Checking the operation parameters of the traction power supply system with a long-term train schedule on the rated section of the railway line

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Abstract. The handling of trains of increased weight and length, consisting of rolling stock with an axle load of 25 tons, and up to 27 – 29 tons in the future, is a difficult technical and economic task facing Russian Railways OAO today. A heavy train cannot be slowed down often, much less stopped, since this leads to a significant loss of energy. In the article, the authors considered the issue of strengthening the traction power supply system on the rated section of the railway line of the Eastern polygon in connection with an increase in the amount of cargo turnover by 2025. Based on the results of the traction calculation, the predicted values of the indicators were obtained. They are the total travel time of the train along the section of the railway line, the free running time of the train, the consumption of active and total electricity, the specific consumption of active and total electricity for each inter-substation zone of the railway line section. The operation parameters of the traction power supply system with a long-term train schedule on the rated section of the railway line are determined. The research results obtained by the authors made it possible to determine the limiting sections and objects of transport infrastructure for the handling of heavy-haul and long freight trains on the rated direction.

1. Introduction

In connection with the implementation of development programs in the energy complex, metallurgical and forestry industries on the territory of the Eastern polygon, a positive trend in the volume of cargo loading and expansion of the geography of railway transportation in general is expected in the long term. Thus, an increase in the volume of coal transportation for export after the implementation of the 1st and 2nd stages of development of the Eastern polygon in 2025 will increase the income of Russian Railways OAO (RZD OAO) and rolling stock operators by more than 180 billion rubles [1, 3, 5, 7].

The development of increasing volumes of freight traffic on the Eastern polygon is impeded by the shortfall in the carrying and throughput capacity of railway lines (which is more than 70% of the entire length of the Eastern polygon), as well as the presence of sections with insufficient track development of railway stations [2, 5, 11]. Intensive growth in traffic volumes also causes rapid deterioration of the...
main equipment of the infrastructure of this direction, which is already operated in difficult natural and climatic conditions: power supply and railway tracks. An increase in traffic volumes without the construction of additional main tracks leads to a decrease in the electricity quality and to significant losses both in the traction system and in external power supply. In this connection, these objects require regular strengthening, updating and technical development.

The handling of trains of increased weight and length, consisting of rolling stock with an axle load of 25 tons, and up to 27 – 29 tons in the future, is a difficult technical and economic task facing Russian Railways OAO today. In order to eliminate the identified problems, a set of measures is being implemented to develop the railway infrastructure of the polygon, included in the investment project "Modernization of the railway infrastructure of the Baikal-Amur and Trans-Siberian railways with the development of throughput and carrying capacity" [2, 4].

Increasing the weight norms is one of the priority directions, allowing one to increase the throughput and carrying capacity of the Eastern polygon, to increase the efficiency of work in these conditions. By 2025, it is planned to complete work on lengthening the reception and departure sidings of railway stations to the standard of 1050 meters along the routes of moving bulk cargo to ports and border crossings. With that, a decision was made to develop regulatory requirements for the arrangement and maintenance of railway infrastructure facilities on the sections of the running of freight trains weighing over 6000 tons, including the development of a method for monitoring their condition [4-6].

In the 1980s the Americans switched to an axle load standard of 27 – 29 tons for eight years. A special track was built on the experimental circle, in which new rails and fasteners were laid. The ones that were more reliable were chosen. The construction gang worked in the same way with the new rolling stock. They strengthened the existing power supply system. As a result, they mastered the technology of motion with high axle loads, and with it, they already headed over to the mainlines. The result turned out to be efficient. Then they spent the same amount of time switching to axle loads over 30 tons. We should have the same approach [7, 19].

2. Checking the existing operating parameters of the traction power supply system of the Gidrostroitel – Korshunikha section of the Eastern polygon
In the article, the authors considered the issue of strengthening the traction power supply system (TPSS) [3, 5, 12] and at the Gidrostroitel-Korshunikha section of the Eastern polygon due to the increase in the amount of the cargo turnover by 2025 (see Table 1).

The total length of the rated section is about 200 km. The traction calculation was carried out using the KORTES software package. The parameters of a given power supply section (separate points, speed limits, longitudinal profile, categories and types of trains), mass of trains and types of electric rolling stock used in the calculation were used as the initial data. For further calculation of the optimal load conditions of the traction power supply system at a given throughput capacity, it is necessary to make a traction calculation for the base train weights of 3000 tons and 6300 tons [8-10, 13, 16, 18].

Based on the results of the traction calculation, the predicted values of the following indicators were obtained:
- total running time of the train along the section of the railway line;
- free running time of the train;
- consumption of active and total electrical energy;
- specific consumption of active and total electrical energy for each inter-substation zone of the railway line section.

