

Assessment of the technical condition of rolling stock and track in order to improve traffic safety

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Abstract. The basic task of the work was to conduct the research aimed at studying the technical condition of the track and its impact on the rolling stock since the car dynamics, especially in curves and on the mountain pass sections of the track, is completely dependent on track deviations. The real time data received from specialized car laboratories show the existence of deviations visually detected, however external deviations are not crucial since the main problem lies inside the structure with changes already taking place in the layers of the subgrade not reflected externally, still affecting the movement of the rolling stock, especially the cars already having permissible technical deviations in operation. The technical condition of the track is directly related to the subgrade and ballast layer therefore the research is aimed at studying the lower base of the track in order to identify defects and malfunctions limiting the speed of the rolling stock and posing a constant threat to the safety of the transportation process. The main task is to identify and study the technical deviation of the subgrade layers, which directly affects the safety of the rolling stock, especially with an increase in freight traffic. The article proposes a method for evaluating GPR sounding of the subgrade, which sees into the depth of the soil up to 8 meters, depending on the equipment used. A theoretical study of the influence of the subgrade on the derailment of the rolling stock due to the deformation of the rail-sleeper grid allows to find the cause of deviations in the dynamics of the car when passing through the corresponding section. This article contains a quantitative and qualitative analysis obtained as a result of a research based on which comprehensive measures were developed to ensure traffic safety. At present, the operation of railways requires increased safety, an increase in the speed of rolling stock and the throughput of the main railway network. With regular inspections at the wagon laboratories, a better study of the track and subgrade is obtained through regular monitoring. Due to the complex of measures for diagnosing the track, a qualitative assessment of the performance of individual operations and the timely detection the railway track faults, as well as subsequent repairs according to the actual state of the track, are carried out.

1 Introduction

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The technical speed of the movement of trains and the permissible static load on the rails from the wheelsets of the rolling stock largely depend on the condition of the subgrade. The reliability of the subgrade directly affects the implementation of transportation plans and the safety of rolling stock. Therefore, the design of the subgrade must have drainage structures and operate reliably at any temperature and under the influence of all dynamic and static loads. The surface of the subgrade is designed so that the water has a runoff into the drains. In train and maneuvering work, the safety of train traffic is quite high, but in the track, locomotive and wagon facilities, the situation with safety is satisfactory. The statistics in the figure shows that only last year, due to various track defects, 96 derailments of trains and 142 due to faults in the design of the car occurred.

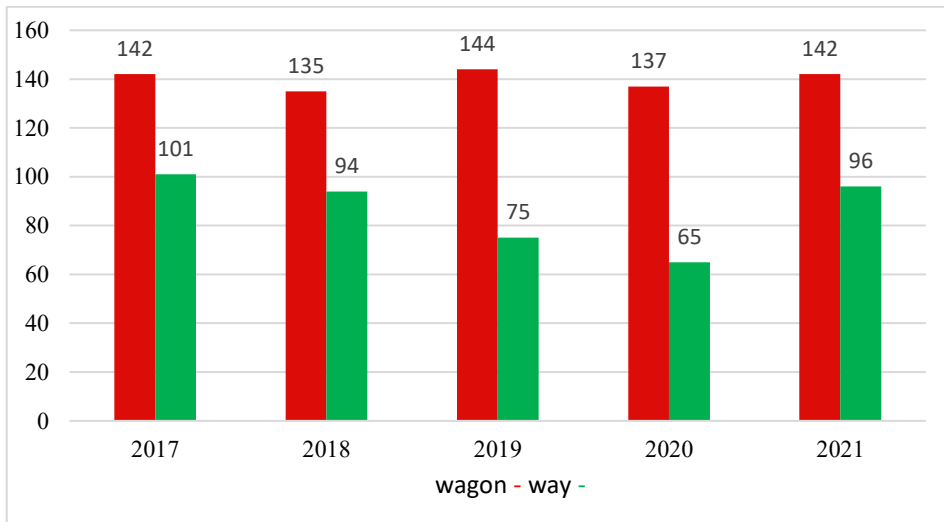


Fig.1. Rolling stock derailment statistics

When developing measures to improve traffic safety, it must be taken into account that all technical means function only in the interaction. The railway track is operated under the conditions of the most complex dynamic interaction of the wheel-rail mechanical system, which is directly affected by the train driving mode. Consequently, the development of methods for ensuring the functioning of the technical means of wagon, locomotive and track facilities is mandatory, but today it is poorly implemented by the requirement to ensure traffic safety. The most typical cases of rolling stock derailment and their causes are discussed in this article. So, the main reason for the descent due to the failure of the wheel inside the track is the unacceptable value of the widening of the track, which occurs as a result of pressing one of the rails by the wheel flange. In this case, the second wheel falls into the track. Such derailment is possible only under one of the following conditions or their combination:

- the action of a large transverse lateral force from the wheel, capable of pressing the rail;
- insufficient resistance to such rail deflection: insufficient transverse rigidity of the rail; the presence of weakened intermediate rail fastenings that do not provide the necessary vertical and horizontal rigidity;
- pressing of snow between the rail sole and the lining.

