continuous monitoring of the railway contact suspension possesses.*

The use of the software of the monitoring system allows the technical personnel of electrification and power supply distances to react promptly to the occurrence of malfunctions (the occurrence of pre-failures and failures), and also to make timely recommendations to the performers who service the contact suspension. All this, together with the existing maintenance and repair activities, helps improve the operation of non-reserved contact suspension objects and contribute to improving the reliability and safety of the transportation process.

REFERENCES

1. Efanov, D. V., Plekhanov, P. A. Provision of traffic safety through technical diagnostics and monitoring of railway automation and telemechanics devices [*Obespechenie bezopasnosti dvizhenija za schet tehnicheskogo diagnostirovanija i monitoringa ustrojstv zheleznodorozhnoj avtomatiki i telemehaniki*]. *Transport Urala*, 2011, Iss. 3, pp. 44–48.

2. Efanov, D. V. Formation and prospects of development of systems of functional monitoring and monitoring of devices of railway automation and telemechanics [*Stanovlenie i perspektivy razvitija sistem funkcional'nogo kontrolja i monitoringa ustrojstv zheleznodorozhnoj avtomatiki i telemehaniki*]. *Avtomatika na transporte*, 2016, Iss. 1, pp. 124–148.

3. Efanov, D. V. Functional control and monitoring of devices of railway automation and telemechanics: Monograph [*Funkcional'nyj kontrol' i monitoring ustrojstv zheleznodorozhnoj avtomatiki i telemehaniki: Monografija*]. St.Petersburg, 2016, 171 p.

4. Bochkarev, S. V., Lykov, A. A., Markov, D. S. Improvement of methods for diagnosing the switch device [*Sovershenstvovanie metodov diagnostirovanija strelochnogo perevodnogo ustrojstva*]. *Avtomatika na transporte*, 2015, Iss. 1, pp. 40–50.

5. Efanov, D. V. Some aspects of development of systems of functional control of railway automation and remote control devices [*Nekotorye aspekty razvitija sistem funkcional'nogo kontrolja ustrojstv zheleznodorozhnoj avtomatiki i telemehaniki*].*Transport Urala*, 2015, Iss. 1, pp. 35–40.

6. Marquardt, K. G. Contact network [*Kontaktnaja set'*]. Moscow, Transport publ., 1994, 335 p.

7. Kovalev, A. A., Nesmelov, F. S. The use of modern modeling methods to improve reliability of devices of the contact network of rail transport [*Primenenie sovremennyh metodov modelirovanija dlja povyshenija nadezhnosti ustrojstv kontaktnoj seti zheleznodorozhnogo transporta*]. *Innovacionnyj transport*, 2012, Iss. 1, pp. 49–52.

8. Park, Y., Cho, Y. H., Lee, K., Jung, H., Kim, H., Kwon, S., Park, H. Development of an FPGA-based Online Condition Monitoring System for Railway Catenary Application. *8th World Congress on Railway Research, COEX*, Seoul, Korea, 2008, 18–22 May.

9. Park, Y., Kwon, S.Y., Kim, J. M. Reliability Analysis of Arcing Measurement System Between Pantograph and Contact Wire. *The Transactions of the Korean Institute of Electrical Engineers*, 2012, Vol. 61, No. 8, pp. 1216–1220.

10. Hisa, T., Kanaya, M., Sakai, V., Hamaoka, K. Rail and Contact Line Inspection Technology for Safe and Reliable Railway Traffic. *Hitachi Review*, 2012, Vol. 61, Iss.7, pp. 325–330.

11. Mizan, M., Karwowski, K., Karkosiński, D. Monitoring odbieraków prądu w warunkach eksploatacyjnych na linii kolejowej. *Przegląd Elektrotechniczny*, 2013, R89, nr. 12, pp. 154–160.

12. Park, Y., Lee, K., Park, C., Kim, J.-K., Jeon, A., Kwon, S., Cho, Y. H. Video Image Analysis in Accordance with Power Density of Arcing for Current Collection System in Electric Railway Journal title: *The Transactions of The Korean Institute of Electrical Engineers*, 2013, Vol. 62, Iss. 9, pp.1343–1347.

