

Innovative doubly-fed freight electric locomotive 2EV120 “Knyaz' Vladimir”

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Abstract. The paper considers a new doubly-fed freight electric locomotive taking into account the world experience of locomotive construction, the regulatory base and operating conditions on the railways of Russia. Its parameters are presented: the main technical characteristics in comparison with currently used electric locomotives of new series, standard traction characteristics, and the characteristic of electric braking. Features of the design of the units and parts of the undercarriage and brake equipment are given. The studied doubly-fed freight electric locomotive is designed taking into account the optimal combination of equipment backup capabilities and increased operational reliability with minimization of the failure flow causing the withdrawal of two or more traction axles due to the faults. It has promising possibilities for replacing outdated locomotives with alternating and direct current, operated on sections with changing and adjacent stations, electrified on a constant and single-phase alternating current in the places where such sections are joined to the extent of the organization of traffic control according to the principles of working domain technologies. In this case, the joints between the two types of the train current can pass nearly without stopping, their running time is shortened, and the performance indicators are improved.

1 Introduction

The development of rail transport in Russia is a strategic task. In the conditions of a dynamically changing economic situation and an active desire to fill a niche of leadership among other modes of transport, modernization, improvement of rolling stock and infrastructure is required, which is impossible without scientific research taking into account global socio-economic changes and innovations. The main base document in our country for setting the direction of the strategic planning vector is Federal Law № 172 of June 28, 2014 “On strategic planning in the Russian Federation” [1]. This law touches upon all spheres of public administration. In accordance with this Federal Law, in the transport sector and, in particular, on railway transport, an innovative stage of development is to be carried out in all areas of activity, taking into account state and industry priorities, goals, and objectives.

The main problems of the locomotive operational complex of the last decade are reflected in the “Strategy for the development of railway transport of the Russian Federation until 2030” approved by the decree of the Government of the Russian Federation on June 17, 2008,

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№ 877-r [2]. They consisted in the absence of serial production of mainline freight electric locomotives of direct current, mainline diesel locomotives, dual-mode locomotives, and locomotives with an asynchronous traction drive. As a result of solving the tasks set before the locomotive facility, supplies for the putting into operation of the mainline electric locomotives of direct current with the collector traction engine 2ES6 are continuing today. At present, the first mainline freight diesel locomotive with electric alternating-direct current transmission and a collector traction engine 2TE25KM of Russian production has been put into operation. The problem of the lack of locomotives with an asynchronous traction drive was solved due to the creation and successful putting into operation of the mainline freight electric locomotives of direct current 2ES10. The mainline freight electric locomotives of alternating current with the collector traction drive 2ES5K are also widely used.

Table 1. Electric locomotives of the new generation operated on the railways of Russia.

Electric locomotive series	Number of operated units	Geography of operation, railways
2ES6 “Sinara”	754	October, Kuybyshev, Sverdlovsk, South Urals, West Siberian
2TE25KM “Peresvet”	317	October, Moscow, North-Caucasus, Privolzhskaya
2ES10 “Granite”	152	October, Sverdlovsk, West Siberian
2ES5K “Ermak”	358	October, Krasnoyarsk, East Siberian, Transbaikal, Far East

Some of the tasks assigned to locomotive engineering have not received their technical solution - serial production and putting into service of dual-mode freight electric locomotives. This issue remains an important strategic direction for the development of the locomotive complex. At present, 58 units of dual-mode freight electric locomotives VL82M which were built at the Novochoerkassk Electric Locomotive Plant in 1979 are operated in the Southern, Caucasus, and October railways. The life cycle of these electric locomotives is being completed due to a sufficiently long operation; there is no modern alternative for replacing these locomotives in JSC “Russian Railways”. This problem can be solved by the putting into operation of the new dual-mode freight electric locomotive 2EV120 (fig.1) of a new generation developed by LLC “First Locomotive Company” in cooperation with Bombardier Inc. (branch of Bombardier Transportation in Russia). The locomotive is produced by the Engels Locomotive Plant.

