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Diagnostics of Track Infrastructure as Part of the Digitisation of Russian Railways

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Summary
Technical diagnostics is an integral part of the railway maintenance process. Through timely maintenance, in addition to ensuring the safety, functional and technical reliability of the infrastructure, maintenance costs are reduced and downtime losses, due to failures or premature repair requests, are eliminated or reduced. The track infrastructure diagnostic tools have evolved. This is related to, among others, the miniaturisation of instruments, reading accuracy during motion, as well as upgraded measurement automation and result analysis. Currently, data obtained from multifunctional diagnostic tools is the basis for the developed Russian railway infrastructure maintenance and operation digital model. The strategic development of mobile diagnostic labs is the gradual transition to solutions with advanced digital analysis, supported by artificial intelligence, monitoring and forecasting. The article presents the development of mobile labs for the railroad infrastructure condition diagnosis up to the current solutions, in which measurements take place without human intervention and the obtained information is transmitted in real time to the analysis and decision centres.

Keywords: rail transport, measuring wagons, digitisation of railways, Russian railways

1. Introduction

The maintenance of railway infrastructure in full operational use includes several important measures, i.e. the process of diagnosing technical conditions, maintenance, repairs and upgrades. The main tasks related to infrastructure maintenance consist of:

- Ensuring that its technical condition is within the limits of the standards and technical conditions established to guarantee safe operation;
- Ensuring that all elements of the railroad surface, the overhead contact line and the other railway infrastructure components are operational as long as possible;
- Preventing emergency situations, and
- Elimination of the causes and possible consequences of infrastructure irregularities.

In order to maintain the infrastructure efficiently, constant supervision of its technical condition is required, based on the processes of diagnosing and determining fault locations and causes, as well as determining the scope of necessary works to restore the original operational properties. This article will deal with some of the diagnostic tools in mobile labs, applied by Russian railways to examine the railroad infrastructure condition.

The developed state-of-the-art diagnostics puts it at the forefront of the railway digitisation process. It is becoming obvious that the time when its main purpose was only to ensure the safety of train traffic has passed. During the period of intensive development of diagnostic systems and tools, automation of measurement processes, as well as processing and analysis of information obtained through diagnostics, a new goal is being defined. It involves rational and efficient maintenance of the infrastructure, based on its actual condition and cost minimisation.

Reading various studies on this subject, one can gain the impression that the main goal of diagnostics is, nowadays, apart from correcting the identified irregularities, its ongoing monitoring. This allows the actual technical condition to be determined so that preventive measures can be undertaken at the right time. This leads, on the one hand, to savings and, on the other hand, it limits the possibility of emergency situations affecting, among others, the railway traffic flow.

The legal framework for screening activities is inherently the most „conservative" part of a diagnostic system as they are based on many theoreti-

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cal and scientific principles of infrastructure design, construction technology, subsequent operation and maintenance. The most important component of lawmaking should be long-term experience, based on the knowledge of many events, their causes and effects, as well as forecasting, which was often mentioned by Prof. Henryk Bałuch from the Railway Research Institute [1]. A legal framework can be developed based on such experience. For comparison purposes, it is worth considering foreign solutions.

The current changes in the economy are characterised by the digital transition. Thanks to digital data processing technologies and their analysis, you gain quick access to information used for the effective maintenance of railroad infrastructure or rolling stock. The main development directions of the Russian railway infrastructure diagnostic and monitoring system are aimed at maximum reduction of used handheld diagnostic tools, removed from the track during train passage, and replacing them with mobile devices.

One of the main tasks in the coming years, as defined in the „Development Strategy of Rail Transport in the Russian Federation until 2030"[15], is the construction and development of high-speed rail in addition to increasing safety in rail transport, as well as increasing passenger and freight traffic. These activities are complemented by the project of diagnostics of railway infrastructure as a system aimed at increasing the efficiency of its operation [3].

The aim of the article is to present solutions of mobile diagnostic laboratories, currently being developed on the Russian railways, which are used to examine the technical condition of the infrastructure and indicate, on this basis, the places, ranges, priorities and time for the necessary repair works.

2. Development stages of railroad diagnostics

Technical diagnostics is an integral part of the railway maintenance process. Through timely repair works, in addition to ensuring the safety, functional and technical reliability of the infrastructure facilities, maintenance costs are reduced and downtime losses due to failures or premature repair requests are eliminated or reduced.

(…) *The diagnostic and infrastructure monitoring system development programme* (…) was approved by Russian Railways in 2009. It provided for the successive replacement of research equipment and upgrade of existing diagnostic tools by 2015. It also envisaged the use of new digital technologies by 2030 with a predominant use of mobile diagnostic tools. An important slogan for the planned actions at that time was that comprehensive infrastructure diagnosis is the key to improving train safety.

