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Ensuring the safety of rolling stock movement when entering transition curves

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Abstract. The main factor in the issue of the safety of the rolling stock movement in the rail track is the change in the magnitude of the lateral forces arising from the interaction of the wheel with the rail. The dynamics of changes in lateral forces directly depends on the increase in rolling stock speeds in curves and, especially, in transition curves. To prevent the sudden appearance of centrifugal force, the outer rail is elevated, the track is broadened when moving from a straight line to a circular curve and a transition curve of variable curvature r = 1 / p, where p is the variable radius of the curve. Within the transition curve, the current elevation h of the outer rail over the inner rail must be proportional to the current curvature value, including at the end of the transition curve, all these factors leading to a sharp dynamic increase in lateral forces. In this case, the elevation h0 of the rail and the curvature r0 = 1/R are the parameters of the circular curve. Due to the fact that r, h and track width S are variables within the transition curve, in case the widening in a circular curve is intended when moving along the transition curve, additional forces and moments arise not present either on a straight line or on a circular curve. It is necessary for any additional force factors (forces and moments) to change gradually and be equal to zero at the beginning (BTC) and end (ETC) of the transition curve, and for the absolute values and intensities (gradients) of their changes within the transition curve not to exceed the allowable values, which is provided by complying with the requirements specified in table.1.

1 Introduction

The first three requirements concerning the inadmissibility of sudden changes in the CPC, CPC and along the transition curve of ordinates y, rotation angles φ and curvature r due to the monotonicity of their change are obvious. The fourth is the requirement for the curvilinearity of the elevation withdrawal of the outer thread and the transition along the tangents to the position of the outer rail thread on a straight and circular curve. Since by condition tan ⟦γ=0⟧ in NPC and CPC, then at these points there should also be dk/dl=0, which is indicated in Table 1. Limiting the maximum angle γ and the intensity of its growth within the interval leads to the same requirements with respect to dk/dl . This is indicated in

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the fourth row of the table. The fifth condition ensures the fulfillment of the previously mentioned requirements with respect to additional force factors. Additional forces and moments are proportional to additional translational or angular accelerations, so the same requirements are imposed on both. When moving in a straight line, the axis of the wheelset is horizontal; when moving along a circular curve, the wheelset is inclined at an angle α to the horizon. When moving along the transition curve, the current angle of inclination of the wheelset axis to the horizon is φ=sin φ = (φ)/S1. Due to the insignificance of changes in the track width within the transition curve, we will consider S1=const. When the wheelset moves along the transition curve, its slope changes (Fig. 1). In this case, the angular velocity of the slope change is equal to $\frac{d\Psi}{dt} = \frac{1}{S_1}\frac{dh}{dt} = \frac{A_0 \cdot dk}{S_1 \cdot dt}$ The forward speed is $v = \frac{dl}{dt}$; hence $dt = \frac{al}{v}$. . Thus $\frac{d\Psi}{dt} = \frac{A_0 \cdot v}{S}\frac{dk}{dl}$

Angular acceleration at constant speed V is $\frac{d^2\Psi}{dt^2} = \frac{A_0 \cdot v}{S_1}\frac{d(\frac{dk}{dl})}{dt} = \frac{A_0 \cdot v^2}{S_1}\frac{d^2k}{dt^2}$.

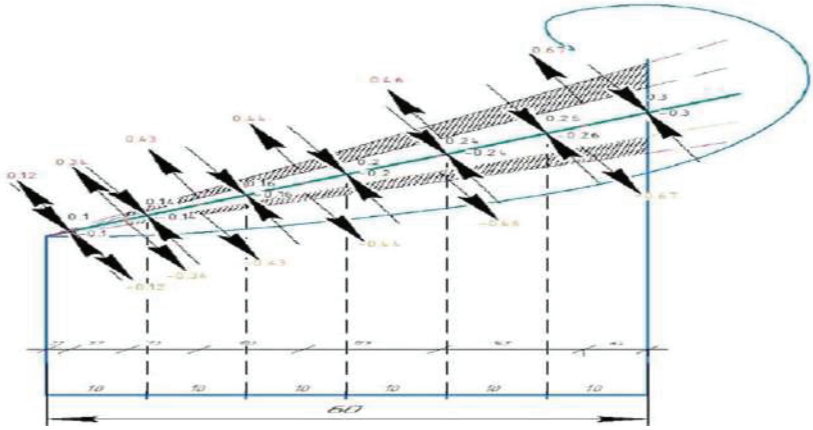

Fig.1. Transition curve.