The results of the traction calculation for the up and down directions of movement of trains weighing 3000 and 6300 tons are presented in Table 2, and the specific consumption of active and total energy is shown in Table 3.
Table 1. Long-term volumes of traffic of a section of the railway line for 2025

| Section of the railway line | Weight trains, tons | Traffic volumes, train pairs per day | Volumes of train traffic during intensive hour | Train interval |
|-----------------------------|---------------------|-------------------------------------|-----------------------------------------------|---------------|
|                             | freight             | passenger                           | of freight trains                              |               |
|                             | 7100                | 35                                  | 4                                             |               |
|                             | 6000                | 8                                   | 4                                             | 1             |
|                             | 4000                | 4                                   | 5                                             |               |
|                             | 3000                | 1                                   | 1                                             |               |
|                             | 3000 con.           | 1                                   | 1                                             |               |
|                             | 3000 ass.           | 5                                   | 5                                             | 0             |
|                             | 1500 - 1700 emp.    | 5                                   | 5                                             | 0             |
| Total                       | 52                  | 52                                  | 6                                             | 6             |

Table 2. Results of traction calculation by the directions of movement on the rated section of the railway line

| Designation of the station-to-station block | Length, km | 3000 Full running time, min | 6300 Full running time, min | 3000 Free running time, min | 6300 Free running time, min | Train mass, tons | 3000 Active electricity consumption, kW*h | 6300 Active electricity consumption, kW*A*h |
|--------------------------------------------|------------|-------------------------------|-------------------------------|-----------------------------|-------------------------------|------------------|------------------------------------------|------------------------------------------|
| Gidrostroitel – Zyaba                      | 25.1       | 20.6                          | 20.6                          | 7.9                         | 7.9                           | 482.1           | 545.1                                    | 436.0                                    | 648.8                                    |
| Zyaba – Kezhemskaya                        | 39.0       | 33.3                          | 33.5                          | 11.7                        | 12.3                          | 1290.2          | 1560.9                                   | 1535.0                                   | 1857.9                                   |
| Kezhemskaya – Vidim                        | 58.1       | 52.5                          | 56.5                          | 34.6                        | 39.8                          | 4012.0          | 5769.9                                   | 4773.7                                   | 6869.5                                   |
| Vidim – Sokhatyi – Chyornaya               | 19.0       | 16.2                          | 17.1                          | 6.5                         | 7.7                           | 739.0           | 1132.6                                   | 879.2                                    | 1348.5                                   |
| Sokhatyi – Chyornaya – Sredneilimskaya     | 21.0       | 18.0                          | 19.3                          | 16.5                        | 19.3                          | 1505.5          | 2127.1                                   | 1791.6                                   | 2530.3                                   |
| Chyornaya – Sredneilimskaya – Korshunikha   | 33.0       | 36.3                          | 37.6                          | 31.8                        | 32.4                          | 3557.6          | 4818.5                                   | 4233.6                                   | 5738.6                                   |
| Sredneilimskaya – Korshunikha              | 17.5       | 18.1                          | 17.1                          | 3.3                         | 2.6                           | 382.5           | 338.2                                    | 455.4                                    | 402.8                                    |

For down direction

For up direction

| Gidrostroitel – Zyaba                      | 25.1       | 22.9                          | 24.6                          | 20.7                        | 22.0                          | 1948.1          | 2921.6                                   | 2318.3                                   | 3477.8                                   |
| Zyaba – Kezhemskaya                        | 39.0       | 35.3                          | 38.3                          | 26.5                        | 29.9                          | 3037.1          | 4214.2                                   | 3613.9                                   | 5017.5                                   |
| Kezhemskaya – Vidim                        | 58.1       | 50.0                          | 52.3                          | 19.5                        | 23.2                          | 2253.5          | 3222.4                                   | 2681.0                                   | 3836.1                                   |
| Vidim – Sokhatyi – Chyornaya               | 19.0       | 18.5                          | 20.2                          | 15.8                        | 17.7                          | 1858.5          | 2632.8                                   | 2211.2                                   | 3135.2                                   |
| Sokhatyi – Chyornaya – Sredneilimskaya     | 21.0       | 19.5                          | 19.1                          | 2.1                         | 1.7                           | 111.7           | 120.8                                    | 133.1                                    | 143.8                                    |
| Chyornaya – Sredneilimskaya – Korshunikha   | 33.0       | 31.0                          | 30.8                          | 1.9                         | 0.8                           | 233.3           | 117.8                                    | 277.5                                    | 140.2                                    |
| Sredneilimskaya – Korshunikha              | 17.5       | 16.5                          | 15.8                          | 13.4                        | 15.8                          | 1464.7          | 1670.6                                   | 1742.6                                   | 1987.3                                   |
To check the operation parameters of the traction power supply system of the Gidrostroitel – Korshunikha section, the authors performed electrical calculations of the operating modes and characteristics of the throughput capacity of railway sections electrified using the 27.5 kV alternating current traction power supply system. The characteristics of the throughput capacity are determined depending on the problem to be solved under the design modes. In this case the calculation was performed in mode B "Determination of the smallest permissible intervals during intensive periods of section operation" and the load mode with a parallel train traffic schedule on the section. The calculation is implemented with two operating transformers and switched on devices for compensation of reactive power of the series capacitor bank at the Kezhemskaya traction substation [14, 15, 17-19]. Figure 1 shows an existing version of the train traffic schedule on the section with the current power supply system.