13. Innovative contact network SNCF V350, tested speed above 500 km/h [*Innovacionnaja kontaktnaja set' SNCF V350, ispytannaja skorost'ju svyshe 500 km/ch*]. *Vesti Evrazii*, 2014, Iss. 6, p. 22.

14. Osadchy, G. V., Efanov, D. V., Sedykh, D. V. Continuous monitoring of contact suspension – a step into the future of railways without traffic accidents [*Nepreryvnyj monitoring kontaktnoj podveski – shag v budushhee zheleznyh dorog bez transportnyh proisshestvij*]. *RZhD-Partner*, 2016, Iss. 13–14 (July), p. 34.

15. Efanov, D. V., Osadchy, G. V., Sedykh, D. V. *et al.* Method of continuous monitoring of mechanical force in wires and cables of the contact suspension [*Sposob nepreryvnogo monitoringa mehanicheskogo usilija v provodah i trosah kontaktnoj podveski*]. *Transport Urala*, 2016, Iss. 1, pp. 9–15

16. Nasonov, G. F., Osadchy, G. V., Efanov, D. V., Sedykh, D. V., Pristensky, D. N. Vibration diagnostics of contact suspension on the line St. Petersburg–Moscow [*Vibrodiagnostika kontaktnoj podveski na linii Sankt-Peterburg–Moskva*]. *Transport Rossijskoj Federacii*, 2016, Iss. 2–3, pp. 49–53.

17. Efanov, D. V., Osadchy, G. V., Sedykh, D. V., Pristensky, D. N., Barch, D. V. Monitoring subsystem for vibration effects on wires and cables of contact suspension [*Podsistema monitoringa vibracionnyh vozdejstvij na provoda i trosy kontaktnoj podveski*]. *Transport Urala*, 2016, Iss. 3, pp. 36–42.

18. Special technical conditions: Railway power supply of Moscow–Kazan section of the high-speed Moscow–Kazan–Yekaterinburg railway line. Technical standards and requirements for design and construction [*Special'nye tehnicheskie uslovija: Zheleznodorozhnoe elektrosnabzhenie uchastka Moskva–Kazan' vysokoskorostnoj zheleznodorozhnoj magistrali Moskva–Kazan'–Ekaterinburg. Tehnicheskie normy i trebovanija k proektirovaniju i stroitel'stvu*]. St. Petersburg, 2014, 46 p.

19. Nasonov, G. F., Chernogorov, Yu. A., Medvedev, M. E. *et al.* Continuous monitoring of tension of contact suspension [*Nepreryvnyj monitoring natjazhenija kontaktnoj podveski*]. *Avtomatika na transporte*, 2016, Iss. 2, pp. 228–258.

20. Efanov, D. V., Osadchy, G. V., Sedykh, D. V., Pristensky, D. N. Features of organization of data transmission by radio channel in the systems of continuous monitoring of railway transport infrastructure objects [*Osobennosti organizacii peredachi dannyh po radiokanalu v sistemah nepreryvnogo monitoringa ob'ektov infrastruktury zheleznodorozhnogo transporta*]. *Avtomatizacija v promyshlennosti*, 2016, Iss. 6, pp. 29–33.

21. Verhulevsky, K. LoRa technology: a new impulse for development of the «Internet of things» [*Tehnologija LoRa kompanii Semtech: novyj impul's razvitija «Interneta veshhej»*]. *Besprovodnye tehnologii*, 2015, Iss. 3, pp. 8–14.

22. LPWAN-technology «Strizh» [*LPWAN-tehnologija «Strizh»*]. [Electronic resource]: http://strij.net/tehnologiya-strizh. Last accessed 01.08.2016. ●

Information about the authors:
Sedykh, Dmitry V. – engineer of St. Petersburg State Transport University (PSTU), St. Petersburg, Russia, sedyhdmitriy@gmail.com.
Efanov, Dmitry V. – Ph.D. (Eng.), associate professor of St. Petersburg State Transport University (PSTU), St. Petersburg, Russia, TrES-4b@yandex.ru.
Osadchy, German V. – technical director of STC Bridge monitoring, St. Petersburg, Russia, osgerman@mail.ru.

Article received 01.08.2016, accepted 23.09.2016.