Table 1. Requirements for the maintenance of curved track sections.

Serial number of a requirement	Spesification	Content of requirements		
		BTC	ETC	Transition curve
1 2 3	$y = \int_0^1 Sin\varphi dl$ $\varphi = \int_0^1 kdl$ K=1/p	0 0 0	Not limited	Should change continuously and monotonously. Absolute values and their gradientsof length changes should not exceed the allowable values
4 5	dk/dl d^{2k}/dl^2	0 0	0 0	Same except the “monotonously” requirement

2 Methods and materials

It follows from this expression that for the angular accelerations of the changes in the inclination of the axes in the NPK and the CPK to be equal to zero and to change continuously on the transition curve, and so that the absolute values of these accelerations and the gradients of their changes along the length of the transition curve do not go beyond the allowable values, it is necessary for the same requirements to apply to the second derivative of the curvature along the length of the transition curve, as is written as the fifth condition in Table 1.

The fulfillment of all the five requirements creates the best conditions for the passage of rolling stock along curves, which is especially important for the mountainous and relief terrain of the East Siberian Railway.

The lengths of the transition curves are determined by a number of conditions that can be divided into the following three groups. The first group of conditions is associated with the removal of the elevation of the outer rail within the transition curve:

– prevention of derailment of the wheels off the rails of the inner thread;

- limitation of the vertical component of the lifting speed of the wheel onto the elevation;

– limitation of the growth rate of the unsuppressed part of the centrifugal acceleration.

The second group of conditions is associated with the presence of gaps between the wheel flanges and rail threads:

- loss of kinetic energy when the wheel of the first axle hits the rail of the outer thread;

- the value of the horizontal component of the gravitational acceleration, which appears immediately before the point to which the vehicle moves in a straight line (not taking into account the wobbling);

–growth intensity of this acceleration;

- the value of the centrifugal acceleration suddenly appearing at point A.

The third group of conditions is connected with the need to ensure the practical possibility of breaking down the transition curve on the ground and its further serviceable maintenance, for which its geometric dimensions must be sufficient.

As an example, the characteristics of the curve of the Kedrovaya-Tankhoy section (Table 1) are presented, on which several derailments of the rolling stock have been registered. The indicated parameters and characteristics of the curve (path profile, radius, rail lateral wear, speed, outstanding acceleration, bogie turning angle) are the main ones when investigating the causes of emergencies and derailments.

Based on the analysis of the technical condition deviations from the normative ones, an assessment was made of dangerous combinations of deviations in the parameters of the car, the track, as well as the mode of movement, and the degree of involvement of each of them in the derailment of the rolling stock was determined. On this basis, an analysis of the causes of specific derailments was performed and a statistical relationship was established between the deviations of the controlled parameters of the elements of the car, the track and the degree of involvement in the derailment of one or another when moving in curves and on mountain pass sections. From these positions, the role of outstanding acceleration in the process of derailment of the car when moving in mountain pass areas was identified and evaluated.

The analysis of the involvement of various classes of deviations in the fact of derailment in the "locomotive-car-track" system is used in the investigation of emergency situations, thus more than 20 derailments that occurred on the Higher Railway for the period 2015–2021 were studied. It turned out that all these exits are localized on the first 5-20 m of the transition curve, which is explained by a number of features of the transition curves of the mountain pass sections: increased gauge compared to straight sections of the track, elevation of the outer rail and significant magnitude (up to 0.95 m / s2 at the maximum allowable value of 0.3 m / s2) of outstanding acceleration (Fig. 2.).