In 2009, the document from 2016 was replaced by a new one, titled "The development concept of diagnostic and monitoring systems for track facilities until 2025" [10]. The document specifies the main tasks in relation to innovative diagnostic methods as part of the upgrade of measuring devices. It was also indicated that, for the widespread use of innovative and comprehensive infrastructure diagnostic mobile devices, it is necessary to include relevant tasks in the scientific and technical development plan, affecting the development of diagnostic methods and technologies applied. The new integrated tools for diagnosing and monitoring infrastructure facilities should take into account, among other things, their specialisation, the authorised speed and train traffic load. The document contains a number of methodological guidelines. And so, in order to diagnose the infrastructure of high-speed lines, it is necessary to ensure the use of, *inter alia*, [10]:

- Measuring systems (primarily for measuring and assessing smooth running) mounted on rolling stock, with automatic data transmission to infrastructure maintenance control centres;
- Diagnostic systems mounted on rolling stock with technical characteristics similar to those in the rolling stock in service on specific lines;
- Flaw detectors, as part of measuring cars that monitor rails at speeds up to 120 km/h.

When it comes to the railway lines with a particularly high volume of passenger and freight traffic, it is recommended to use [10]:

- High-speed diagnostic systems, including traffic measurement systems, flaw detection systems and video monitoring systems with automatic visual recognition of identifiable defects of sleepers, rail fixing elements and ballast, mounted on rolling stock with technical characteristics similar to those in service on specific lines;
- Diagnostic systems located on locomotives that provide track control under increased load, to identify unstable track sections.

Diagnostic tools have evolved considerably. Their advance is connected with intensive functionality development, improved automation of measurement processes and information analysis. Further work has combined the functionality of individual measuring tools with automation, while maintaining the compactness of the measuring devices and real-time data transfer to decision-making sites. Currently, by defining a new generation of diagnostic tools, all built-in capabilities have been added with built-in intelligence, autonomy and full integration with the rolling stock in use. In addition, the latest tools implement elements of the "Internet of things." The local on-board network combines all measuring and diagnostic tools in a complex integrated system, excluding human intervention in the measuring, result processing and proposals for required decisions.

Infrastructure diagnosis is increasingly implemented by multifunctional diagnostic units, operating in a shuttle mode and capable of operating on a passenger train. The data obtained from multifunctional diagnostic tools is the basis for the Russian railway infrastructure maintenance and operation digital model. Innovative solutions also affect problem solving related to increasing the capacity of railway lines [16]. This is the direction in which infrastructure diagnostic tools are developing not only in Russia, but also in Germany, Switzerland and other European countries.

The development of diagnostics on Russian railways is also affected by the participation of Russian Railways (*Rossijskije żeleznyje dorogi*) in the work of various international organisations, such as Condition Monitoring and Diagnostic Engineering Management (COMADEM), which implements "Technical diagnostics and monitoring." Each year, an international congress is held to exchange experiences between scientists and practitioners from different countries working in this field. The main objective of the congresses is to exchange experiences between experts on the development of different methods of information systems (information technology), integrated measurement and monitoring tools [10].

In Russia, there is a research and production association RISCOM, which connects many diagnostic companies and scientists from the Russian Academy of Sciences. The committee for technical diagnostics operating within its framework performs many works useful for the development of railway infrastructure and rolling stock diagnostics. Systems for monitoring and technical diagnostics of complex technical systems, as well as risk assessment and the forecasting of technical condition are currently being developed[2] [10].

3. Overview of mobile diagnostic lab solutions

In terms of diagnostics of the railway infrastructure based on mobile labs, the Russian railways distinguish several stages of development: upgrade of measurement techniques and their accuracy, IT level and, finally, the use of digital technologies[3]:

- The period until 2000, in which the diagnostic cars-labs equipped with mechanised devices with a narrow specialisation and electronic advances were used to a small extent (e.g. lab models, such as "KWL P" and "CNII 2");
- The years 2000-2007, in which mechanised devices were still in use, supported by new electronic solutions, which allowed the measurement capabilities to be extended (e.g. „KWL-ARKS", „CNII-4" lab models);
- The years 2007-2011, when the mechanisation of measuring devices was replaced by their full automation, which extended the measurement capabilities (e.g. DKI „ERA", „INTEGRAL" lab models);
- The years 2011-2014, when the miniaturised measuring devices started to support automation, which enabled their use on locomotives converted to traction measuring units (e.g. locomotives: SM-DL-2TE116, SPL-CzS200 and WL-11);
- The years 2015–2017, in which autonomy based on the further development of automation, miniaturisation, and artificial intelligence began to play a special role (e.g. the Infotrans – Valero Rus SAPSAN – a passenger train adapted for measurement), and
- The period after 2017, when new solutions of digital technologies and artificial intelligence were used for diagnostics (e.g. DKI „ERA" cars, Infotrans – „Łastoczka" electric multiple unit).

