Methodology for evaluating of the interaction of wagons and path on the mountain-gorge areas

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Abstract. In recent years, the number of rolling stock derailments, especially unladen wagons has begun to increase on railways located in hard geographical and climatic conditions in Eastern Siberia. In view of this, we propose the methods for evaluation of the interaction of wagons and railroad track for safety train movement and determination of appropriate schedule for train operation.

1. Introduction

Modern wagons represent a complex statically indefinable mechanical system which has a variety of operational and dynamic loads (vertical, horizontal, transverse and longitudinal). As a rule, these loads are statistical. The movement of trains depends on the profile of the track [1]. Tensile or compressive longitudinal forces on draw-and-buffer gear are caused by the train movement and switching operation. The magnitude and signs of these forces depend on the interaction of wagons with different modes of motion [2-3]. Nowadays, we need to find solutions to the problem of interaction of rolling stock and track on the mountainous sections resulting by the increased weight of the trains (fig. 1). Only in 2018 there were 8 cases of derailment of rolling stock with R = 250-400 m (40%) and R = 800-1200 m (60%).

The particular attention is paid to the problem of maintenance and operation of rolling stock on the areas of the East Siberian Railway (ESSR), located in hard climatic and geographical conditions. The track mileage is 6188 km, the length of federal-aid railway is 3848 km, the length of joint-less track is over 3000 km. The length of curved tracks is 45.1%, including a 25.4% of 250-650 m radius. According to the data about ESSR, the track has about 8,000 right – left curves on such areas. Historically, since 1995, the types of rails such as R65 (88%), R75 (3%) and others (9%) have been laid for the reinforcement of load-carrying capacity. The strength of the railway increased after the transition to the new rail type R65.

More than 20 years have passed. During this period the speed and the weight of trains have changed significantly. The problem is not only in rolling stock, but also in railroad condition, particularly in hard conditions on mountainous sections. This is due to the presence of sharp transitions profile of track, curvature radii, elevations of the outer rail, which have an impact on the ratio of inertial and centrifugal forces and traffic safety, in general.
2. Material and research methods

One of the major challenges in dealing with the problem of safety of rolling stock is to find effective methods and tools that enable likely describe dynamical processes that occur when moving rolling stock on railway based on actual system states wagon-way [4].

To solve the problem of preventing derailment it’s necessary to explain and change individual rules of maintenance of wagons, regulate the speed of traffic on such areas. It is necessary to investigate various technical condition of cars and tracks [5-7]. For these purposes it’s possible and appropriate to use mathematical and computer modelling methods, as well as a real investigation of the reasons of derailment.

Traffic safety and evaluation of dynamic qualities are often associated with the wagon stock wheelset sustainability indicator. Factor of resistance to the rolling into the head rail is an integral indicator of traffic safety. To avoid derailment and ensure sustainability of reserve boundaries are established, expressed using defined indicators $K_{stability}$.

$$K_{stability} = \frac{tg(\beta)-\mu}{1+tg(\beta)} \cdot \frac{P_v}{P_H} \geq [K_{stability}]$$

For safe driving cars, the value of the coefficient of stock sustainability should not fall below the permissible value of the GOST [8].

In work [9] one of the criteria considered gathering influence of longitudinal forces arising from violations of driving trains. When the cars at an angle to each other (fig. 2) in terms of lateral raises horizontal components of the longitudinal forces; and when the difference in elevation between them-vertical components that create additional loading or unloading the appropriate wheel crew depending on his hesitation.

**Figure 1.** The map of derailments of the rolling stock on network East-Siberian rail roads for 2000-2019.
3. Research results
To organize the safe movement and determine the optimal modes in operation, we propose the methods of evaluation of the interaction of wagons and tracks on the mountainous sections. There are several stages:

1) the theoretical model of parametric oscillation excitation and galloping body bouncing wagon to carts was developed (fig. 3);

2) the complex tests on the train carriage-laboratories was conducted;

3) the vertical coefficient measurement of dynamics and coefficient of stability was made based on the results of the calculation (fig. 6) (fig. 7);

4) the roller booth was developed (truck model 18-100) to evaluate the dynamic qualities of the wagon within the parameters of the curves plots tracks and various faults of wheels (fig. 8);

5) a set of recommendations for high-speed trains on modes of mountainous sections was developed.

Stage I. Train brake tests for the wagon. The purpose of the tests is determination of the lateral forces generated, taking into account the longitudinal effort passed from the coupler that affect wagon in the curves of the mountain - a crossover way when performing the prescribed instructions types of braking. To determine the dependence of lateral loads from the longitudinal forces, we executed the experienced travel on caboose, equipped with load cell automatic coupling type SA-3 [10]. According to the results of tests, we built waveform (fig. 4) change of the outstanding longitudinal acceleration when moving the car from outside site path.
Figure 4. Waveform change of the outstanding longitudinal acceleration.

Train tests on the measuring car. The purpose of the tests is the definition of real characteristics of mining and crossover plots ways to transform coordinates of the unevenness of the track as a function that describes the unevenness of the track under each wheel pair (fig. 5).

