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Freight Electric Multiple-Unit Trains as an Alternative to Locomotive Traction. Comparison and Analysis

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ABSTRACT

The advantages of introduction of modular freight electric trains in comparison with freight trains using locomotive traction are described, the main prerequisites for introduction of a distributed multiple-unit freight traction are indicated. The results of comparison of the technology of transportation with traction by locomotive situated at the head of the train and by the train with self-propelled coaches, as well as the analysis of traction calculations of two types of trains are suggested. The international experience of developing freight trains with distributed traction is described.

The main directions of implementation of the concept of accelerating freight transportation on the territory of the Russian Federation are noted. It is concluded that in modern conditions, when speed becomes an economic category, it is necessary to create rolling stock of a new generation (wheel and magnetic suspension), and introduction of freight trains with distributed traction becomes extremely relevant.

Keywords: *railway, distributed traction, accelerated freight transportation, multiple-unit freight electric trains, innovative transport, traction calculations.*

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Introduction. Improving the efficiency of freight transportation is one of the main challenges the railways of the world are meeting. The most discussed solution is to extend the use of heavy long-haul trains.

However, long-haul heavy traffic has several disadvantages and risks:

• breaks of automatic couplers and squeezing of cars in curves when the train is driven through difficult sections;

• generation of large reverse currents caused by high power of electric locomotives used for heavy-haul traffic. This circumstance negatively affects the signaling and communication devices, and causes growth of the cases of burnout of the contact wire when using concentrated current collection [1];

• decrease in the operational efficiency of a power plant of a locomotive while reducing train mass, which tends to zero when the train is idling [2, p. 23];

• heavy locomotive (particularly gas turbine locomotives, multi-unit locomotives) create big concentrated dynamic load destroying railway bridges, tracks and surrounding structures [1, p. 17].

The introduction of freight trains with distributed traction, capable to increase train mass and speed, allows to eliminate these risks.

Besides, it is fundamentally important that the bet made in favour of increasing the train mass in transportation of goods is inevitably associated with additional costs and time, which grow dramatically with the mass of trains from 9 thousand tons and more [1, p. 28]. The raise of the weight of trains of up to 8–10 thousand tons on a massive scale is problematic, since it will require a high-cost, radical modernization of all structures that provide cargo transportation, and concentrated traction (heavy trains) may not provide significant advantages compared to trains with distributed traction with conventional weight norms. The speed of heavy trains will be lower than the speed of ordinary ones, which will lead to a decrease in the transit capacity of sections [3, p. 23].

The main prerequisites for introduction of a distributed multiple unit traction:

• significant increase in operational efficiency of the power plant of the train;

• ability to form the train of any desired capacity by including or excluding additional self-propelled cars;

• improvement of train controllability, increase in acceleration and braking features;

• improved adhesion between wheel and rail;

• reduced destructive impact on a track;

• increased transit capacity of railway lines;

• digitalization of transportation management [4, p. 17].

The modular scheme eliminates the loss of longitudinal stability of the train which happens when braking is done by the lead locomotive, and the locomotive and the front cars brake first, and the middle and tail cars brake with a significant delay [5, p. 14]. Under the action of inertial forces, they «pile on» the locomotive and the front cars, and there is a high probability of rupture of the train and of overturning of wagons.

At the same time, in the non-modular train, recovery of the kinetic energy of a heavy train headed by a leading locomotive cannot be implemented, primarily due to insufficient adhesion force of the locomotive on the railway track. Therefore, the stopping of the traditional freight train is made exclusively by the mechanical braking system of the cars of the train [6, p. 70].

The *objective* of the study is to verify the comparative advantages of freight electric trains with self-propelled cars basing on traction calculations and analysis of operating experience of modular trains in a number of countries.

To achieve this goal, the *methods* of comparative analysis, content analysis of engineering information, special engineering methods for traction calculations for railway transport were used.

Results.

