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Monitoring System for Railway Automation Devices Based on the Industrial Internet of Things

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ABSTRACT

The features of monitoring systems for railway infrastructure and rolling stock are considered. The main approaches to organisation of monitoring of railway infrastructure and rolling stock objects are described, their advantages and disadvantages are noted. The main objective of this work is to present to the reader a conceptual vision of a system for monitoring devices and systems for ensuring train traffic safety, using technologies for transmitting diagnostic information over a radio channel. The methods of the theory of technical diagnostics and monitoring were used. Attention is focused on the use of wireless data transmission technologies and the use of autonomous industrial automation sensors for monitoring systems for railway automation devices.

The architecture of the monitoring system is presented. The description of the system itself and the monitoring technology is given, the main advantages of the presented approach are noted, which, first, are linked to reduction of the volume of design work and of energy consumption of the system as a whole. The disadvantages are associated with the need to replace autonomous power supply sources, ensure security of the data transmission network, to proceed with periodic verification and calibration of measuring instruments. The basic diagrams of connecting sensors for measuring physical quantities to the circuit units of railway automation are presented. A list of parameters necessary for high-quality and effective monitoring of railway automation devices is given. The need is noted for both the control of mechanical and geometric parameters of devices and the accounting of data from interconnected objects of railway infrastructure and rolling stock. The proposed approach can find its application in the field of railway automation and, first of all, at those facilities that are located in premises with limited area (e.g. at subway facilities).

Keywords: railway, system of monitoring of railway automation devices, industrial automation sensors, wireless data transmission, diagnostic parameter of the railway automation device, effectiveness of the monitoring technology.

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Background.

Monitoring technologies are widely used in all areas of industry and transport. Monitoring sensors are used to equip unique engineering structures and buildings, technical automation equipment, machines, and mechanisms. At the same time, the spectrum of measured parameters and their values are remarkably diverse, and devices and sensors themselves are capable of both measuring analogue values and converting them into digital form, and only giving out signals about reaching a pre-set threshold value. The objectives of monitoring are also different: in some applications, accounting for the work performed, the energy spent on it (for example, fuel metering or accounting of the operator's work) is required, in some applications, an indication of achievement of a dangerous (subcritical) value of the measured parameter (monitoring in the construction industry) is needed, in some cases there is the need for automation of measurement (to automate maintenance work and determine pre-failure conditions), and some cases require the use of this information in feedback circuits to adjust the control mode (for example, in operation of an aircraft control system).

Monitoring technologies are also used in the field of railway traffic control systems. The main technical means of train traffic control (objects of railway automation), as well as on-board automation equipment are equipped with tools of automated technical diagnostics and monitoring [1; 2]. Data from on-board monitoring devices are transmitted directly to on-board automation devices as well as to locomotive maintenance personnel. Data from systems monitoring railway automation objects via a cable network (less often – via wireless channels [3]) are transmitted to station data concentration points and then to the upper levels of the control hierarchy – to the equipment of signalling, centralization and blocking (SCB) sections and monitoring centres [4].

It should be added that, besides the indicated technical means for measuring the parameters of automation devices, measures are taken to periodically monitor the state of the upper structure of the track using flaw detectors and specialized rolling stock, to measure the parameters of the railway overhead catenary using laboratory cars, and also to measure the parameters of rolling stock units «on the move» by stationary complexes for monitoring the technical condition of cars and locomotives. The data received from the means of measuring the state of the track and the contact network are accumulated and transmitted to specialists for their decoding. Data from systems for monitoring train parameters «on the move» are analysed in real time and used to prevent emergencies in operation of rolling stock.

Let us dwell on the problem of monitoring the state of objects of railway automation [5]. In the sectors of automation and telemechanics, monitoring systems have long formed a separate class of signalling devices [6; 7]. There are standards that govern the use of these automation tools, standard materials for the design of individual systems, and so on. The approaches to obtaining, processing and analysing diagnostic data are constantly being developed and improved [8–13].

One of the difficulties arising in the process of introducing monitoring systems for railway automation devices is the need to develop a complex project, taking into account laying of cables for connecting diagnostic devices. In addition, for the tools of technical diagnostics and monitoring, metering of consumed electricity is required. The *objective* of this article is to describe an approach to development of a monitoring system for railway automation checkpoints based on industrial automation sensors with autonomous power supply and data transmission using its own Internet of Things, while applying the methods of the theory of technical diagnostics and monitoring. Such sensors and information transmission technologies have long proven themselves in many applications [14], and their implementation in the field of railway automation is constrained, perhaps, by the industry's conservatism, but not by the technical features of modern automation systems. The use of the proposed approach to organisation of the monitoring system allows to reduce the cost of its design, as well as to simplify the procedure for its subsequent operation.