Figure 5. The right and left rails, vertical undulations.

Stage II. Calculation of the coefficient of vertical dynamics of wagon and the coefficient of resistance. The values obtained in tests of train accelerations (longitudinal with coupler) introduced the system of differential equations for parametric oscillation and galloping bouncing wagon. Is used as an optional parameter from the train test and time variable axial force \( N(t) \) and real roughness parameters path.

The system of differential equations for parametric oscillation, describing the process of bouncing and galloping carriage:

\[
\begin{align*}
    m \ddot{z} + \left( 4Cz + \frac{N(t)}{a} \right) \cdot z &= \left( 4Cz + \frac{N(t)}{a} \right) \cdot \eta, \\
    I_y \ddot{\phi} + \left( 4Cz \cdot l^2 + \frac{N(t)}{a} \cdot l \cdot L \right) \cdot \phi &= \left( 4Cz \cdot l^2 + \frac{N(t)}{a} \cdot l \cdot L \right) \cdot \eta,
\end{align*}
\]

where \( m \) – tare weight, kg; \( I_y \) – the moment of inertia of the bodywork relative to the y axis, kg·m²; \( Cz \) – the stiffness of the spring suspension, N/m; \( l \) – car base, m; \( L \) – distance between the rear or front rims coupler, m; \( a \) – hull length coupler, m; \( N(t) \) – time variable axial force; \( \eta \) – real roughness parameters path.

As the object of modelling wagons we selected gatherings over the past 19 years: indoor model 11-2135-01, gondola model 12-132, platform model 13-192-01, tank model 15-150-04, hopper model 19-6870. Wagons were loaded and integrated in an unladen state.

Integrating the resulting differential equations of the second order obtained by the classical method, Runge-Kutta methods of the fourth order helped receive modified coefficient of vertical dynamics in the process of movement on the studied site path (fig. 6). Results of calculation of the vertical dynamics were used in formula (1) and gave real results of calculation of safety factor of sustainability against derailment (fig. 7).
Analyzing the results (fig. 6-7) we define a range of maximum train speeds on researched mountinous areas.

**Stage III.** Physical simulation. To evaluate the dynamic qualities of the wagon within the parameters of the curves plots path and various faults wheel (navar) we elaborated a pilot roller booth [11-13]. Stand (fig. 8) allows you to simulate the movement of wagons in straight and curved sections of road with various external rail and eminence to take into account the effect of pressing comb wheels to the lateral surface of the rail with a possibility to change the load along the axis of the wheel.

![Roller booth for estimating the dynamic qualities of the wagon.](image)

Measurement of dynamic characteristics arise when driving, made with the help of measuring complex based on MIC-036R. Results are presented in graphical form (fig. 9). Zero envelope chart accelerations on the y-axis correspond to $K_{\text{stability}} = 1$. These are measurements limits in accordance with [8]. We see that maximum amplitude of deviations is quite frequent repetitions that has a significant impact on the stability of wheel pair against the derailment.
Figure 9. Measurement of the coefficient of stability of wheel pair against the derailment.

Stage IV. Development of technical recommendations for high-speed trains on regimes of mountainous areas. The stages of a complex technical recommendations for reducing power effects on parts of the wagon while driving on the studied sections are due to changes in speed. Knowing features paths (curve radius, elevation of the outer rails) and vertical dynamics, we expect optimum speed in the investigated areas (table 1). Maximum speed limit is determined by the following formulæ:

\[
V_{\text{max pass}} = 0.283 \cdot \sqrt{R \cdot (h + 115)},
\]

\[
V_{\text{max gruz}} = 0.283 \cdot \sqrt{R \cdot (h + 50)}.
\]

where \(R\) – curve radius, m; \(h\) – elevation of the outer rail, m.

Calculation of the optimal speed of trains for the plot takes into account elevation of the outer rail.

Table 1. Proposals for high-speed modes

| Track part | The name of the site, ferrying, station | The proposed path service rate | Speed according to the order of the ESRR | Research speed | The proposed rolling stock service speed |
|------------|----------------------------------------|-------------------------------|------------------------------------------|----------------|----------------------------------------|
| 1          | Tayshet - Bayronovka                   | 80                            | from 65 up to 72                          | up to 70       |
| 1          | 4522-4529 km                           | 80                            | 60                                        | up to 60       |
| 2          | 4537 km pk 2                           | 60                            | 60                                        | 60             |
| 2          | Bayronovka - Razgon                    | 60                            | from 52 up to 58                          | up to 60       |
| 2          | st. Razgon                             | 60                            | 60                                        | 60             |
| 2          | Razgon - Oblepiha                      | 60                            | from 52 up to 58                          | up to 60       |
| 2          | st. Oblepiha                           | 60                            | 60                                        | 60             |

4. Conclusion

Comparative analysis of the data presented shows the calculated speed settings that provide safety for a particular lot of investigated ways. Thus, the application of the proposed method allows a wide range of characteristics and path trains speed modes determining the safest speed range.

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