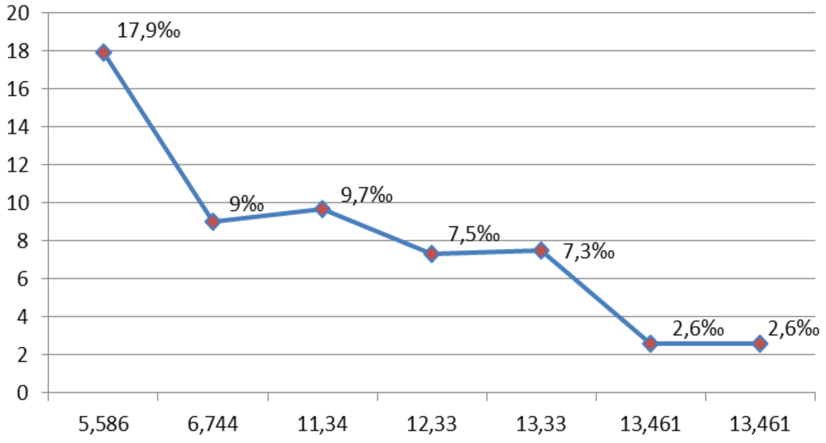

Fig. 2. The length of the transition curve, m.

The growth of outstanding acceleration within the transition curve should be limited, since the factors affecting its change are associated not only with the driving mode of the train, but also with the location of dangerous areas in which additional lateral forces arise. Currently, attention is paid to the speed modes of the train, especially in curves and transition curves, whose curvature radius is not a constant value, and the problem of passing the rolling stock of these sections of the track is important in the investigation of emergency situations. The main parameters that determine traffic safety and rail wear are the magnitude and nature of the change in forces arising from the interaction of the track and rolling stock, as well as the length of transition curves. In curved sections of the track, to balance centrifugal force the outer rail thread is located above the inner one. The maximum elevation of the outer rail in the curve is determined by taking into account the speed and the radius of curvature and should not exceed 150 mm. On lines with freight and mixed traffic of trains, the least impact on the track in curves, which reduces the intensity of wear disorder of track elements, is performed at a close to zero at the weighted average speed of freight trains. To do this, on lines with a specialization of O, G, T, the outstanding acceleration in freight trains should be in the range of ±0.3 m/s2 at actual speeds.

An increase in outstanding acceleration in freight trains over the range of 0.3 m/s2 is allowed subject to a feasibility study (on directions with a large difference between the maximum speeds of passenger and freight trains). The data varies depending on the maximum allowable slope of the outer rail elevation and the travel speed. With an increase in speed, the outstanding acceleration (in calculations, the value of the undamped acceleration assumed to be 0.3 m/s2 in a circular curve, and the elevation of the outer rail is 90....150 mm) increases and varies from 0.3 to 0.95 m/s2 (Fig. 3).

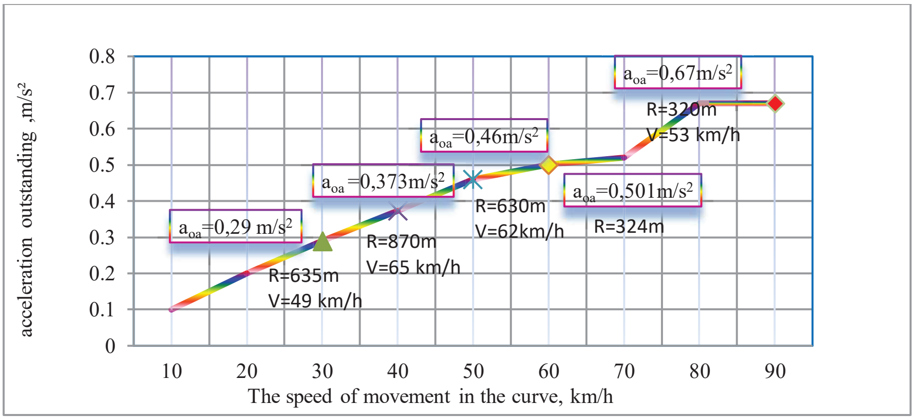

Fig. 3. Values of outstanding acceleration at the moment of deraiment determined by the speed of movement in the curve and the elevation of the outer rail.