International experience in development of freight trains with distributed traction

Attempts to develop operations of freight trains with distributed traction were undertaken in the mid-1990s and early 2000s in Germany and Japan.

The German freight train CargoSprinter had constant composition, was uncoupled only at the shed for maintenance work and was intended for transportation of containers and interchangeable bodies [7, p. 33]. Adtranz developed variants of such a train with different types of traction drive (electric, diesel and hybrid diesel-electric) of different capacities (from 1 to 2,5 MW). Thanks to this, the trains of CargoSprinter series could be operated on the alpine lines of a complex plan and profile. It was assumed that they will carry out transportation of goods, eliminating costs of sorting work. For long-haul routes, it was possible to link up to seven CargoSprinter trains into one train or couple them to ordinary freight trains [8, p. 39].

The electrically operated train CargoSprinter based on a traction module located in the middle of the train, which was tightly integrated into the train. Besides, a diesel engine could be additionally installed in the same module in order to move the train along adjacent non-electrified lines. Two terminal cars with control cabins allowed the use of trains on adjacent tracks without replacing the traction unit and additional shunting operations.

The Japanese electric train of M250 series, launched under Super Rail Cargo brand, is a 16-car container electric train with distributed traction: two self-propelled cars are located at each end of the train, besides there are also 12 intermediate self-propelled cars. Self-propelled cars are equipped with a traction drive with converters based on IGBT transistors and asynchronous traction motors with a total power of 16 • 220 = 3520 W. Gross train weight is 730 tons, maximum speed is 130 km/h [8, p. 39].The bogies of cars do not have a pivot beam; spring suspension uses pneumatic cylinders. A small axial load allows to pass the curves without reducing speed. The brake system of the train uses the combination of electrodynamic and friction disc brakes. One thirty-foot container can be installed on motorized cars, and two containers can be fit on trailer ones [9, p. 31].

During test operation of those trains some weaknesses were revealed, and too high cost of transportation was the reason why new trains could not compete with road transport. There were problems with vertical unloading of containers on electrified tracks. According to some authors, there were also certain miscalculations in organization of operation of trains of this type [10, p. 329].

Results of comparison of the technology of transportation of goods with the traction by locomotive in the head of the train and by trains with self-propelled cars in the train

We have conducted comparative traction calculations for two sections powered by AC and DC current with different track profiles:

1. Medvezhia Gora–Noviy Posyolok of October railway (a branch of JSC Russian Railways) with ruling gradient of 0,0125 (12,5 ‰).

2. Krivenkovskaya–Goitkh of North-Caucasian railway (a branch of JSC Russian Railways) with ruling gradient of 0,0184 (18,4 ‰).

To make the calculations regarding relevant sections we used features of three-unit AC electric locomotive 3ES5K, three-unit DC electric locomotive 3ES4K, and of multiple-unit freight electric train (or MFET – for modular freight electric train) with distributed traction (traction and braking features of its self-propelled cars were assumed to be the same as those of electric train ES1 «Lastochka» for respective AC and DC powered sections).

The following assumptions were considered during calculations:

• mass and dimensional parameters of trailer cars of electric train were deemed to be equal to parameters of the fitting platform 23–469–07;

• the weight of carried cargo is equal for both trains;

• full and maximally admissible power load of power plants of the trains;

• train led by locomotive (concentrated traction) has one locomotive at the head of the train; 7 self-propelled cars in MFET are distributed equally along the train; for Krivenkovskaya–Goitkh section the ratio of self-propelled and trailer cars is 1:5, for Medvezhia Gora–Noviy Posyolok 1:9.

The number of trailer cars per 1 motorized (self-propelled) car is calculated according to the track plan, profile, and weight of carried cargo.

The choice to include fitting platforms in the composition of the motor-unit train is determined by the urgency of solving ambitious tasks set for the railway transport and providing for:

• creation of transit transport corridors in the territory of the Russian Federation, connecting East and West;

• 4 times increase in container transportation;

Electric locomotive 3ES5K.

