Increase of the throughput and processing capacity of the railway line mountain pass section by strengthening the devices of the system of traction power supply

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Abstract. According to the forecast target indicators values of the JSC "Russian Railways" integrated development project until 2023, it is necessary to increase the East Siberian railway capacity of the mountain-pass section of the Bolshoy Lug – Slyudyanka-II up to 137 pairs of trains per day. The freight trains number should be 107 pairs per day, a raft of pushing locomotives in the odd direction up to 19 units. The section transportation capacity will increase to 116.7 million tons per year. According to the specified operation parameters, with the growth of cargo turnover on the Irkutsk – Slyudyanka section by 2023, the available capacity shortage will be 14 pairs of trains. In freight traffic, if all provided reserve lines of the the regulatory schedule are used, the capacity deficit will be 11 pairs of various categories trains. The article offers a solution of the existing section power supply devices strengthening problem until the inter-train interval of 8 minutes is reached, for this purpose, the technical parameters of the section substations are considered, and the performance indicators that can provide reliable and cost-effective working conditions are determined. The operation conditions of a traction power network (TPN) of the Bolshoy Lug – Slyudyanka-II section under the existing traffic schedule and under the prospective train schedule are compared. Traction calculations have a special role, since they serve as the basis for drawing up optimal train schedules, determining the railway lines capacity, effectively placing separate points, traction substations, fuel depots, determining the locomotives electricity and fuel consumption rate, solving other practical problems. Traction operation calculation of the electrified mountain pass section of the Bolshoy Lug – Slyudyanka-II railway line was performed using the KORTES software package. The power supply parameters of a given section were used as input data: the separate points number and location, the current speed limits for trains on this section, the longitudinal profile of the railway track, the categories and types of trains that pass through the section, the trains weights and the electric rolling stock types used in the calculation.

1. Introduction

The planned and implemented measures of the JSC "Russian Railways" within the modernization program framework, complete renovation of railway transport infrastructure facilities, introduction of
new operation organization ways of the traction power network for railway lines with a constantly increasing traffic volume, impose new requirements for the work of the industry structural divisions. In order to optimally address technical equipment issues and improve the work technology, it is necessary to ensure such a ratio between the volume of work performed and the available fixed assets of the railway transport infrastructure facilities, their technical means, so that the value of total operating costs tends to a minimum value, which in turn will reduce the transportation cost and reach a higher level of this transport type attractiveness.

The planned volume of the company's investment development program for 2020 amounted to 657.4 billion rubles, the investment program structure includes seven main sections, the main of which are ensuring the transportation process safety and increasing the throughput and transport infrastructure facilities processing capacity. The optimal solution of this problem can be achieved only if the actual operating conditions of railway transport infrastructure objects are taken into account, i.e. if all technical devices are loaded unevenly. The unevenness amount in the train traffic organization on a section is affected by a number of factors: the concentrated passenger trains passage, including suburban ones; the duration of transport infrastructure devices repair; the process of organizing train traffic on adjacent sections, etc. [1, 2, 18].

Russian President Vladimir Putin instructed to include in the comprehensive plan for the main infrastructure measures of modernization and expansion in the development of the Baikal-Amur mainline and the TRANS-Siberian railway, these railway lines capacity should be increased by 1.5 times by 2024. The most important measure to ensure a high level of unified standards for the freight trains weights on these sections is to organize their pushing on calculated and difficult ascents.

The history of Russian railway transport development shows that at all times the increase in traffic volumes was realized by pushing trains, this technology was used as the most effective way to increase the train mass on the transit section, which was assuring minimal operating costs level and it was increasing the carrying capacity of railway lines.

For the same purpose, train pushing is also used in Europe, Asia and the Americas, where the use of this technology allows changing the amount of locomotive power per ton of train weight, depending on the complexity of the mountain-pass sections profile of the railway lines. As a result, it is possible to avoid not only changes in the mass of the train at technical stations, but also to increase the traction force use efficiency of the head locomotive throughout the railway direction.

2. The problem of increasing the bandwidth of the railway line mountain pass section

The East Siberian Railway (hereinafter referred to as the ESR) is one of the main and largest transport enterprises in Eastern Siberia today. The operational length of the analyzed transport company is more than 4% of the entire railway transport system network (hereinafter RTSN). Over the past 10 years, freight turnover on the main line has increased by 60%, which was made possible only thanks to a large-scale program of railway infrastructure modernization. Cargo turnover since the beginning of 2020 amounted to 160 billion tariff tons-kilometers.