As the years have passed, the strategic development of mobile diagnostic labs has been a gradual transition to solutions with advanced digital analysis, supported by artificial intelligence, monitoring and forecasting. Currently, Russian Railways operate: 65 diagnostics cars, 90 lab cars and 76 cars for personnel performing manual measurements.

3.1. CNII-2 measuring car

The serial production of the CNII-2 measuring car began in 1960 (Fig. 1). It was created on the basis of a four-axle passenger car, and all measuring devices were placed on bogie frames. The operating speed of these cars was 70 km/h. When measuring superelevation on curves, a gyroscopic system was used and was not affected by centrifugal force, shock and vibration of mechanisms. The measurement results were recorded on two paper tapes (master copy and duplicate). The kilometre distances were marked manually. Track geometrical parameters, such as: radius, length

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[2] The purpose of technical condition forecasting according to GOST 20911-89 is to determine the interval during which the operating condition of the facility is maintained.

[3] It should be noted that every day there are, for example, about 8.5 thousand devices for measuring the condition of the track surface and rails, which are operated by 14,000 people [2].

of transition curves, and superelevation, were determined on the basis of tape recordings. The results read by the staff were used to determine the authorised speed limit.

Fig. 1. CNII-2 measuring car [20]

In line with the national programme to improve train safety, new measuring instruments, including an on-board automatic track assessment system (BAS), started to be fitted on cars after 1993. The system was used to automate the monitoring and evaluation of railway track parameters, with indication of the coordinates of each deviation, its volume and length. The data was displayed both on the screen and on the tape of the graphic recorder. With the development of computer technology and modern measuring instruments, it has become possible to significantly simplify the mechanical part of the measuring system, reduce its inertia, introduce automatic decoding of primary measurement data, and minimise subjective errors, etc.

3.2. CNII-4 measuring car

The production of the CNII-4 measuring car (Figure 2) started in the mid-1990s. The care was used to check the parameters of the railway track in the horizontal and vertical planes. The installed equipment recorded, *inter alia*, the subsidence of track sections, grade line deviations, track width, track curvature in the horizontal plane, slope of the longitudinal profile, horizontal and vertical track unevenness, horizontal and vertical acceleration, car speed and distance travelled. The measuring cars of this type were used to assess the conformity (with the design) of the actual track parameters after the completion of repair works or to identify sections requiring repair works and their pre-design inspection.

The measuring cars of this type are constantly being upgraded. The fourth generation of CNII-4 is equipped with a laser for extreme limit measurements, CCTV surveillance systems, a gyroscopic system integrated with GLONASS/GPS satellite receivers to control curvature parameters, and a system for measuring the track geometrical system in the horizontal and vertical planes, connected by a multiprocessor computer network. In terms of destination, volume, stability and performance of the obtained information, today's CNII-4 is no match for the latest measuring cars from MER-MEC and Plasser & Theurer. The CNII-4 measuring car allows plans and profiles of main lines to be reviewed. This test is conducted using a precise inertial navigation system integrated with GLONAS/GPS satellite receivers at high speeds. Measurements allow the determination of long irregularities and fractures of critical profile set-backs, which are important at high speeds. It is also possible to identify, recognize and document (high resolution images) surface defects associated with e.g. metal defects on the rail head surface or missing fastening elements or their components. More than 20 parameters are controlled. The video monitoring systems used in the car enable monitoring of the condition of sleepers, identification of shortages or excess ballast and its contamination. The information is related to the line mileage. The system for precise video surveillance of track components can record data at speeds up to 140 km/h.

Fig. 2. CNII-4MA measuring car [21]

Specialist cars were created at the same time (operating independently or in complex research assemblies) to measure a specific group of railroad infrastructure parameters, including:

- The RDM-WIGOR flaw detector car (Fig. 3), which is designed to detect rail defects using ultrasonic and magnetic test methods, with travel speeds up to 70 km/h.

Fig. 3. RDM – WIGOR flaw detector car [14]

- The Era car (Fig. 4) for comprehensive testing of overhead contact lines, automation and remote-control equipment creating a measuring unit with a second car, which measures the structure gauge, track surface and substructure, indicators of dynamic interaction between track and rolling stock, and video monitoring of infrastructure facilities. Two such measuring cars are in operation. The first has been used for research on the North Caucasus Railway, since 2009, and the second since 2011 on the Railways of Western Siberia.

Fig. 4. Testing car for overhead contact line, ERA automation and remote-control devices [14]

3.3. Latest solutions of measuring cars on Russian railways

The rail transport development strategy requires an integrated approach to assess the technical infrastructure condition of railway lines based on global experience. The advantages of comprehensive diagnostics include:

- Improved reliability of diagnostics by monitoring and analysing the entire range of parameters;
- Reduced maintenance costs of diagnostic tools and technical infrastructure, due to the undertaken repair work as the case may be;
- Reduced number of qualified personnel, while maintaining high-quality measurements obtained under varying weather conditions and temperatures, and
- Diagnosing much longer track lengths.