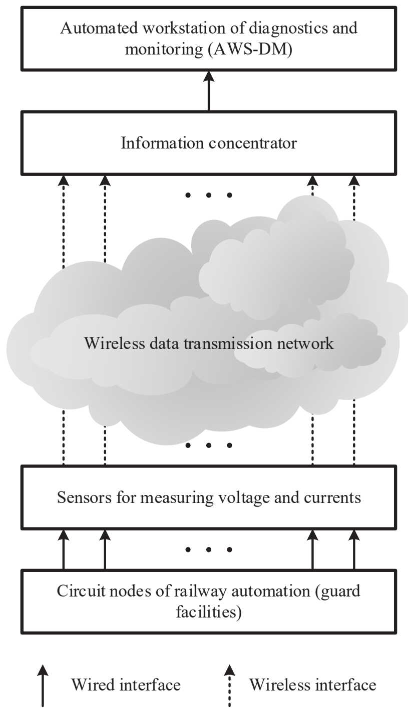
Monitoring system architecture, composition of sensors and their connection diagrams

Modern monitoring systems for railway automation devices use both widely used sensors and industrial automation devices and unified measuring controllers of manufacturing companies, examples of which are also in [6; 7], and on the developers' websites. Such devices are included in the register of measuring instruments. And also, their periodic verification is required. Data from diagnostic devices entering storage, processing and analysis software are considered reliable.

The disadvantage of measuring instruments of own design is their high price and the absence of recommended analogues: model design materials exclude the use of other means than those indicated in the project.

As an alternative to widely used diagnostic devices of own manufacturers' design, devices for measuring voltages and currents of industrial manufacturers with wireless data transmission and autonomous power supply can be considered [15]. An example of such a device is shown in Pic. 1. Such devices are designed to convert physical values of voltage and current into a digital signal. When measuring with a sensor polling rate of 10 seconds (which is quite enough for solving problems of monitoring slow-flowing processes in railway automation devices), the batteries serve for more than a year and a half. An alternative of the use of battery power either of constant power supply for such sensors can be noted. The technical descriptions of the devices themselves with their features can be found on the manufacturers' websites.

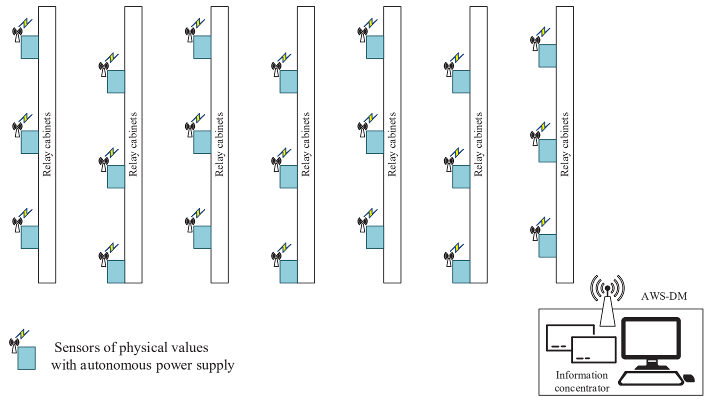
Pic. 1. Voltage and current measuring device with wireless data transmission.



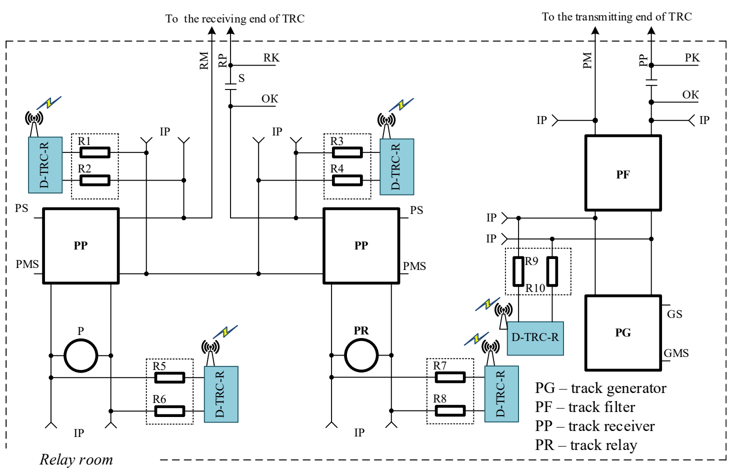
Pic. 2. Organizational structure of the system.

