Evaluation of operational performance parameters of rolling stock when driving over bumpy roads

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Abstract. The current situation on the railway network of Russia and the East Siberian Railways in particular, the increase in the number of wagon cuts and unsatisfactory condition of the track and rolling stock, require the search for optimal solutions to these problems. Considering this topical subject it is necessary to touch upon the issues of modern strategies and trends in the development of railway transport with the introduction of modern technologies and technological equipment. As a result of a detailed consideration of the cause-and-effect relationship of the occurrence of factors affecting the dynamics of the car passing the track irregularities, the starting point will be an in-depth analysis of the system of interactions between the wheel and the rail. This analysis will make it possible to objectively assess the causes of existing problems in the field of operation, describe the emerging phenomena with a sufficient degree of justification, offer progressive topical solutions and possible promising developments in this industry. Turning to the statistics on failures over the past 3 years, one can trace the growth of malfunctions associated with defects in the rolling surface of wheel sets. Indeed, an increase in the speed of rolling stock, and in the volume and quantity of transported goods resulted in an increase in the intensity of rolling stock operation. Consequently, there was an increase in loads on the main components of the rolling stock and in the intensity of parts wear. Keywords: uncoupling of wagons, unsatisfactory condition of the track and rolling stock, track irregularities, cause-and-effect relationship, rolling surface defects.

1 Introduction

Intensive wear of wheels and rails was accompanied by a noticeable increase in the number of defective rails on the way and lateral wear of the rail. As a result an irreversible increase in the number of fractures of the rails and wheels of the rolling stock during their contact interaction was observed. This entailed extremely adverse consequences for the safety of train traffic in general.

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Table 1. Curve Characteristics in the section Tankhoi–Kedrovaya.

Name of the haul	Kilometer	Defect name	Degree of deviation	Deviation range, mm	Number of faults
		Gauge narrowing	2	6..15	42
			1	4	1
		Deviation in plan	2	40	350
			3	50	1
Tankhoy-Kedrovaya	13807	Skew	2	20	736
			3	25	3
		Track broadening	2	8..20	264
		Level deviation	2	25	644
		Drawdown	2	25	876

The studies carried out by car laboratories and the investigation of rolling stock derailments showed the track irregularities to create a stressed state in the rail threads in curves and transition curves at the smallest radii of 200 to 450 m.

An analysis of the edge stresses of the rail in a curve with a radius of 200-450 m showed that they significantly exceed the corresponding stresses for similar irregularities in the straight section of the track. The excess value depends on the type of malfunction, as well as on the type of bogies and their technical condition.

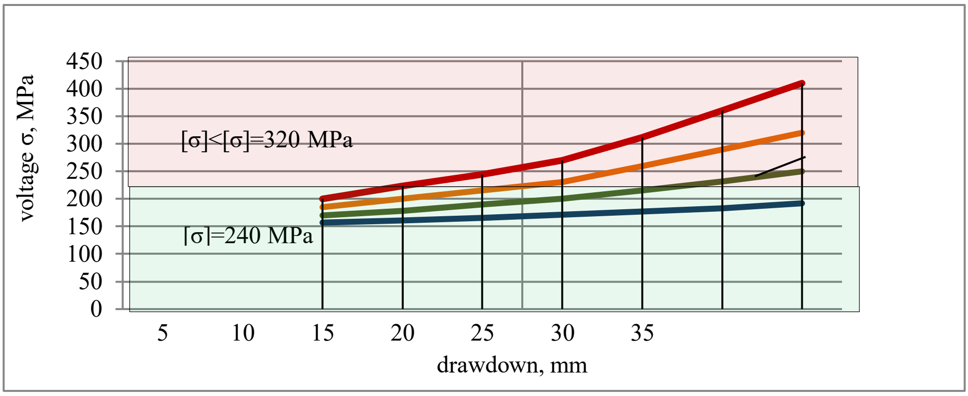

Fig. 1. Analysis of rail edge stresses in a curve with a radius of 200-450 m.

In the process of research, especially with one-sided subsidence, it was found that at the top of the humps of irregularities, tensile stresses arise in the rail head with compressive ones in the sole. The greatest stresses occur in the curve, in the presence of irregularities of the IV degree in such curves the increase in edge stresses, all else being equal, can reach 50%, which significantly affects the permissible speeds of movement and can also lead to a break in the rail when the locomotive enters this section at speed (fig.2).