The results of calculating the minimum allowable train interval for the existing power supply scheme for the existing amount of traffic are presented in Table 4.

Table 3. Energy consumption depending on the series of locomotives.

| Locomotive Series | 2ES5K | 2ES5K | 2ES5K | 2ES5K |
|-------------------|-------|-------|-------|-------|
| Directions of traffic | Up     |       |       | Down  |
| Train weight, tons | 6300   | 3000  | 6300  | 3000  |
| Consumption of active energy, W*h/t*km | 10.2   | 11.0  | 11.3  | 12.0  |
| Consumption of total energy, V*A*h/t*km | 12.2   | 13.1  | 13.5  | 14.3  |

Figure 1. The long-term version of the train traffic schedule on the rated section.
3. Checking the operation parameters of the traction power supply system with a long-term train traffic schedule on the rated section of the railway line

Figure 2 shows a long-term version of the train schedule on the section with the current power supply system. The results of calculating the minimum allowable train interval for the existing power supply scheme for the long-term amount of traffic are presented in Table 5.

Table 4. Allowable train intervals under the existing version of the train traffic schedule on the rated section

| Designation of the inter-substation zone | Interval value, min, limited | The resulting value |
|----------------------------------------|-----------------------------|-------------------|
|                                        | By power of the step-down transformers | By overhead contact system voltage | By heated wires of the overhead contact system |
| Gidrostroitel – Zyaba                   | 7                           | 6                 | 6                | 7                |
| Zyaba – Kezhemskaya                    | 8                           | 10                | 6                | 10               |
| Kezhemskaya – Vidim                    | 8                           | 16                | 6                | 16               |
| Vidim – Chyornaya                      | 7                           | 11                | 6                | 11               |
| Chyornaya – Korshunikha                | 6                           | 13                | 6                | 13               |

Figure 2. The long-term version of the train traffic schedule on the rated section.
Table 5. Allowable train intervals for the long-term version of the train traffic schedule for the rated section

| Designation of the inter-substation zone | Interval value, min, limited | The resulting value |
|----------------------------------------|------------------------------|--------------------|
|                                        | By power of the step-down transformers | By overhead contact system voltage | By heated wires of the overhead contact system |
| Gidrostroitel – Zyaba                   | 6                            | 6                  | 6                  |
| Zyaba - Kezhemskaya                    | 12                           | 12                 | 6                  | 12                  |
| Kezhemskaya - Vidim                    | 12                           | 24                 | 6                  | 24                  |
| Vidim – Chyornaya                      | 6                            | 16                 | 6                  | 16                  |
| Chyornaya - Korshunikha                | 6                            | 13                 | 6                  | 13                  |

The calculation of the minimum voltage on the current collector of the locomotive with the available power supply scheme for the existing and long-term amount of train traffic on the section, as well as the calculation of the loads of transformers and heating of the catenary wires [14, 17, 18]. Based on the obtained values, a comparative analysis of the minimum voltages across the current collectors of locomotives for up (1) and down (2) railway tracks, respectively, with the existing and long-term train schedule was carried out. U1 is the voltage across the current collector under the long-term train schedule. U2 is the voltage across the current collector under the existing train schedule (Figures 3 and 4).

Figure 3. Minimum voltage across current collector 1, main track.

Figure 4. Minimum voltage across current collector 2, main track.
Figure 5 shows a comparative analysis of oil heating in a traction transformer under the existing and long-term train schedule. $T_1$ is the oil temperature of the traction transformer under the long-term train schedule. $T_2$ is the oil temperature of the traction transformer under the existing train schedule.

**Figure 5.** Oil temperature of traction transformer.

4. **Conclusion**

The research results obtained by the authors made it possible to determine the limiting sections and objects of transport infrastructure for the handling of heavy-haul and long freight trains on the rated direction. Thus, after the calculations under the existing scheme with a predetermined train interval of 10 minutes, on the section of the railway line Gidrostroitel – Korshunikha for the amount of traffic 3000 tons on the down track and 7,100 tons on the up track, there are four limiting station-to-station blocks of Zyaba – Kezhemskaya – Vidim, Vidim – Chyornaya, Chyornaya – Korshunikha. The train interval on this section was 12, 24, 16, 13 minutes, respectively.

Considering the obtained calculation results, we can conclude that to ensure the passage of trains of a given amount of traffic with a given inter-train interval of 8 minutes, measures are required to increase the voltage level at the limiting station-to-station blocks [12, 14, 18].

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