The maintenance of railroad infrastructure according to the designed technical and operational parameters means a quick response to any damage resulting in a reduction in speed, which reduces railway line capacity.

In recent years, work has begun on the development of a diagnostic complex for monitoring infrastructure facilities, called „INTEGRAL." For monitoring tasks the complex uses the infrastructure facilities: 16 matrix cameras, 12 linear cameras, 22 laser sensors, 2 laser scanners, 180 ultrasonic sensors, 49 magnetic sensors, 1 thermal imaging camera, and 10 temperature sensors. This allows 117 technical infrastructure condition parameters to be recorded. The modularity of the integrated diagnostic unit also allows for the use of all systems in the complex, as well as in separate modes in any combination. Measuring cars in the diagnostic unit allow speeds up to 160 km/h, and the equipment installed in them is designed to operate at speeds up to 250 km/h.

Figure 5 shows a measuring module for structure gauge measurements and overhead line diagnostics, while Figure 6 shows a VD-UMT-2 flaw detector car designed for comprehensive diagnostics of railway infrastructure facilities using ultrasonic, magnetic and optical non-destructive testing methods.

Fig. 5. The Integral car on the measuring instrument calibration station [19]

Fig. 6. The VD-UMT-2 flaw detector car is designed for complex diagnostics of railway infrastructure using ultrasonic, magnetic and optical non-destructive testing methods [17]

Fig. 7. Sprinter Integral measuring unit [8]

The „SPRINTER INTEGRAL" measuring unit is the latest solution of vehicles for infrastructure diagnostics, which in 2016 passed all required technical and operational tests to obtain relevant certificates. This work took nearly three years. The unit consists of an employee lounge car and a measuring car (Fig. 7). The unit is designed to measure the track surface and substructure, overhead contact line and for rail flaw detection. The equipment includes: the

„ECHO-COMPLEX-3" multi-channel ultrasonic flaw detector with tracking systems, the „SOKOL-2" non-contact system for measuring geometrical parameters of railway track, the „CONS-2" vision and measurement system for flaw detection, the „Dimension" fast three-dimensional laser scanning system, a system for diagnosing automation and remote-control devices, and the „INTEGRAL" measurement result management software [22]. At the same time, the unit is the last generation of the „INTEGRAL" measuring car solutions, and is able to measure and evaluate 194 infrastructure parameters while in motion. Railroad testing can be conducted remotely by means of laser devices (without lifting the pantograph, part of the vehicle equipment).

Special attention should be paid to an innovative solution for ultrasonic monitoring of rails. Thanks to this solution, it is possible to measure them in trains travelling at speeds up to 140 km/h. Currently, one of the units of this type is used for permanent monitoring of the line between Moscow and Saint Petersburg. According to experts, with the introduction of the Sprinter Integral unit, the operating costs of checking 1-km of track are 2-3 times lower than those of other remote-control means and 4-5 times lower than devices requiring their removal from the tracks [16]. Figure 8 shows examples of some of the measuring equipment that is fitted to the measuring car. Descriptions for figures: 8c, f, g, h are provided in Table 1.

By the end of 2020, Russian Railways will have seven such measurement units.

4. Diagnostic equipment to be fitted to self-driving vehicles

The rail transport development strategy in the Russian Federation until 2030 provides for the development and implementation of the latest technical measures and technologies, which can have a major impact on the condition of train safety and the cost reduction of the ongoing infrastructure maintenance, through the use of self-driving diagnostic vehicles. The vehicle type is associated with the set tasks and the types of railway lines on which the diagnostics is to be performed (currently 76 self-driving diagnostic vehicles are in operation).

4.1. SEVER self-driving vehicle

The SEVER self-driving vehicle (Figure 9) uses the RA1 railbus design. There are currently five versions of this vehicle that differ in purpose.

1. A diagnostic unit (various options of the interior layout allow the desired configuration of the vehicle equipment to be chosen for specific measurement tasks, which can be, for example, a system for measuring geometrical parameters of the railway track, ultrasonic detection of defects in the rails, three-dimensional laser scanning of the gauge limits, and GPR for monitoring the substructure).
2. A secondary diagnostic unit and emergency operations to confirm previous test results and solve problems with infrastructure identified during the initial di-