Fig. 2. Rail break at the derailment site.

The greatest impact on the track in the considered variants of irregularities in plan and profile is exerted by electric locomotives with a large axial load and a design feature of the undercarriage. The simulation of the rolling stock – irregularities interaction in a circular curve occurs with stable initial conditions and the scatter of readings is determined only by the influence of changes in parameters in the system. In straight sections of the track, the process is much more complicated: when moving at a speed above the critical oscillation, the wobbling of the car is superimposed on the oscillations caused by track irregularities. In modeling carried out to identify the influence of the amplitude and degrees of irregularities on the dynamic processes of interaction between the rolling stock and the track, it was found that each time the irregularity had different parameters. The external additional force acting on the crew in the curve is the centrifugal force. This force presses the carriage against the outer rail, overloading it and increasing the resistance to the movement of the carriage, which accelerates the wear of the outer rail. In combination with a strong side wind of the same direction, the centrifugal force can lead to the overturning of the car. To reduce the impact of centrifugal force and the adverse consequences caused by it, an elevation of the outer rail is arranged in curved sections of the track, but each mm of lateral wear of the rail increases the centrifugal force and the elevation ceases to influence the occurrence of an additional force entailing the collapse of the car (fig. 3). Lateral forces in curves, especially in those of small radii, can reach such values at which the rail threads, together with the linings, move from their places on the sleepers or the outer rail thread "rebounds", which leads to a broadening of the gauge. In addition, the rails can move along with the sleepers, distorting the track position in the plan.

The outstanding acceleration is responsible for traffic safety and corresponds to the norm only if there are deviations in the state of the rail track not higher than the II degree. The allowable level of outstanding accelerations in curves is a function of not only the parameters of the curve structure, but also the design of the rolling stock, as well as the state of the track:

- curves corresponding to the project, in which it is practically impossible to significantly increase the speed without increasing the radius;
- curves with insufficient length of transition curves;
- peened sloping curves, in which the maximum outstanding acceleration is 1.52 times higher than the average due to irregularities 50-150m long;
- curves in which the elevation does not correspond to the curvature.

2 Methods and materials

The non-compliance of the parameters of the rail track geometry structure with the current standards and the coincidence of design standards and traffic safety tolerances lead to frequent exceeding of the limit values of anp and, accordingly, to limiting the speed of movement. An analysis of the experimental data showed that due to the body roll of the car and the locomotive, a quasi-static outstanding acceleration occurs in the curves, which acts on the car and the locomotive by an average of 32-35% more than the calculated outstanding acceleration. When the cars are located at an angle to each other in the plan, transverse horizontal components of the longitudinal forces arise; and with a difference in the heights of their automatic couplers - vertical components that create additional load or unloading of the corresponding wheels of the vehicle, depending on its vibrations. It should be noted that the presence of longitudinal forces not only leads to an increase in the intensity of wobbling, but also contributes to a decrease in vertical loads in the "wheel-rail" system, that is, to a decrease in the forces that prevent the wheel from rolling onto the rail head, as well as a greater turn of the bogies with an increase in the running angle of the wheel on the rail.

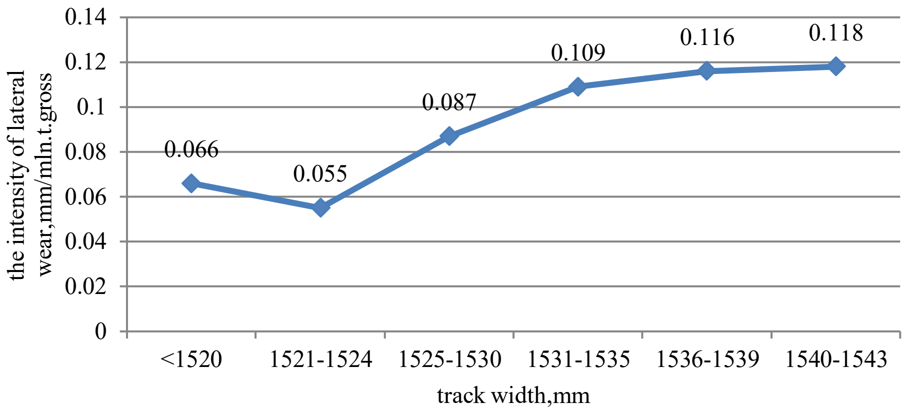

Fig .3. Rail side wear rate.