The advantage of using devices with wireless data transmission and autonomous power supply is the ability to install them at almost any point for data collection, no need for cables and complex design work. The disadvantages are associated with the need to periodically replace power sources (replacement, by the way, is not done so often, and the work itself is not so time-consuming).

The use of wireless sensors for obtaining physical values allows organising a monitoring system according to the architecture shown in Pic. 2. With it, sensors of physical quantities are located directly in the premises, where the relay cabinets of the system of electrical interlocking of switches and signals are installed, and also, depending on the size of the premises, additional communication means are selected (components for amplifying and relaying signals to the concentrator). Data from sensors through a wireless network enter the information concentrator, where they are stored, processed and analysed. Unlike traditional monitoring systems used in the field of railway automation, the proposed system does not have cable data transmission paths. This is an undoubted advantage of the system and it might be in great demand for facilities where premises with automation devices have limited area (e.g., at subway). It should be noted that the use of wireless data transmission is not new in the field of signalling, centralization, and blocking. In [16], a monitoring system for the gear mechanism of a switch electric drive is presented, in which sensors are mounted directly in the housing of the switch electric drive, and the data transmission is also wireless between the devices and the monitoring server. In [17], methods of monitoring the geometric parameters of the turnout switch (the location



Pic. 3. Principles of equipment placement in relay rooms.



Pic. 4. Connecting voltage sensors to the tone frequency rail circuit.

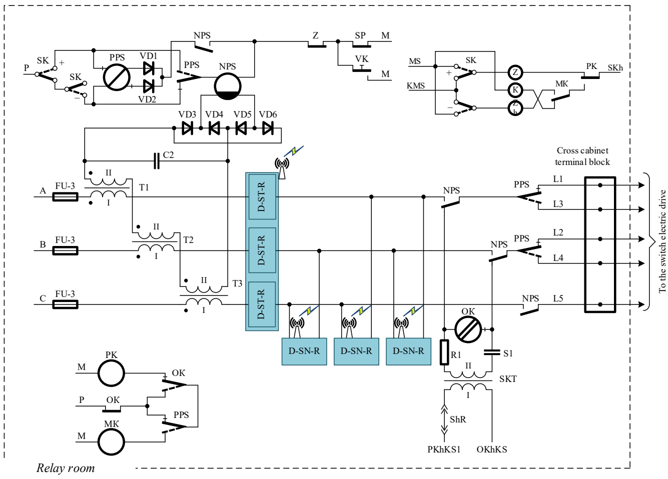
and state of the points relative to frame rails) with a wireless interface are proposed. In [3], the authors propose the use of a radio channel and GSM-modules for transmitting information from objects of level crossing automation in the zones of railway lines equipped with semi-automatic blocking. The given examples point to international experience in the field of application of wireless data transmission technologies and their features regarding proposed solutions.

A schematic diagram of location of sensors of physical values in the relay room is shown in Pic. 3. Data from the sensors enter the information concentrator located in the same room, are synchronised, and recorded into the database. Further, as the measured values accumulate, the diagnostic information is analysed, trends in the measured parameters are determined, and procedures for diagnosing and forecasting are performed, considering the characteristics of the measured values and a set of parameters affecting each other. The data are supplemented by information on the climatic conditions in the room and on the conditions directly in the area of location of the analysed object («in the field»).

Pics. 4–6 show the typical schemes for connecting measuring sensors to the circuit units of railway automation. Wireless sensors are designated as D-TRC-R (sensor for receiving data from track circuits of speech frequency with transmission over a radio channel), D-ST-R (sensor for receiving data from a switch with transmission over a radio channel), D-SN-R (sensor for receiving data from a traffic light with radio transmission).

When connecting sensors, safety conditions must be ensured and it should be provided that there is no influence of devices on critical control circuits [18].