The most difficult section in the operational work field of the ESR, in all years, was and remains the mountain-pass section of the railway line between the Bolshoy Lug and the Slyudyanka-II railway stations, which is 83 kilometers long. The track profile is characterized by a prolonged rise in the area Bolshoy Lug of Podkamenaya, which greatly complicates its operational and technical specifications, generates a large amount additional train operation, because the freight traffic organization feature on the analyzed railway line section is the procedure of pushing by locomotives more than 80% of freight trains on the even directions from the Bolshoy Lug train station, and also pushing of the freight trains in the odd direction from the Slyudyanka-I to the Bolshoy Lug stations. The standard value of pushing locomotives for freight trains on the section is 37 units. The speed on the section does not exceed 60 km/h. The difficult terrain does not allow speeding up the trains’ passage along the section [2-4, 6].

The average unified length of freight trains that follow the same even and odd numbered sections of the road under consideration is 71 conventional railway wagon. The freight trains weight standards data is presented in table 1.
Table 1. Average freight trains weight standards on the considered section of the same railway line.

| Locomotive | Freight trains weight standards, t | Power of the locomotive (for railway line trains) |
|------------|----------------------------------|--------------------------------------------------|
|            | Odd direction | Even direction | Odd direction | Even direction |
| VL85       | 6000          | 6000           | 6300          | 6300           |
| VL80t      | 2000          | 4200           | 2000          | 4200           |
| VL80t      | 4200          | 4400           | 4200          | 4400           |
| 2ES5K      | 4200          | 4400           | 4200          | 4400           |
| 2VL80v     | 7500          | 7500           | 7500          | 7500           |
| 2*2ES5     | 7500          | 7500           | 7500          | 7500           |

Five years ago, 75 freight trains pairs passed through the section per day, the capacity factor was approximately 0.8. Today, this value has reached 96 pairs, and the coefficient is close to one. However, the site is operating almost at the limit of its capabilities. The qualitative composition of the railway wagon traffic on the section fully depends on the functional purpose and the cargo turnover size, so the freight trains transit traffic without processing mainly pass through the precinct stations, while 20-30% are transit trains with processing and local section trains. Figure 1 shows a diagram of the train traffic organization on the Bolshoy Lug-Slyudyanka-II railway section, Figure 1.

![Figure 1. Average daily train traffic diagram.](image)

The site is consist of five traction substations. Table 2 shows data about the installed transformers types at substations and the power of three-phase short circuits.

The forecast growth value in the volume of traffic to the Eastern Russian Federation ports puts forward among the most important tasks the further increase in the capacity of this section, the planned value is aimed at 137 pairs of trains per day. The number of freight trains should be 107 pairs per day, a pushing locomotives raft in the odd direction should be 19 units. The section transportation capacity will increase to 116.7 million tons per year [2, 4, 6].

Table 2. Parameters of substations of the Bolshoy Lug-Slyudyanka II section.

| Substations | Short-circuit power, MVA | Type of transformer          | Number |
|-------------|--------------------------|------------------------------|--------|
| Rassoha     | 1584                     | TDTNJ-40000/110-71U1        | 1      |
| Podkamenaya | 1663                     | TDTNJ-40000/110-71U1        | 1      |
| Andrianovskaya | 1235              | TDTNJ-40000/110-71U1        | 1      |
| Angasolka   | 1125                     | TDTNJ-40000/110-71U1        | 1      |
| Slyudyanka  | 1570                     | TDTNJ-40000/110-71U1        | 1      |
3. A proposal to increase the throughput and processing capacity of the railway line mountain-pass section by strengthening the power network system devices

The purpose of mathematical calculations of the power network system for railway lines and sections is to establish such parameters for the functioning of this system that would ensure the reliability and cost-effective conditions for the operation of an electrified railway section [7, 8]. In this case, traction calculations play a special role, since they serve as the basis for drawing up optimal train schedules, determining the railway lines capacity and effective placement of separate points, traction substations and fuel depots, determining the rate of electricity and fuel consumption by locomotives and solving other practical problems [11, 12].