For the operation process, it is of significant interest to assess the danger of outstanding transverse accelerations of cars leading to their derailments. From the presented results, it follows that the combination of rail elevation deviations in the curve with excess speed is of a particular danger and requires increased control over track maintenance and speed. The combination of speeding and subsidence of the track should also be considered dangerous. In particular, the subsidence of the track of 2-3 degrees leads, as a rule, to a derailment when moving at the maximum allowable speed. In table 2. the values of the main characteristics of the movement corresponding to the event of the derailment of cars on various sections of the Higher Railway are given.

Table 2. Technical characteristics of the exit.

№	Section	Speed. km/h	Axial load. kN	$a_{нп}$. м/с²	$K_{дг}$	Frame force kN
1	Keshevo-Targiz	55	227.5	0.119	0.18	40.95
2	Nizhneudinsk-Taishet	78	229.3	0.44	0.249	57.1
3	Kasyanovka-Half	62	230.3	0.46	0.201	46.3
4	Taldan-Gudachi	49	230.3	0.29	0.162	37.31
5	Atamanovka-Kruchina	53	232.5	0.67	0.174	40.45
6	Tankhoy-Kedrovaya	77	215.8	0.43	0.246	53.1
7	Kamarchaga-Taiga	46	222.9	0.5	0.153	34.1
8	Zalari Tyret	44	230.3	0.34	0.147	33.85
9	Kamarchaga-Balay	50	230.3	0.6	0.165	37.9
10	Delure-Tyret	65	230.0	0.37	0.21	48.36
11	Black-Sredneilimskaya	58	230.3	0.95	0.189	43.5
12	Slyudyanka-Angasolka	51	225.4	0.62	0.168	37.86

The derailment investigation facts (those occurring in curves and on the mountain pass sections of the Eastern Railway), presented in Table 2, show that the derailment is influenced by the speed modes of the rolling stock, the value o into account. The de pendence of outstanding acceleration and frame force is shown in Fig.4. f outstanding acceleration with axial loads, frame force and the coefficient of horizontal dynamics taken into account.

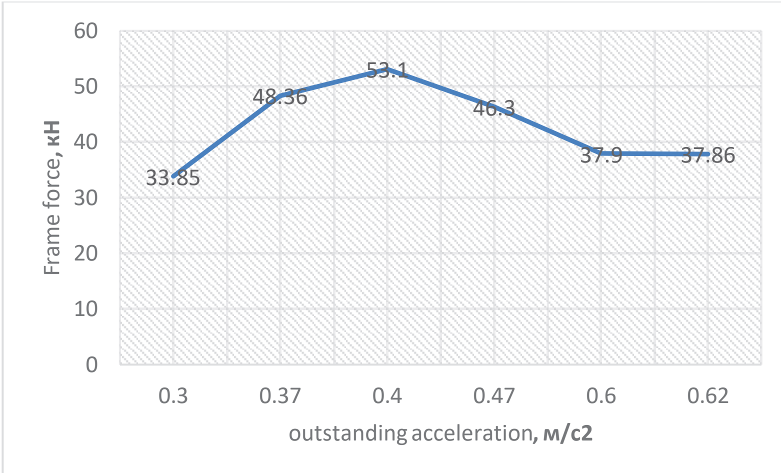

Fig. 4. Dependence of the frame force change on the increase in the outstanding acceleration.

The maximum unabated acceleration occurring in the curves was observed at short transition curve lengths and radii of 300-650 m with a lift profile of 7 to 9 ppm. With large positive values of outstanding acceleration, the body roll on the springs can approach the limit value, if it is exceeded, a heel transfer occurs with the body resting on the slippers. Under these conditions, the presence on the outer rail thread of a one-sided subsidence such as a depression or a hump, as a rule, leads to the overturning of the car. The deviation in the plan differed by the wavelength, which can vary from minimum to maximum values, the impact force (lateral force) is the largest with the minimum length of the roughness of the path.