Of particular interest is the issue of choosing the period for polling sensors. For some objects,



Pic. 5. Connecting current and voltage sensors to railway switch control circuit.

measurements with a short sampling period (fractions of a second) are required, and for some less frequent measurements are sufficient. In this regard, measurements in the working circuits of controlled objects under load are recommended to be performed at least as often as it is implemented with existing measuring controllers. In this case, there are several ways of operating the sensors themselves: with a switching threshold adjustable for triggering circuits and continuous measurement, with measurement and accumulation of data with transmission in the next set period, with non-autonomous power supply, etc. The issue of technical implementation and adjustment of operating modes is decided considering the features of a particular monitored object. For example, the features of operation of wireless diagnostic devices in the field of railway transport with high energy efficiency are considered in [19].

Completeness and depth of technical diagnostics

A separate issue is to ensure completeness and depth of technical diagnostics. When using modern existing monitoring systems, the indicated diagnostic parameters are obviously unsatisfactory. The reason for this is often impossibility of technical implementation of the measurement itself or an economically ineffective option [18]. The analysis showed that to improve quality of the monitoring technology, it is necessary to expand the diagnostic parameters for devices and systems of railway automation.

Here is a list of the main diagnostic parameters of the main railway automation devices (both already measured and intended for measurement):

1. Discrete data about the objects of diagnostics:

• state of the sensors for monitoring if the track is clear (track circuits, axle counting systems, etc.);

• state of traffic light lamps;

• extreme positions of railway switches;

• state of objects of level crossing automation;

• state of power supply facilities, etc.

2. Analog data about the monitored objects:

2.1. Data about rail circuits of 25, 50 and 75 Hz:

• voltage at the supply end;

• voltage at the relay ends of rail circuits;

• insulation resistance of cable conductors;

• time parameters of codes of automatic locomotive signalling;

• currents of automatic locomotive signalling when the train enters the track section at the beginning of transmission of codes;

• state of the environment (humidity, temperature etc.);

• measurement of ballast resistance.

2.2. Speech frequency rail circuit data:

• currents and voltages at the inputs of track receivers;

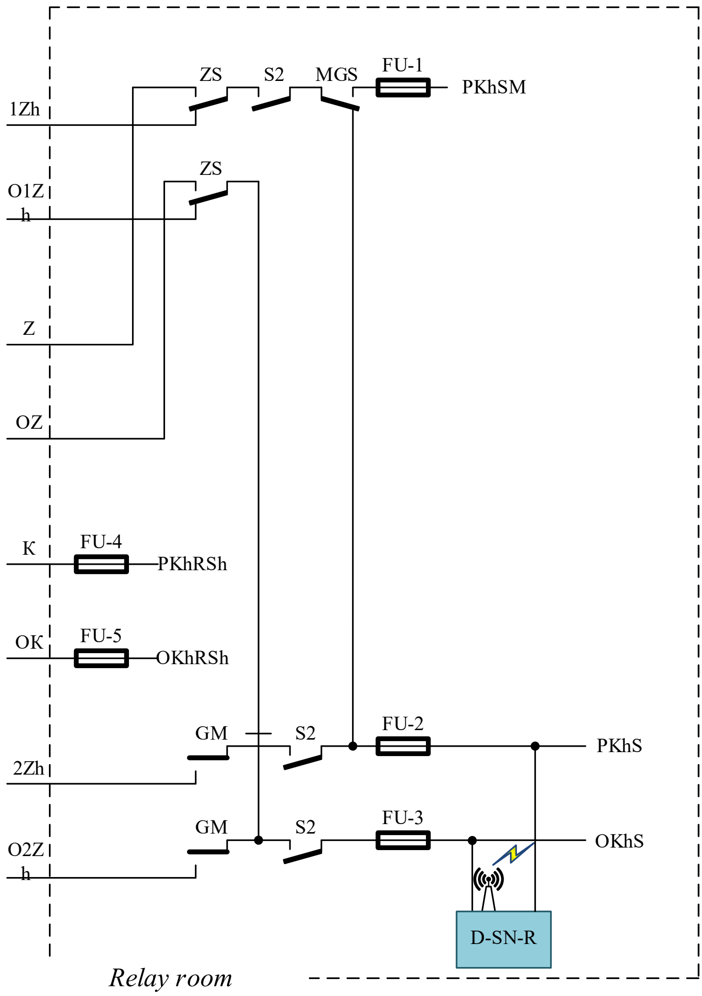
• voltage at the outputs of the track receiver;

• current and voltage at the output of the track generator;

• voltage at the output of the track filter;

• insulation resistance of cable conductors;

• signal frequency (carrier and manipulating one);



Pic. 6. Connection of voltage sensors to the traffic light control circuit.