Traction calculation of the operation of the electrified mountain pass section of the Bolshoy Lug-Slyudyanka-II railway line was performed using the KORTES software package. The given section power network parameters were used as input data: the number and location of separate points, the current speed limits for trains on this section, the railway track longitudinal profile, the categories and trains types passed through the section, the trains weight and electric rolling stock types used in the calculation [5, 6, 13].

In order to further calculate the traction power network load modes when passing trains, it is necessary to make a traction calculation for the basic freight trains weights. The traction calculation results are: the total travel time; the travel time under current; the active and full electricity consumption; the specific consumption of active and full electricity for each inter-substation zone [9-10, 14-15].

The traction calculations results for even and odd directions of the train movement on the considered section for different weight norms are presented in Table 3.

| Table 3. Traction calculation results for even and odd directions of train movement. |
|---|
| Name of the stage | Length, km | Locomotive serie | Train weight, t | Total running time, min. | Running time under the current, min. | Consumption of active energy, kW*h | Total power consumption, kW*h |
| Weight 6300 tons | |
| Even direction | |
| Bolshoy Lug-Podkamennaya | 25.8 | 31 | 6300 | 26.0 | 7762.1 | 9481.6 |
| Podkamennaya - Glubokaya | 12.4 | 14 | 6300 | 13.3 | 3794.1 | 4641.9 |
| Glubokaya – Andrianovskaya | 11.9 | BJ85 | 6300 | 14 | 11.4 | 2155.8 | 2645.4 |
| Andrianovskaya – Angasolka | 11.9 | 609.5 | 769.9 |
| Angasolka – Slyudanka-II | 21.4 | 26 | 609.9 | 0.0 | 401.2 | 515.8 |
| Odd direction | |
| Bolshoy Lug-Podkamennaya | 25.8 | 31 | 6300 | 0.6 | 607.7 | 774.7 |
| Podkamennaya - Glubokaya | 12.4 | 14 | 609.5 | 0.2 | 269.9 | 345.7 |
| Glubokaya – Andrianovskaya | 11.9 | BJ85 | 6300 | 14 | 2.9 | 690.5 | 859.0 |
| Andrianovskaya – Angasolka | 11.9 | 609.9 | 769.9 |
| Angasolka – Slyudanka-II | 21.4 | 26 | 609.9 | 22.2 | 7792.7 | 9513.9 |
| Weight 4400 tons | |
| Even direction | |
| Bolshoy Lug- | 25.8 | 4400 | 31 | 31.0 | 4508.3 | 5161.3 |
| Route                        | Length (km) | Weight (tons) |
|------------------------------|-------------|---------------|
| Podkamennaya - Glubokaya     | 12.4        | 2288.4        |
| Glubokaya – Andrianovskaya   | 11.9        | 1288.4        |
| Andrianovskaya – Angasolka   | 11.9        | 323.4         |
| Angasolka – Slyudanka-II     | 21.4        | 200.3         |

**Weight 4200 tons**

| Route                        | Length (km) | Weight (tons) |
|------------------------------|-------------|---------------|
| Bolshoy Lug - Podkamennaya   | 25.8        | 4721.6        |
| Podkamennaya - Glubokaya     | 12.4        | 2373.0        |
| Glubokaya – Andrianovskaya   | 11.9        | 1272.9        |
| Andrianovskaya – Angasolka   | 11.9        | 290.2         |
| Angasolka – Slyudanka-II     | 21.4        | 200.3         |

**Weight 2000 tons**

| Route                        | Length (km) | Weight (tons) |
|------------------------------|-------------|---------------|
| Bolshoy Lug - Podkamennaya   | 25.8        | 284.2         |
| Podkamennaya - Glubokaya     | 12.4        | 201.2         |
| Glubokaya – Andrianovskaya   | 11.9        | 267.5         |
| Andrianovskaya – Angasolka   | 11.9        | 2535.5        |
| Angasolka – Slyudanka-II     | 21.4        | 4461.1        |

**Weight 7500 tons**

| Route                        | Length (km) | Weight (tons) |
|------------------------------|-------------|---------------|
| Bolshoy Lug - Podkamennaya   | 25.8        | 7622.7        |
| Podkamennaya - Glubokaya     | 12.4        | 3811.8        |
| Glubokaya – Andrianovskaya   | 11.9        | 2239.5        |
| Andrianovskaya – Angasolka   | 11.9        | 630.7         |
| Angasolka – Slyudanka-II     | 21.4        | 333.8         |
Graphical images of the performed calculations are shown in figures 2-5.