The probability of such a descent is higher in steep curves, on wooden sleepers, with rails P50 and P43 (low transverse rigidity), with spike fastenings. Extremely dangerous is the pressing of snow under the sole of the rail or the presence of several adjusting shims, in which the sole of the rail rises above the edge of the lining. The process of formation of a gap between the sole of the rail and the lining at the beginning proceeds without a noticeable widening of the track and therefore is not easy to detect. But after raising the sole of the rail above the flange of the lining, the broadening of the track increases intensively - initially on two or three sleepers, since the adjacent linings are held by the rail. With further pressing of snow on the neighboring five or six linings the track is broadened to unacceptable measurements under the influence of lateral forces from the wheels, which may cause the wheels to fall inside the track. The stability of the gauge on reinforced concrete sleepers is much higher than on wooden ones. However, in long-term exploited sections, especially in curves with a radius of less than 600 m, as a result of the increased transverse rigidity of the track with CB fastenings, the sleeper pads are gradually destroyed at the point of their contact with the outer edge of the rail sole. After the edge of the lining is destroyed, the rail rests against the side of the sleeper recess and breaks off the concrete. Under the influence of lateral forces, the rail begins to push the lining out of the recess in the sleeper and breaks it. This results in an unacceptable widening of the track, which can lead to derailment.

One of the encountered track disorders is considered in Figure 2. In accordance with the Technical Instructions for the Construction, Laying, Maintenance and Repair of a Seamless Track, track ejection is defined as "a sharp violation of the longitudinal stability of a seamless track in the form of a single- or multi-wave horizontal or vertical curvature of the track grid under the action of compressive longitudinal forces (temperature and (or) jacking forces).



Fig. 2. Railroad track ejection

If the structure of a seamless track is reliably fixed to prevent jacking, then the main factor on which the stability of the track depends is the action of longitudinal temperature forces. When the critical values of the temperature forces are reached the loss of stability or the ejection of the rail-sleeper grid occurs, as a rule, in the horizontal plane. It is known that in front of a moving train, the rail has the shape of a reverse bend, and the rail grid rises slightly. As a result, the resistance to lateral movement of the track is somewhat reduced. This "reverse wave", running in front of the train, may appear in the section of local

weakening of the track (loose terminals, etc.) and provoke track ejection. The ejection itself will occur in front of the locomotive. When a wheel pair hits a wave of a curved rail, the crest of one of the wheels rolls onto the rail head and the wheel jumps out of the track with the second wheel jumping into the track. The exact place of the beginning of the descent can be found by the scuffs of the metal on the head of the rail, by the deformed parts of the fasteners and potholes on the sleepers.

When studying the subgrade, geological exploration is carried out - along the entire length of the track, wells and pits are drilled with a certain step to take samples of the disturbed and undisturbed structure. In addition to field work, these methods provide for further laboratory testing of the obtained samples. This is labor-intensive and expensive work. To reduce the cost and increase productivity, non-destructive testing methods are needed. To solve complex problems when examining railways, geo-radar sounding is used which is a geophysical method for studying the structure of the Earth and various media, including inhomogeneous ones.

2 Methods and materials

The geolocation method is based on the emission of electromagnetic waves by the transmitter and registration of signals reflected from the boundaries of the layers of the probed medium with different permittivity " ϵ ".

Such interfaces are, for example, contacts between dry and water-saturated soils (groundwater level), between rocks of different lithological composition, between rock and material of artificial origin, between thawed and frozen soils, between loose and bedrock, etc. A certain dielectric constant and geotechnical properties of subgrade materials are not directly related to each other. For these purposes, a geo-radar is used - a portable radar that emits nanosecond ultra-wideband pulses in the meter and decimeter range. Such signals can penetrate media with a high dielectric constant - wet sand, concrete, wood, and others. The device is equipped with interchangeable antenna units operating at different frequencies. By changing the blocks, one can increase the depth of sounding or the resolution when examining the upper boundaries of the geological section. In addition, the geo-radar has a control unit (amplifies the signal received by the antenna units and converts it into digital information), a recording device (mobile or built-in computer), various additional equipment (motion sensor, path meter, GPS receiver, transport carts and special suspension devices for fastening on automobile or other transport).