Table 1

Descriptions for figures 8

No. figures	Descriptions
8c	The principle of operation of the system is based on the visual detection of defects by a lighting system of a linear video camera illuminating the surface. The reflected light rays pass through the glass housing, the video camera lens and fall on the matrix. The resulting image is converted to a digital format and sent via a high-speed interface to a server where the data is stored for later decryption. The system allows real-time monitoring and processing of 64 detected defects, including rail cracks, condition of fastening elements, joint damage (including welded joints), sleepers, ballast damage, etc.
8f	The principle of operation of the MGS multi-channel GPR is based on the emission of electromagnetic wave pulses and registration of signals reflected from the interfaces of the surveyed soil layers with different electrophysical properties. Such boundaries are, for example, the contact between dry and water-saturated soils, contact between rocks of different lithological composition, between rock and artificial material, between frozen and thawed soils, areas protected by non-woven geotextile fabric. As a result of all the tests, a reliable continuous section of the examined centre is obtained, which is called a GPR profile or a radarogram. The profile analysis allows the operator to make the right decisions in order to neutralise processes dangerous to the substructure and to carry out appropriate repairs. GPR can operate at speeds from 0 to 120 km/h [18].
8g	The system is based on a laser scanner, which works by measuring the phase shift. The high accuracy and quality of the equipment allows a minimum measurement error to be obtained over the entire working range. The system integration capabilities ensure the implementation of such functions as the shared use of scanned data and information from video surveillance and tracking systems [18].
8h	There are no moving parts in the measuring system. All components operate in a static position, which increases measurement accuracy and eliminates frequent system calibrations. The system also works in daylight and can take up to 6000 measurements per second, ensuring high accuracy.