• state of the environment (humidity, temperature, etc.).

2.3. Data about switch electric drives:

• current of operation of a switch with a DC motor;

• phase currents of operation of a switch with an AC motor;

• voltage between phases;

• control of serviceability of the working circuit of the switch electric drive with the drive off;

• resistance of cable conductor insulation;

• time of operation;

• mechanical parameters of the automatic switch (point blade movement);

• vibration effects on the switch drive;

• the state of the environment (humidity, temperature, etc.).

2.4. Data on optical signalling means:

• supply voltage of traffic lights lamps;

• currents in power supply circuits of traffic lights lamps;

• state of lamps in the off state;

• burning times of filament of traffic lights lamps;

• times of deceleration of switching off of signal indications;

• resistance of cable conductor insulation;

• monitoring of mast corrosion (vibration diagnostics and tilt sensors);

• control of mast dimensions (vibration diagnostics and tilt sensors);

• burning times of main filaments of LED lamps;

• burning times of backup filaments of LED lamps;

• supply voltage of LED lamps;

• currents in power supply circuits of LED lamps;

• supply voltage of LED lamps of route indicators;

• operating times of LED light-optical systems from the main power source (from the backup power source);

• times of switching lights from permissive to restrictive indication;

• the state of the environment (humidity, temperature, etc.).

2.5. Impedance bond data:

• actual temperature and oil level;

• current on the secondary winding of the impedance bond;

• insulation resistance of cable conductors;

• the state of the environment (humidity, temperature, etc.).

2.6. Power supply devices:

• operating parameters of the power supply unit, diesel generator set and uninterruptible power supplies;

• electric power quality;

• insulation resistance of cable conductors;

• the state of the environment (humidity, temperature, etc.).

2.7. Level crossing automation devices:

• currents and voltages in the control circuits of level crossing gate and road blocking devices;

• video monitoring of the state of the crossing in the area of direct intersection of the road and the railway;

• vibration effects on the equipment of level crossing automation;

• the state of the environment (humidity, temperature, etc.).

The above parameters are key and are required for comprehensive monitoring of the state of railway automation facilities. Since they are also influenced by the objects of the railway infrastructure (track and contact network), as well as by the rolling stock itself, it is advisable to supplement this dataset with information from the systems monitoring the indicated technical means and structures. Unfortunately, at the moment of development of railways, at least in the Russian Federation, the noted expansion of the range of diagnostic parameters is impossible due to the specifics of functioning of the railway complex itself and the peculiarities of operation of the railway infrastructure facilities themselves. In the future, such an expansion will undoubtedly be achieved [20; 21].

Conclusion.

The development of technologies in management and monitoring of technical means of automation goes along the path of improving the methods and principles of management, reducing the human influence on the processes occurring in systems, increasing reliability, safety and availability of devices, etc. This fully applies to control and monitoring technologies in the field of railway automation and telemechanics. Microprocessor control systems in railway transport have spread all over the world, and data processing technologies have stepped from the analysis of unit parameters in comparison with threshold values to complex machine learning systems for solving these problems. There is also a gradual integration of technologies based on the use of the industrial Internet of things. The first railway automation systems, in which it is both possible, available, and necessary today, are monitoring systems, which today are not limited by requirements regarding safety of operation (except for a dangerous effect on the objects being diagnosed). This makes it possible to install diagnostic sensors directly on distributed and remote-controlled objects and transmit the received information using wireless data transmission channels.

The approach proposed in the article to organisation of systems monitoring railway automation facilities and devices makes it possible to abandon traditional structures of monitoring systems, to simplify the process of their design and operation, as well as to develop technical solutions that expand the set of diagnosed features and thereby increase completeness and depth of diagnosis and prediction. Interest in the presented technology may arise in case of limited dimensions of the premises where the monitored devices are installed, for example, at subway facilities.

The disadvantages of the proposed approach are obvious: it is necessary to consider the service life of autonomous power supplies during operation of sensors, organise communication channels protected from interference, and also carry out periodic verification and calibration of measuring instruments. Despite the noted shortcomings, monitoring technologies using wireless data transmission channels are developing and will be developed and implemented at many technically complex and unique structures. Their use in the transport industry, including in the field of railway automation, is promising for the next decade.

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