3 Conclusion

The investigations facts of derailments that occurred in the curves and on the mountain-pass sections of the Eastern Railway, presented in Table. 2 show that the derailment is influenced by the speed modes of the rolling stock, the magnitude of the outstanding acceleration with axial loads, frame force and the coefficient of horizontal dynamics taken into account. An analysis of the situations of specific derailments shows that the derailments of the rolling stock of freight cars occur at the initial sections of the transition curves, whose length of in the mountain pass sections is 80-160 m. Therefore it is recommended to designate dangerous initial sections with a length of 5-20 m. It should be noted that the application of the described methodology makes it possible to assess the degree of involvement in an emergency situation resulting from an outstanding force when entering the curve, which is essential for ensuring traffic safety. This moment is explained by the fact that deviations along the route lead to a redistribution of forces acting on the mechanical part of the car and an increase in the reaction of the inertia of the rail during reverse kickback to the wheel, the centrifugal force, in turn, increases due to the instantaneous lateral force and outstanding acceleration, which must be normalized for freight wagons and goes out of limits when the height of the outer rail does not correspond to the size of the height in this section.

References

1. A.N. Baibakov, V.M. Gurenko, V.I. Paterikin, S.P. Yunoshev, S.V. Plotnikov, V.V. Sotnikov, Yu, Automatic control of the geometrical parameters of wheel sets during the movement of the train URL: https://cyberleninka.ru/article/n/lazernyy
2. A.V. Belousov, *The use of spring suspension with a bilinear characteristic to improve the dynamic qualities of freight cars: thesis of a candidate of technical sciences* (Moscow, 2000)
3. Analytical material on the operation of the rolling stock for the period from 2004 to Design Bureau of Carriage Facilities (2018)
4. V.M. Bogdanov, Railway transport **12**, 30-34 (1992)
5. A.V. Borodin, *Increasing the resource of cylindrical bearings of the axle box of a freight car* (Omsk State Transport University, Omsk, 2011)
6. A.M. Boronakhin, Proceedings of the St. Petersburg State Electrotechnical University "LETI" SPbGETU "LETI" **10**, 84-91 (2011)
7. Yu.P. Boronenko, Railway transport **8**, 50-53 (2008)
8. M.F. Verigo, *Interaction of the way and rolling stock in small radius curves and the fight against lateral wear of rails and wheel flanges* (PTKB TsPMPS, M., 1997)
9. M.F. Verigo, A.Ya. Kogan, *Interaction of track and rolling stock* (Transport, M., 1986)
10. A.Z. Venediktov, V.N. Demkin, D.S. Dokov, ZhDM **9** (2003)
11. S.V. Vershinsky, *Car Dynamics: A Textbook for Higher Educational Institutions of Railway Transport* (Transport, M., 1991)
12. I.I. Galiev, Izvestiya Transsib **4(16)**, 102-110 (2013)
13. I.I. Galiev, Izvestiya Transsib 2(18), 100-106 (2014)
14. I.I. Galiev, *II All-Russian scientific and technical conference with international participation "Technological support for the repair and improvement of the dynamic qualities of railway rolling stock": a collection of works* (Omsk, 2013)
15. I.I. Galiev, Izvestiya Transsib 3(15), 133-142 (2013)
16. L.V. Martynenko, Transport research procedure **63**, 465-471 (2022) DOI: https://www.sciencedirect.com/science/
17. Yu.S. Romen, B.E. Gluzberg, E.A. Timakova, V.A. Bykov, Particularities of Mathematical Modeling of Dynamic Processes of Carriage Passing a Turnout Switch **79(3)** (2020) DOI: https://doi.org/10.21780/2223-9731-2020-79-3-119-126
18. Yu.S. Romen, Vestnik VNIIZhT **78(3)**, 149 - 154 (2019) DOI: https://doi.org/10.21780/2223-9731-2019-78-3-149-154