In steep curves, according to the experiments, the average value of the stability coefficient of the wheel on the rail is 2.74. If the value of the probable spread is assumed to be 1.4, then one also can assume that the minimum probable value of the stability coefficient in steep curves is 1.34, which is slightly higher than the permissible value. Thus, based on the studies carried out, it can be assumed that in order to ensure traffic safety in a train consisting of empty and loaded cars, the magnitude of the longitudinal force acting on an empty car should not exceed 300 kN or 30 ts.

3 Results and discussion

The results of the study show that the longitudinal forces are a factor that sharply reduces the resistance against wheel creep during wobbling, although wagons in the train do not squeeze out due to the loss of its stability as a hinge-rod system. This explains the numerous cases of derailment of empty wagons, in which no clearly expressed track disorders, wagon malfunctions, and abrupt changes in control modes were found. As an example of the influence of the magnitude of longitudinal forces on the processes of interaction in the "wheel-rail" system, the results of calculations of the movement of an empty car at a speed of 80 km/h along a section of track with a curve radius of 650 m are given. The longitudinal force is smoothly growing starting from the mark of 100 m keeping the maximum value of 30 tf within the transition curve (fig. 4).

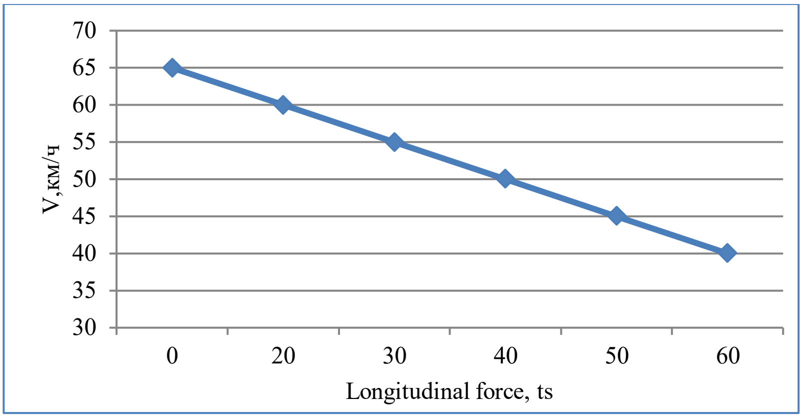

Fig. 4. The dependence of the longitudinal force on the speed of the train.

With the presence of such a longitudinal force in a sloping curve, the value of the lateral interaction forces remains practically unchanged, however, the longitudinal forces, due to a decrease in vertical loads, affect the value of the derailment stability coefficient. The simulation results showed that at operating speeds, the stability of the movement of vehicles, the track plan (the largest forces are usually observed in transition curves) and the magnitude of the longitudinal forces in the train have the greatest influence on the interaction forces. Since the longitudinal forces not only cause the wagon to be squeezed out, but are part of the totality of interaction processes, the influence of their magnitude on traffic safety is very significant. Thus, in the course of modeling it was shown that the application of a longitudinal force of 20 ts reduced the average value of the slip resistance coefficient by about 20%, and for a force of 40 ts this value is about 50%.Thus, even in the absence of "squeezing out" according to the classical theory of train stability, the presence of longitudinal compressive forces can become a factor provoking the derailment of cars, despite the fact that the main reason for the wheel crawling onto the rail is a combination of dynamic interaction processes of the wobbling oscillations Npr, ts V, km /h of the rolling stock and the track, and not the violation of the train stability as a core system. With an increase in the loading of the car, the critical speed of the beginning of the wobble increases and the influence of the magnitude of the longitudinal forces on the wobble processes decreases (fig. 5).