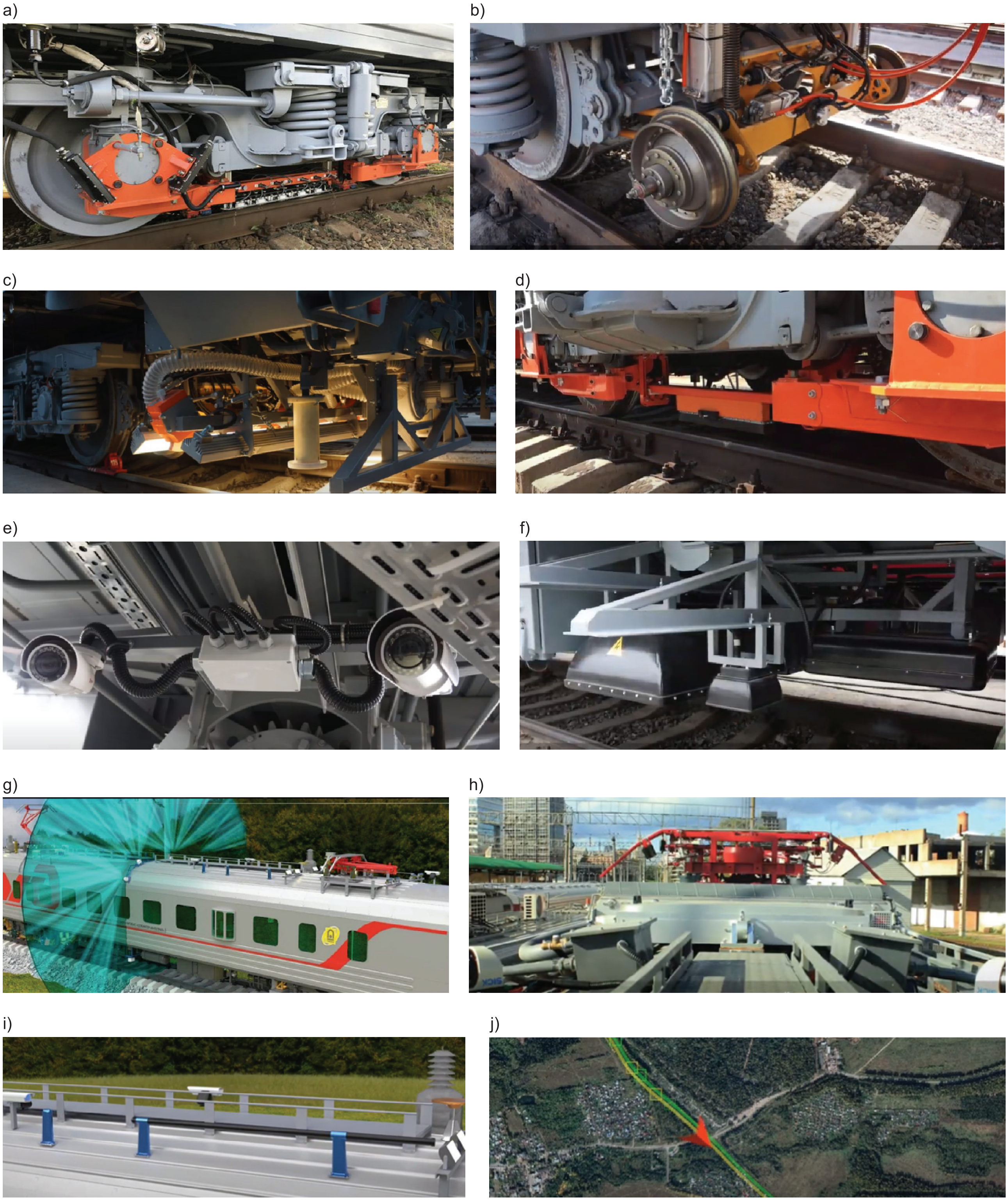

Fig. 8. Examples of measurement and control equipment of the SPRINTER INTEGRAL car [4, 9]: a) The device for testing internal rail defects, b) Piece of equipment for checking track gauge and geometry, c) Equipment for inspecting track surface and detecting missing elements, d) Rail head wear detection system equipment, e) Track video surveillance system equipment, f) GPR for rapid assessment of lower track structure condition, g) Infrastructure spatial scanning system in search of elements infringing the structure gauge, h) Overhead contact line parameter control system, i) Control unit for analogue and digital communication networks, j) GPS tracker

agnostics. The unit is additionally equipped with a passenger cabin with 15 seats and a place to store tools and spare parts, which enables the transport of repair crews with necessary equipment to the workplace.

3. An inspection vehicle, equipped with video surveillance systems.
4. A diagnostic unit to identify the causes of track instability, ballast and track substructure diagnostics. It is additionally equipped with a drilling platform and a set of drilling tools. The large set of equipment allows geological surveys to be conducted.
5. A vehicle with social facilities for the convenient transport of track repair crews with tools to the workplace.

Fig. 9. SEVER measuring vehicle [13]

4.2. Measuring diesel locomotive

The self-driving multifunctional diagnostic lab based on the 2TE116 (SMDL-2TE116) diesel locomotive is designed for automatic monitoring of the railway infrastructure condition under actual interaction between the track and the locomotive (Fig. 10). It is characterised by:

- Monitoring the parameters of the infrastructure under load – under conditions of real interaction between the track and the locomotive;
- A set of devices placed in a limited space to monitor a wide range of diagnosed infrastructure parameters;
- Advanced automation of all management, measurement, control, evaluation and analysis processes, which allows several workers to be involved in measurements, and
- Preparation of social facilities for the measuring vehicle crew.

The diagnostic unit is capable of monitoring the state of the track infrastructure, automation and signalling equipment and provides comprehensive diagnostics of the overhead contact line and train radio communication at operating speeds up to 100 km/h. The lab is multi-purpose and can work on both electrified and non-electrified track sections. Track parameters are monitored at a pressure of 23.7 t/s, which is particularly important for lines with heavy freight traffic – hence the vehicle is used on the BAM and Trans-Siberian lines. During one inspection, more than 120 parameters of technical infrastructure facilities are monitored; more than 140 parameters of automatic performance evaluation and analytical processing are created [6].

a)

b)

c)

d)

Fig. 10. SMDL- 2TE116 measuring diesel locomotive [6]; a) View of the locomotive, b) Rail condition laser monitoring devices, c) GPR for monitoring the substructure, d) Overhead contact line condition monitoring equipment

4.3. Electric measuring locomotive

The development of the SPL-CzS200 self-driving measuring lab, based on the CzS200-08 electric locomotive, was aimed at creating a suitable measuring tool for automated rail condition monitoring at operating speeds up to 200 km/h, with increased track load up to 19.5 t/axle. The SPL CzS200 project developed a non-contact laser system for measuring geometric parameters of a railway track, which is small in size, making it possible to install it on virtually any mobile unit. All output data can be obtained in any format and evaluated according to any standard. It is also possible to identify weak substructure spots. The measuring locomotive and the rail testing laser device are shown in Figure 11.

The SPL-CzS200 diagnostic lab includes the following subsystems [7]:

- Monitoring the track geometric layout;
- Monitoring the rail cross-section;
- Checking the longitudinal track profile;
- Gauge layout video surveillance;
- Monitoring of horizontal and vertical accelerations of the body and axle boxes;
- Monitoring the residual rail magnetisation;
- Combining obtained data in geodetic and railway coordinate systems, and
- Remote data transmission.

If necessary, the measuring vehicle can be equipped with extra systems, such as spatial scanning, and video surveillance of the sleeper fittings, etc. The touch control panel makes operation of the SPL-CzS200 automatic information measurement system simple and intuitive. It ensures that all diagnostic equipment is automatically switched on and off in a fixed sequence, in accordance with the start-up sequence, and automatically maintains the required temperature regime of the measuring equipment. The vehicle is the first lab of its kind to work on a broad-gauge railway (1520 mm). The lab can be operated at any time of the year, within the ambient temperature range from –40 to +55°C [8].