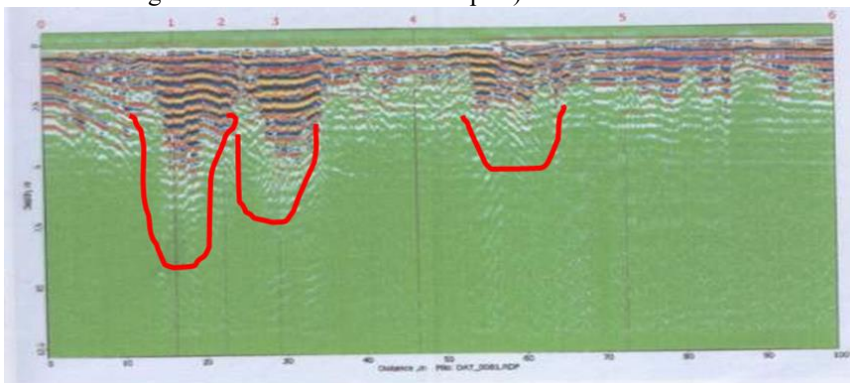


Fig.3. Water in the embankment body at the top of the subgrade

In Figure 3, quicksand was found in the body of the embankment. This subgrade defect led to malfunctions on the superstructure of the track. The rail-sleeper lattice on the site sank, thereby leading to the derailment of three gondola cars. Geo-radar is a high-performance, accurate multi-task device. It can be used to inspect any concrete structures, including vertical supports. Thanks to special marking mats and a laser pointer, it is possible to increase the accuracy of the survey so that a radargram data can be used as initial data for restoring reinforcement schemes and creating drawings during major repairs and reconstruction.

3 Results and discussion

The result of radar sounding is a radargram, which is a continuous section of the soil thickness along the survey profile. The radargram displays echo signals in the coordinates “time (y-axis, “depth”) – position on the surface”, that is, it records the time of passage of an electromagnetic wave pulse from the antenna to the interface and back in relation to the location of the device. Using formulas (1) and (2), it is possible to calculate the time and speed of radio wave propagation in different media.

$$t = \frac{2H}{V} \quad (1)$$

where t is time, sec;

H is the distance from the antenna to the boundary of the soil layer, m;

V is the speed of radio wave propagation in the medium, m/s;

The length of the train, depending on the weight and parameters of the cars, namely: length, axle, carrying capacity, which should not exceed the useful length of the station's receiving and departure tracks. The train installation takes into account a tolerance taken to be equal to 10 m. The length is determined by the formula (2)

$$V = C_0/\sqrt{\varepsilon} \quad (2)$$

where C_0 is the speed of light in vacuum, m/s;

ε is the permittivity of the medium.

To survey the soil foundation of railways, the geo-radar can be mounted on a trolley in specialized laboratory cars or vehicles (handrails, railcars). It can continuously probe soils throughout the entire linear object (travel distance); to clarify the data, only control drilling of wells in certain areas may be required. Thanks to the continuous operation of the geo-radar, flooded areas, voids, boulders, buried objects, areas of uneven soil mixing and other deviations will be detected with high accuracy. Upon completion of the field work, office data processing and a report on subsurface sounding are carried out. This document can become the basis for scheduling of an emergency repair, serve as initial data or for other purposes. To obtain complete information about the structure and properties of the strata studied, the GPR method should be used in combination with other geophysical methods (sounding, seismic sounding, etc.) and with traditional methods (drilling wells and arranging pits with sampling and laboratory studies of soil samples, etc.).

Ground-penetrating radar diagnostics is performed by hard- and software complex. The quality of measurements depends on the correct choice of parameters and operating modes of the equipment and the selection of appropriate antennas. The interpretation of the data

obtained is carried out by processing radargrams using special software systems. With a decrease in the antenna frequency, the resolution of the device increases, as well as the depth of the studied stratum, while the size of the "dead zone" from the surface also increases (Table 1).

Table 1. Geo-radar characteristics

depth (m)	dead zone (m)	resolution (m)	frequency (MHz)
up to 1.0	0.08	0.06-0.1	2000
up to 2.5	0.1-0.2	0.2	900
up to 3.0	0.2-0.25	0.2-0.5	750
up to 5.0	0.25-0.5	0.5	500
up to 10-12	0.5-1.0	1.0	300
up to 17-20	1.0	1.0	150
up to 23-25	2.0	2.0	75
up to 30 4.0	4.0	2.0-4.0	38

The indicators given in Table 1 depend on the technical characteristics of the equipment and the properties of the medium being probed (the data are given for the medium with $\epsilon_{rel}=4$ and with a specific attenuation of 1-2 dB/meter). The "depth" in the table refers to the depth of detection of a flat boundary with a reflection coefficient of 1.0. When applying the geo-radar method for diagnosing the subgrade, one should take into account variations in the electromagnetic conductivity of soils. Non-cohesive soils serve as a good conductor of electromagnetic waves: sands, gravel and crushed stone ballast, as well as light sandy loam and peat. In clay soils, a strong attenuation of pulses occurs, therefore, the application of the method with cohesive (loamy and clay) soils is limited. At the same time, the surface of clay soils is a good (contrasting) reflective interface between different media. The contrast of the boundaries also depends on the degree of water saturation of the soil: the contrast increases with an increase in the difference in moisture between adjacent soil layers. The principle of operation of the multichannel geo-radar system "MGS" is based on the emission of pulses of electromagnetic waves and the registration of signals reflected from the boundaries of the layers of the probed soil, which have different electrophysical properties. Such boundaries, for example, are the contact between dry and water-saturated soils, contacts between rocks of different lithological composition, between rock and material of an artificial structure, between frozen and thawed soils, etc.

