Evaluation of the compatibility of the power traction supply system with a use of a "virtual coupling" technology

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Abstract. This article will propose the practical use of the interval control technology that will reduce the interval of passing trains and will increase the capacity of railway lines. Controlled approbation of the technology was carried out on railway sections for freight traffic: Shkotovo - Nakhodka, Novonezhino - Krasnoarmeysky of the Far Eastern railway and Koshurnikovo - Shchetinkino of the Krasnoyarsk railway in terms of "push locomotives" transferring to the opposite direction using the "virtual coupling" system; Mogocha - Urusha of the Trans-Baikal railway in terms of traffic organizing using the "virtual coupling" system for empty trains during long "Windows" on infrastructure; Slyudyanka - Bolshoy Lug of the East Siberian railway in terms of testing interval control technology to ensure the return of odd freight trains "push locomotives" using the "virtual coupling" system. The practical experience of the system use considered in the article allowed us to identify the main directions for its further development: protected radio channel stability improvement in obstacles of the rough terrain and the presence of tunnels; auto-driving algorithms operation.

1. Introduction
Since the new railway lines construction is not economically justified, it is necessary to find alternative ways to meet the growing demands of local businesses and industrial enterprises, one of which is the "virtual coupling" technology, which can potentially increase the maximum of the possible cargo delivery volume more than five times [1-5].

The existing infrastructure assessment ability to implement the proposed technology is the main goal of the presented work. The development of the connected train driving technology has made it possible to connect trains using the "virtual coupling", which does not imply physical coupling using an automatic coupling device, the distance between trains is determined taking into account the track profile and the weight of the train. The above factors are evaluated on the basis of the maximum stopping distance.
2. Use of modern software tools for mathematical modeling to assess the compatibility of the traction power supply system

The "virtual coupling" technology when comparing the connected trains movement is to assess the reserve capacity and train schedules. The use of modern software tools for mathematical modeling will allow us to solve not only the tasks set, but also to assess the compatibility of the currently used traction power supply system [2, 6, 7].

The developer of the "virtual coupling" system is the Research and Design Institute of informatization, automation and communication in railway transport (NIIAS). The main proposed technology of train movement is based on the following principles: the transportation process is performed only in fully automatic mode; the exchange of information processes between moving trains occurs continuously with a delay of no more than 100 MS; the distances between trains are controlled by radio data on the location, speed and acceleration of the rolling stock in front; the distance and speed monitoring to the train in front is determined by means of the obstacle detection unit; the running time of all trains is accurately synchronized.

Controlled approbation of the technology was carried out on railway sections for freight traffic:
• Shkotovo - Nakhodka, Novonezhino - Krasnoarmeysky of the Far Eastern railway and Koshurnikovo - Shchetinkino of the Krasnoyarsk railway in terms of "push locomotives" transferring to the opposite direction using the "virtual coupling" system;
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• Slyudyanka - Bolshoy Lug of the East Siberian railway in terms of testing interval control technology to ensure the return of odd freight trains "push locomotives" using the "virtual coupling" system.

The practical experience of the system use considered in the article allowed us to identify the main directions for its further development:
• protected radio channel stability improvement in obstacles of the rough terrain and the presence of tunnels;
• auto-driving algorithms operation.

The established traffic schedule on the Far Eastern railway allows passing 5 pairs of trains using virtual coupling technology every 24 hours. If the new practice proves itself as well as representatives of the railway transport system hope, in the near future each section of the railway infrastructure will be able to pass 15 more trains than it does now. And all this happens without upgrading and building new tracks.

One of the modern Railways fundamental principles is that passing trains should be separated by a sufficient interval so that each train can stop before reaching the last known position of the train tail in front. The "virtual coupling" technology assumes that trains in a combined group follow each other at a distance less than the braking distance, which is due to the fact that the train in front does not stop instantly. The technical device that makes it possible to implement the system is a modem radio installed on both the master and slave locomotives. The protected digital channel of the radio modem will allow you to determine the trains driving modes and to reduce the inter-train intervals.

The distance between trains is set not by free traffic light sections, but by train electronic control systems: radio modems installed on electric locomotives support communication between the master and slave trains and transmit train driving modes via a secure digital channel. As a result, the intensity of train traffic increases: if under the classical scheme, the inter – train interval on sections of railway lines can be 10-15 minutes, then with the new technology - 5 minutes, and the distance between trains is reduced from 4-5 km to 1.5 km.

The difficulty is in the fact that four or five trains are very long, and therefore there are difficulties in transmitting a radio signal from the main locomotive to the final one, for example, in conditions of a complex track profile. To increase the range of information transmission, it is proposed to use additional stationary digital radio stations DMR as retransmitters that can provide communication
between five trains. The number of such stations will depend on the terrain, which also significantly affects the radio signal propagation.

The effectiveness of implementing train interval traffic regulation using the "virtual coupling" system is presented in [8, 9, 10]; however, the issues of using the existing infrastructure of the traction power supply system are not considered in them.

3. Traction calculation of freight trains on the Achinsk – Mariinsk section

The article considers the calculated section of the Mariinsk – Achinsk railway (Figure 1).

Figure 1. Profile of the Mariinsk – Achinsk section.

The forecast values of freight train weight standards and the freight train traffic value for 2025 are shown in table 1.