5. New directions of diagnostic tests

New solutions for diagnosing railway infrastructure are heading towards autonomous solutions, where very precise measuring devices are not operated by humans. The measuring equipment is mounted on the vehicles in service and the measurement takes place during the train's linear operation. The most important information received during train travel is automatically sent via a radio channel to specific analytical and decision centres that can make quick decisions to eliminate identified irregularities, while preventing the possibility of undesirable events. Thanks to this, the diagnostic costs are further reduced as, during the measurement, the train carries passengers according to the timetable and does not limit the capacity of the line on which the measurements are performed [2].

5.1. Infotrans-Velaro RUS pilot project

The Infotrans-Velaro Rus project includes the integration of measurement systems with an electric multiple unit of the high-speed train Sapsan[4] and the creation of a diagnostic unit based on this. It allows the measurement and assessment of railway infrastructure parameters which are crucial for maintaining the line in full technical operation. It also allows the simultaneous analysis of measurement results obtained during operational travel, as well as of track section identification systems with increased high-speed rolling stock dynamics in order to improve the efficiency of Sapsan high-speed trains (Fig. 12).

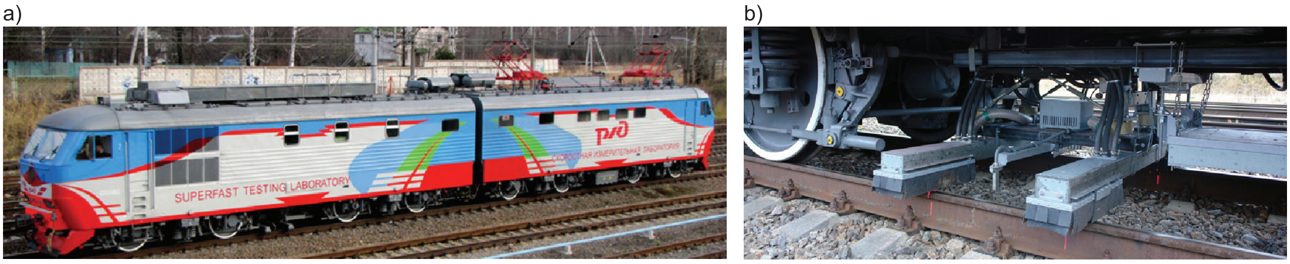

Fig. 11. SPL-CzS200 electric measuring locomotive (a), miniaturised laser device for rail condition measurement (b) [7].

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[4] Sapsan is a high-speed train running on the following routes: Moscow-Saint Petersburg and Moscow-Yekaterinburg. Currently, two vehicles of this type are equipped with measuring devices.

Fig. 12. Sapsan train laser device for rail condition measurement [5]

The train has been equipped with fast and comprehensive track diagnostic systems of track geometry, cross-rail profile, short rail irregularities and longitudinal track profile, video surveillance systems and remote data transmission. Precise diagnostic equipment for monitoring multiple parameters operates at high speeds in all weather and climate conditions. The installation of the diagnostic equipment was performed without interference with the train's standard systems and with all passenger seats. Frequent inspections enable the effective monitoring and forecasting of all maintenance and repair measures. It is noteworthy that diagnostics takes place under conditions of real-time interaction of high-speed rolling stock with the track and overhead contact line, with full automation of all diagnostic equipment management processes, making measurements, processing of measurement results and their evaluation, conducted without the presence of an operator. The project uses an information measurement system developed in Russia with the participation of German companies. The diagnostic system can operate without interruption of measurements at speeds up to 350 km/h.

5.2. Infotrans–Łastoczka pilot project

The INFOTRANS-Łastoczka project is an integration of diagnostic systems in the "Łastoczka" (ES2G) electric passenger train[5]. All processes of measurement management, their performance, result processing and track diagnostic evaluation, are fully automated and require no operator presence. The smart data management system in decision-making centres using Big Data technology is associated with the measuring equipment[6]. Obtaining the most important information takes place under the conditions of the real interaction of an electric train with the infrastructure, over 100 parameters of which are controlled by the operated vehicle. Figure 13 shows the control and measuring equipment of the electric multiple unit.