Figure 4 shows the undercarriage equipment of the SPRINTER-INTEGRAL diagnostic complex, consisting of three antenna units, which make it possible to detect deviations dangerous for the roadway in their infancy, neutralize them in a timely manner and take the necessary measures to stabilize the earthen embankment.

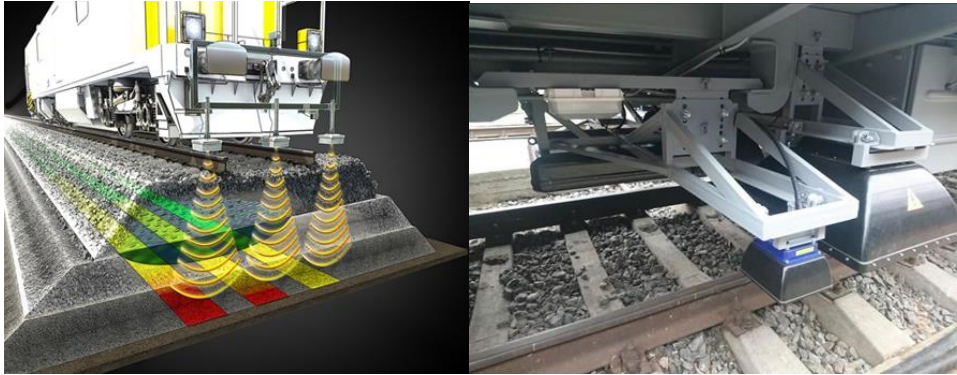


Fig.4. Undercarriage equipment of the SPRINTER-INTEGRAL diagnostic complex

When conducting research, a reliable continuous section of the probed medium was obtained, called a geo-radar profile or a radargram. Its analysis allows the operator to make the right decisions to neutralize processes that are dangerous for the subgrade and to carry out appropriate repair measures. The results of the passages (sheets of output forms) are loaded into the EKASUI SDMI software, then the employees of the IGB RTsDM process and analyze the results, subsequently send letters to the addresses of the distances of the track with updated results, for subsequent use in planning the current maintenance of the track and capital works. For example, a section of the path was considered, the distance of which was 120 meters. A cable and a pipe were laid to a depth of up to 8 meters to illustrate the experiment. Within this area, it is possible to determine the distribution of strength and deformation properties of soils. It should be noted that the traditional interpretation of the results of shallow tomography often does not allow to determine the boundaries of heterogeneous layers with sufficient accuracy. The resolution of seismic methods is determined by the wavelength excited in the medium and recorded in the frequency range of the “source-receiver” system, that is, the diameter of the cylinder of the studied soil volume is approximately equal to half the wavelength. In such cases, the additional information is required as well as the use of specialized equipment. On the radar-gram obtained during the study of this section of the track, you can see only the pipe along and the embankment while the cable is not visible at all. We come to the conclusion that smaller details such as a cable cannot be determined on a radar-gram, thus we will not be able to determine more accurate details from the structure of the subgrade layers.

As a result of the research, theoretical and experimental data were obtained for assessing the track and rolling stock. In the course of the work, studies were carried out with the interpretation of subgrade radargrams, which help to visually see how changes in the inner layers of the subgrade affect the state of the track and the rolling stock as a whole with a different geographical location of this section of the track. A multifunctional radar system was also considered, with the help of which the layers of the subgrade were studied for compliance with the moisture standards and the structure of the subgrade soils.

4 Conclusion

This system showed that at different frequencies it is possible to detect deviations at a depth of 2 to 50 m. This is the optimal solution for monitoring and maintaining the railway track and timely detection and elimination of track subsidence and inconsistencies in the layer structure. When using the geo-radar system, data were obtained in which violations were

revealed in the lower layers of the railway track, where humidity is increased. In such areas, derailments are more frequent. This method of studying the subsurface layers of the subgrade is definitely of a higher accuracy as compared to other geophysical methods and can provide continuous and reliable information about the state of the subgrade objects. The use of this technique will help to significantly improve the quality of solutions in the course of designing, and reduce the cost of the current maintenance and repair of the railway track as well as the number of derailments associated with violation of the track topography.

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