Table 1. Freight train traffic sizes up to 2025

| Section name          | Weight standards of freight trains, tons | Size of freight trains, trains/day |
|-----------------------|-----------------------------------------|-----------------------------------|
|                       | 7100                                     | 7                                 |
|                       | 6000-6300                                | 14                                |
|                       | 4000-4200                                | 19                                |
| Mariinsk – Achinsk    | 3000                                     | 10                                |
|                       | 3000                                     | 1                                 |
|                       | 1500-1700                                | -                                 |
|                       | Total                                    | 51                                |

Table 2 presents the summary of the power consumption for the stage, specific power consumption, travel time (full time and time under current), maximum overheat of the engine windings and the maximum current of the train, at the considered road section, separately in the even and odd directions.

The traction calculations results with a use of the LVI-table in the program complex "KORTES", were acquired total current variation graphs, see figure 2 [11-13].

The system loads and throughput are calculated based on train schedules for a single connected train weighing 12600 tons and for a train in the “virtual coupling” mode weighing 6300-6300 tons. The interval between trains in the “virtual coupling” mode was assumed to be 4 minutes. The main characteristics of the operating mode of the Mariinsk – Achinsk section according to the calculations results are presented in table 3.
Table 2. Traction calculation of freight trains on the Achinsk – Mariinsk section.

| Weight of the train, t. | Running time, min | Power consumption | Max. overheating of the motor windings, °C |
|------------------------|------------------|------------------|------------------------------------------|
|                        | full active, kW·h | under current, kW·h | total, kW·h | active, kW·h | total, kW·h | A per km | °C |
| Odd                    | 2x3ES5K          | 167.7 12600       | 16169.8 22989.6 | 6.4 8.0       | 51° 1221 A per km | 3868.61 |
| Even                   | 3ES5K            | 170.4 7100        | 12416.3 14118.1 | 8.8 10.0      | 60° 1223 A per km | 3799.72 |
| Odd                    | 3ES5K            | 171.6 6300        | 14107.6 16056.1 | 10.0 1223 A per km | 3799.72 |
| Even                   | 3ES5K            | 176.1 6300        | 7776.2 9004.9  | 6.2 612 A per km | 3868.61 |
| Odd                    | 2ES5K            | 168.2 3245        | 9861.6 11350.7 | 7.9 612 A per km | 3799.14 |
| Even                   | 2ES5K            | 172.1 3245        | 5997.4 6920.6  | 8.0 408 A per km | 3799.10 |

Figure 2. The total current dependences graphs on the coordinates of odd (a) and even (b) trains of different masses on the Achinsk – Mariinsk section.
Table 3. Main characteristics of operating modes of the Mariinsk – Achinsk section.

| Parameters                          | Type of train                  | connected train | in the "virtual coupling" mode |
|-------------------------------------|-------------------------------|----------------|-----------------------------|
| Air temperature, ºС                |                               | 20.00          | 20.00                       |
| Power active, kW·h                 |                               | 37162          | 36829                       |
| Power reactive, kW·h               |                               | 7596           | 6397                        |
| Traction network losses, kW·h      |                               | 1129 (3.0 %)   | 754 (2.0 %)                 |
| Load limiting factor               | (EChE Kashtan)                | 1.27           | 1.20                        |
| Transformer oil temperature, ºС    | (EChE Mariinsk)               | 21.10          | 23.04                       |
| Voltage, kV                         | (2nd way of the Mariinsk –    | 21.81          | 23.38                       |
|                                    | Tyazhin zone, train No. 2     |                |                             |
|                                    | on km 3752.38 in 34 min        |                |                             |
| Load limiting factor               | (EChE Mariinsk)               | 65             | 65                          |
| Transformer oil temperature, ºС    | (EChE Kashtan)                | 21.00          | 20.00                       |
| Voltage, kV                         | (2nd way of the Tyazhin–       |                |                             |
|                                    | Kashtan zone, train No. 4     |                |                             |
|                                    | on km 3792.02 in 72 min        |                |                             |
| Average 3-min voltage              | (2nd way of the Mariinsk –    | 22.00          | 21.00                       |
|                                    | Tyazhin zone, train No. 2     |                |                             |
|                                    | on km 3754.62                  |                |                             |
| Temperature limit, ºС in the contact | (F4 EChE Tyazhin)              | 21.00          | 20.00                       |
|                                    | (EChE Kashtan)                |                |                             |
| Temperature limit, ºС in the suction line | (F4 EChE Tyazhin)              | 22.00          | 21.00                       |
|                                    | (EChE Kashtan)                |                |                             |

The parameters shown in table 3 indicate that the load limiting factor for the two types of trains does not exceed the permissible value, and the transformer oil temperature does not exceed the permissible value.

4. Conclusion

On the basis of the obtained results, it is proved that the "virtual coupling" technology assumes that radio modems installed on the electric locomotives maintain communication between the master and slave trains via a secure digital channel and transmit energy-optimal driving modes for locomotives that also ensure the minimum safe interval between trains.

As a result, the "virtual coupling" mode, since the energy consumption, the inter-train interval with the new technology will be 5 minutes, and the distance between trains will be reduced to the required stopping distance, losses in the traction network, the limiting load factor, the temperature in the contact network and the suction line are lower than when the connected train technology is used.

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