• setting speed of delivery of containers along the East-West route, providing that the delivery will be made in no more than 7 days [11, pp. 17–18].

Analysis of the results of traction calculations shows that:

1. The coefficient of a tare weight of a train with locomotive is lower than that of a multiple-unit train. If the need for self-propelled cars reduces (e.g. in case of a more even profile of railway sections), the coefficient of a tare weight of MFET decreases, tending to equal the value of the coefficient of the tare weight of a train with locomotive traction.

2. The flexibility in formation of multiple-unit trains depends on the power of the traction motors used on motorized cars: the use of traction motors of increased power reduces the number of motorized cars within electric trains and, accordingly, reduces capital and operating costs.

By reducing the specific power of electric motors per motorized car, the flexibility of formation of trains regarding the most complete use of power increases. However, the coefficient of the tare weight of a train increases as there are more motorized cars. Besides, the cost of train maintenance increases.

Consequently, when designing the considered electric rolling stock, it is necessary to find the optimum specific power of the traction motors per motorized car.

3. The resulting acceleration at starting is about 2 times higher for a modular electric train, and the tension force in the automatic coupling of the multiple-unit train is about 5,5 times lower as compared to a train with 2ES5K electric locomotive. When comparing with a train driven by electric locomotive 3ES5K the same figures are respectively 2,8 and 8; when comparing with electric locomotive 4ES5K – 2,6 and 10,7. The increase in acceleration and braking features of freight trains will allow to enhance transit capacity of railroads, particularly at the rail network sections used for mixed passenger and freight transportation, where cargo trains frequently stop to let passenger trains pass.

Thanks to more than a sevenfold reduction of loads on automatic coupling devices, it is possible to reduce the load on the frame of the car, to make the cars lighter and less material intensive. Calculations of the parameters of such cars is now made by the authors and will be later suggested.

A modular traction train may have a fixed length as the power of its power plants will be varied by changing the ratio of trailer/motorized cars in the train. This allows to adapt it to the length of the receiving and departure tracks of various rail networks serviced by those trains without additional costs of developing their track infrastructure.

Transportation of goods by modular electric trains will manifest its maximum efficiency primarily on landfills with unstable cargo traffic, as well as in areas with a complex profile of the track, where forced stopping and acceleration on steep ascents and descents are possible (and where pushing and double traction are applied).

By adjusting the number of motorized cars in the train depending on the net freight to be transported at the current time, the duty station officer of the freight station forms a train with the most complete load of power plants of traction units, bringing their operation efficiency closer to one. And, on the contrary, if there is insufficient loading of the cars, or the train leaves the section with a flat profile after passing long climbing sections, it is possible to promptly turn off the power plants of individual motorized cars, thereby regulating power and saving energy for train traction.

Conclusions. On the basis of the tasks that the Russian railways face now, one can actually talk about creation of a new paradigm, a new technology for organizing transit transportation within the territory of Russia. This new technology should absorb the entire flow of containerized cargo in Russia. The basis of this technology is container transportation at high speeds. The implementation of the concept, in which priority is given to increasing the speed, does not require additional costs, providing, however, a radical improvement in the operational performance of the railway [6, p. 72].

The main technological tool for development of this technology is, in our opinion, a modular train scheme that provides distribution of traction within a train. It is necessary to create multiple-unit freight trains consisting of motorized and trailer cargo platforms that will transport standard containers or interchangeable bodies for various cargoes, including bulk cargoes.

In general, as a universal conclusion, it can be noted that in modern realities, when speed becomes an economic category, when it is necessary to create rolling stock of a new generation (wheeled and magnetically suspended) for mastering world freight flows within international transport corridors, issues of implementation of freight trains of distributed traction are again becoming extremely relevant due to their tangible advantages over heavy long-length trains. But to implement those advantages, it is necessary to specify technically and economically the replacement of locomotive-led heavy-haul trains by multiple-unit trains, to correctly develop technology that will be adapted to real conditions.

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