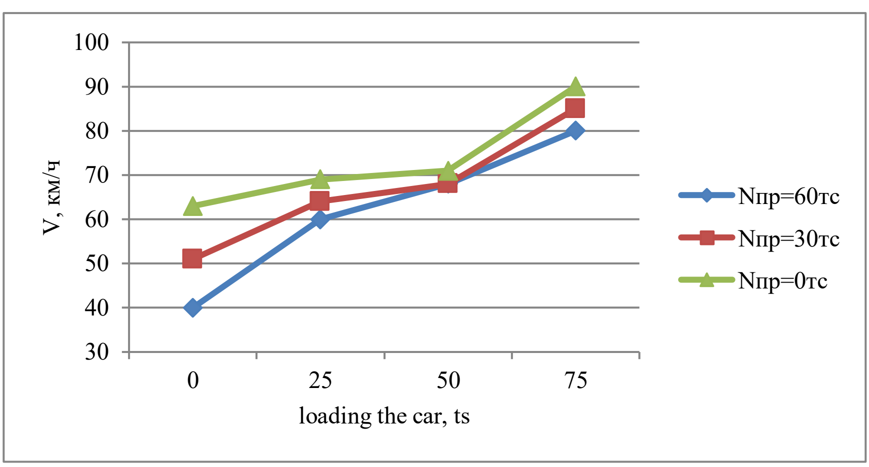

Fig .5. The dependence of speed on the loading of the car.

The influence of the wagon weight on its stability in the rail track is determined by the following main factors:

-changing the loading of the wagon leads to a change in its inertial parameters;

- the load prevents the wheel flange from crawling onto the rail;

- with an increase in the weight of the body, the influence of the magnitude of the longitudinal forces decreases, causing a change in the vertical and lateral forces in the "wheel-rail" system;

- a change in the vertical load on the contact area in the "wheel-rail" system leads to a change in the creep forces, causing wobbling of the railway vehicle.

The main influx of energy into the system, which causes wobbling, is determined by the work of the longitudinal pseudo-slip forces arising from the difference in the rolling circles of the bevel wheels when they are displaced in the rail track. The moment of longitudinal forces causes the wheel pair of the vehicle to turn and the wobbling amplitude to increase. Dissipation of energy in the system of running gears of the carriage occurs during the interaction of the wheel pairs of the bogie with the bolster, and in the "wheel-rail" system - due to an uneven change in the profile of the rolling surfaces of the wheels and the rotation of the bogie when the wheel pair runs onto the rail. Therefore, a decrease in the magnitude of pseudo-slip forces leads to a decrease in speed.

With an increase in the growth in the volume of railway transportation and their speed, the load on the rolling stock and the track as a whole increases. An important role in ensuring traffic safety is played by the identification of the causes of emergency situations, and the development of appropriate recommendations on this basis. A significant factor in this process is also the analysis and assessment of the involvement of various deviations in the parameters of the “locomotive-car-track” system in the fact of a wagon derailment or other emergency situations. The increased load on the car parts and on the track increased the number of failures during operation and reduced their turnaround time. This increase led to a deterioration in the technical condition of the "locomotive-car-track" system and influenced the growth trend in the number of derailments of freight cars in curves and on mountain pass sections of the track. In particular, according to investigations of emergency situations, the number of wagon derailments in such sections, due to various deviations in the state of the system, more than doubled over the period 2012-2021. In this regard, the calculation-empirical assessment and classification of the danger of various deviations in the characteristics of the state of the system, as well as the development of mathematical models of these processes and situations, is of significant importance for ensuring traffic safety.

4 Conclusion

The problem under consideration is now partly resolved on the basis of an investigation into the causes of damage and emergency situations in the "car-track" system, the subsequent identification of the most dangerous damage in this system and the development of appropriate recommendations aimed at improving traffic safety in curves and mountain pass sections. This approach does not fully take into account the impact of violations of the speed limit combined with other deviations, as well as the degree of danger of various deviations in the "locomotive-car-track" system elements when driving on mountain pass areas. In particular, the effect of unsuspended lateral acceleration that occurs when the train moves in such sections (track slope 8-25 ‰), including its combination with track subsidence, high-speed mode and violation of the outer rail elevation norms in a curve, has not been fully assessed. In addition, the effect of wear on the rolling surfaces of wheels and ridges when driving in curves and on mountain pass sections of the path has not been fully studied.

Development of a computational-empirical approach and mathematical models for assessing the risk of individual malfunctions in the "locomotive-car-track" system and their combinations, as well as developing recommendations aimed at identifying the causes of emergencies and improving traffic safety in curves and mountain pass sections of the track, is an urgent issue.

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