**Figure 2.** Graphic representation of the traction calculation result for a 6300-tonns train of even (a) and odd directions (b).
Figure 3. Graphic representation of the traction calculation result for a 4200-tons train of even (a) and for a 2000-tons train odd directions (b).
Figure 4. Graphic representation of the traction calculation result for a 7500-tons train of even (a) and odd directions (b).
The operation parameters of the traction power network systems (TPNS) of the Bolshoy Lug – Slyudyanka-II section under the existing traffic schedule are shown in Figure 6.

The calculations results of the minimum allowable inter-train interval under the existing power scheme for the existing train traffic value are presented in Table 4.
Figure 6. Parameters of the section’s TPNS operation under the existing train schedule.

Table 4. Calculations results of the minimum allowable inter-train interval for the existing train traffic value.

| Inter-station section name | Step-down transformers power value | Voltage in the contact network | Heating the contact network wires | Resulting value |
|---------------------------|-----------------------------------|--------------------------------|----------------------------------|-----------------|
| Bolshoy Lug-Podkamennaya  | 7                                 | 6                              | 6                                | 12              |
| Podkamennaya - Glubokaya  | 8                                 | 10                             | 6                                | 8               |
| Glubokaya – Andrianovskaya| 8                                 | 16                             | 6                                | 14              |
| Andrianovskaya – Angasolka| 7                                 | 11                             | 6                                | 16              |
| Angasolka – Slyudyanka-II | 6                                 | 13                             | 6                                | 13              |

The calculations results of the minimum allowable inter-train interval for prospective traffic value showed that there are several limiting stages on the considered mountain-pass section Bolshoy Lug – Slyudyanka-II:
- Bolshoy Lug-Podkamennaya, inter-train interval of 12 minutes;
- Glubokaya-Andrianovskaya, inter-train interval of 14 minutes;
- Andrianovskaya-Angasolka, inter-train interval of 16 minutes;
- Angasolka-Slyudyanka-II, inter-train interval of 13 minutes.

Figure 7 shows the determination of the parameters of the section's TPNS operation in the perspective train schedule on the Bolshoy Lug – Slyudyanka-II section.

The calculations results of the minimum allowable inter-train interval under the existing power network scheme for the prospective traffic values, taking into account the measures implementation to strengthen the traction component, see table 5.

Taking into account the obtained calculations results, we can conclude that to ensure the passage of trains of the specified traffic value with a given inter-train interval of 8 minutes, are needed measures to increase the voltage level on the limiting stages [4, 15-17].
Figure 7. Parameters of the section's TPNS operation in the perspective train schedule.

Table 5. Calculations results of the minimum allowable inter-train interval for prospective traffic values.

| Inter-station section name | Interval value, min, limited |
|----------------------------|-----------------------------|
|                            | Step-down transformers power value | Voltage in the contact network | Heating the contact network wires | Resulting value |
| Bolshoy Lug-Podkamennaya   | 7                           | 6                           | 6                           | 8               |
| Podkamennaya - Glubokaya   | 7                           | 8                           | 8                           | 8               |
| Glubokaya – Andrianovskaya | 8                           | 9                           | 8                           | 9               |
| Andrianovskaya – Angasolka | 7                           | 8                           | 8                           | 8               |
| Angasolka – Slyudanka-II   | 7                           | 8                           | 7                           | 8               |

4. Conclusion
With the existing scheme with a given inter-train interval of 8 minutes, based on the performed traction calculations, it is determined that the inter-train interval can be reduced to 8 minutes by strengthening the traction power network systems of the mountain-pass section. Based on the obtained calculations, on the section under consideration was organized train schedule and its indicators were determined. The number of even-numbered freight trains can be increased to 144, which are 35 trains more than with the existing power network technology. In the odd direction, the increase will be 26 trains and will reach the level of 105 trains per day. Accordingly, the number of pushing locomotives will increase from 28 to 37 units. Strengthening the TPNS will increase the section speed by 7.8 km/hour, and the locomotive's performance by 536 tons-km-gross. The locomotive's turnover will be reduced by 1.02 hours.

The required financial resources value to enhance traction substations will amount to 66 million rubles. Annual operating costs for new equipment maintenance and service – 108 million rubles/year. This project payback period is 5 years.

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Modern technologies and scientific and technical progress

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