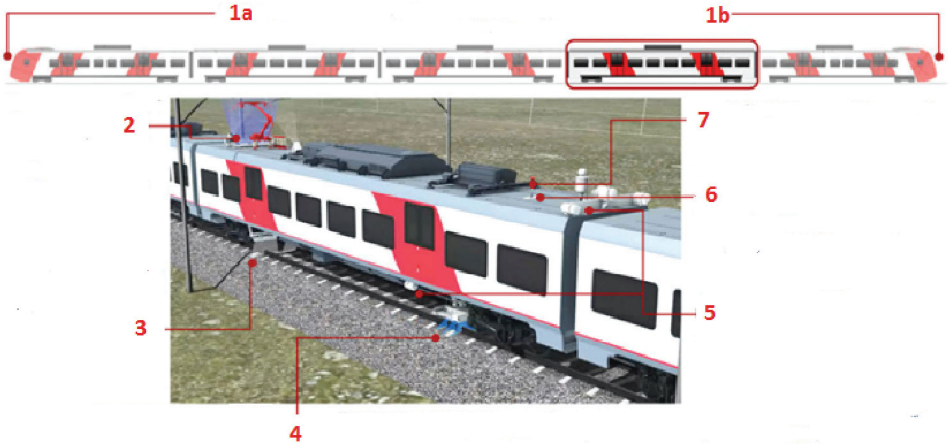

Fig. 13. Diagnostic equipment of the ES2G electric multiple unit[10]: 1a and 1b – trackside video surveillance (bridges, platforms, gauge limits, crossings, etc.), 2 – overhead contact line check (11 parameters), 3 – trackside video surveillance with automatic recognition (13 parameters), 4 – track and rail geometric layout check (4 parameters), 5 – structure gauge scanning system, track gauge, ballast layer shape, etc. (14 parameters), 6 – positioning in railway and geodetic coordinates (7 parameters), 7 – transmitter transmitting information about violation of parameters together with their values and location

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[5] The ES2G train is an electric multiple unit which, according to the Russian Railways rolling stock upgrade project, is gradually becoming the standard type of train used in Russia for regional traffic and, as in the case of Moscow, on the modern ring line (line 14) – for urban traffic.

[6] *Big Data* refers to the tendency to search for, download, collect and process available data. It is a method of collecting information from various sources and then analysing and using it.

6. Other mobile means used to diagnose track infrastructure

To solve the problems of monitoring and handling short sections of railway track, in early 2000, Russia mastered the production of an entire series of specialist motor vehicles adapted to ride on railway tracks (entry from the road to railway track is possible, for example, at level crossings). The vehicles are equipped with various measuring devices to monitor and diagnose tracks at low speeds. They can be operated at any time of the year and day, when they are exposed to rain and snow, in the temperature range from −40°C to +50°C. This form of track infrastructure diagnostics is being systematically developed and modified. Currently, there are 30 such diagnostic units in operation on Russian railways. An example of such a vehicle is shown in Figure 14.

Fig. 14. Road vehicle used for trackside infrastructure measurements [12]

The use of automotive diagnostic vehicles for monitoring selected railroad sections, railway station tracks or sidings has various benefits:

- Limiting track occupancy to the minimum to get to the measurement site;
- Limiting the use of measuring cars, especially the track occupancy when reaching the measuring site;
- Speeding up work on manually operated equipment;
- The vehicle can also be used as a means of transport for repair or measurement crews; and
- Minimising operating costs.

7. Conclusions

Technical diagnostics of railway infrastructure is an integral part of maintenance. Its main task is to ensure the safety, functional reliability and operational efficiency of railway lines, as well as to reduce maintenance costs and losses caused by downtime due to failures or premature repairs.

In recent years, there has been an international trend in the use of mobile diagnostic units (cars, trains) with multifunctional measuring equipment that provides control over all parameters of the railway technical infrastructure. As shown in this article, Russian Railways has created an effective system for diagnosing and monitoring infrastructure. Currently, the greatest attention in diagnostics is being paid to track issues, as it is the most significant and capital-intensive part of the infrastructure complex. Its technical condition is a decisive link in the efficiency of rail transport, significantly affecting transport costs, speed and safety of train traffic. Currently, the Russian railways have more than 8000 track diagnostics means, 427 of which are mobile measuring vehicles and 7650 are manually operated devices that are removed from the track when the train passes.

With the rail transport development, the railways in Russia are systematically moving away from the use of handheld devices in diagnostics to mobile ones (Fig. 15). The new direction of diagnostics is noteworthy as it consists of a movement away from placing measuring devices in special vehicles – labs. The effect of systematic work in this field in Russia is reaching the highest level of diagnostics by placing measuring devices in modern passenger trains (Sapsan, Łastoczka), in which the line infrastructure is measured without the participation of the operators, and the obtained results are automatically sent to analyti-

Fig. 15. One flaw detector car eliminates 40 manually operated devices and 200 people necessary to operate them [11]

cal and decision-making centres. Such measures are an important element of the digitisation of railways, as well as the maintenance of the assumed parameters affecting the quality of services offered.

The information presented in the article, on the development of track infrastructure diagnostic tools on railways in Russia, confirms the statements of Prof. Henryk Bałuch [1] concerning the current strategy of railway road maintenance. The strategy is now based on diagnostics and forecasting of changes, and not, as it was a few decades ago, on preventive repairs, which involved a high expenditure on premature works and frequent track closures. (…) *The current strategy, however, requires an appropriate diagnostic technique, supported by decision support systems, databases on the condition of railways and the history of their repairs, and above all a high level of professional skills* (…) [1].

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