The new locomotive was first introduced in September 2015 at the international fair Expo 1520. He immediately attracted the attention by a complex of unusual for domestic electric locomotive engineering solutions. In June 2016, after commissioning works and preliminary testing, the acceptance and certification tests of two experimental electric locomotives were started. In May 2017, the interdepartmental acceptance commission recognized the dual-mode electric locomotive 2EV120 as corresponding to the technical task developed by the company JSC “Russian Railways”, thereby confirming the technical conditions for the production of the pilot batch. In October 2017, the electric locomotive received a certificate of compliance with the requirements of technical regulations TR TC 001/2011 “On the safety of railway rolling stock”. From November 2017 to May 2018, two experimental electric locomotives 2EV120 passed the controlled operation on the North Caucasus, Privolzhskaya, and Kuibyshev Railways. And in November 2016, traction-energy tests were conducted on the South Urals Railway [3]. Over 80% of cargo and passenger traffic of JSC “RZD” network is performed on electric traction. From the position of traction, the railway sections are a system with three basic standards: traction of a direct current of 3 kV, traction of a single-phase alternating current with a voltage of 25 kV at a frequency of 50 Hz, and autonomous

(diesel) traction. This diversity leads to difficulties in the organization of transportation and increased operating costs.



Fig. 1. Dual-mode electric locomotive 2EV120 “Knyaz' Vladimir”.

To connect areas electrified by a different kind of current, jointing stations have been widely used. There are 27 such stations on the railway network. Most of them by the nature of operation - are the section stations, the main purpose of which - the change of locomotive crews and the replacement of the locomotive of one type of traction on the other. The presence of jointing stations along the train route has a number of significant shortcomings. On average, the replacement of electric locomotive in cargo traffic takes at least 1 hour, taking into account the time for fastening and unfastening the train, maneuvering the locomotive exchange, and performing the mandatory full brake testing. The down time at jointing stations can also include non-productive losses, such as the waiting time of an electric locomotive of the needed kind of current, the train path, especially in areas with intensive traffic of passenger trains. All this negatively affects one of the most important quality indicators of operational work - the daily speed of the train. In particular, due to the down time at such stations, the route speed of the trains passing through them is reduced by 40-80 km/day and more [4-7].

It is not paid enough attention to the issues of increasing the efficiency of the use of traction and energy resources of the locomotive fleet, the improvement of the electric rolling stock, and the improvement of its operational performance due to the introduction of dual-mode electric locomotives on the railway network.

In this paper, the innovative electric rolling stock of the new generation is considered. Features of its technical characteristics and electrical equipment are presented. The implementation of traction capabilities of dual-mode freight electric locomotives on the country's railway network will improve the efficiency of the transportation process, revise the service areas of locomotives and locomotive crews, and reduce operating costs.

2 Design features of the innovative dual-mode electric locomotive 2EV120

2.1 Technical characteristics

The dual-mode electric locomotive 2EV120 is designed to increase traction services for various types of freight traffic with increased speeds and masses of trains. The concept of its project is created on the basis of analysis of the features of freight traffic in Russia and abroad for the non-uncoupling driving of freight trains over distances of more than 3 thousand km

on sections with different kinds of current. Table 2 presents its main technical characteristics in comparison with electric locomotives of new series widely used on the network of JSC “RZD” [8-11].

Table 2. The main comparative technical data of electric locomotives of new series operated on the network of JSC “RZD”.

Parameter	Electric locomotives				
	2EV120 “Knyaz' Vladimir”	2ES10 “Granite ”	2ES6 “Sinara”	2ES4K “Donchak”	2ES5K “Ermak”
Rated voltage on the current collector, kV: direct current alternating current	3 25 (50 Hz)	3 –	3 –	3 –	– 25(50 Hz)
Maximum operating speed, km/h	120	120	120	120	110
Service mass with 2/3 reserve of sand, t	200	200	200	192	192
Type of TEM	Asynchronous		Collector		
The axial formula	$2(2_0 - 2_0)$				
Static load from the wheel set on the rail, kN	245	249	245	235	235
Maximum power on the rim of wheel set, kW	9600	8800	6440	6440	6560
Power on TEM shafts in continuous operation, kW	8800	8400	600	5735	6120
Speed of continuous operation, km/h	52,8	55	51	53,4	51
Traction force on the rim of wheel sets in continuous mode, kN	600	538	466	391	423
Maximum starting traction force (hourly mode) on the rim of wheel sets, kN	700	784	667	434	464
Efficiency in continuous operation,%: direct current alternating current	88 86	87,5 –	86 –	88 –	– 85

Analyzing the main technical characteristics of the dual-mode two-section freight electric locomotive 2EV120, it is clear that due to the asynchronous drive, it shows the best traction characteristics than electric locomotives using the collector type of traction motors. It is also comparable with locomotives equipped with an asynchronous traction motor.

2.2 Traction and braking characteristics

The most important indicators for carrying out pilot tests of new locomotives are traction and braking characteristics. When carrying out controlled operation for certification and acceptance tests on the Chelyabinsk-Kartaly-Magnitogorsk section, the traction characteristics of the electric locomotive included in performance specification and presented in fig. 2 were proved [12, 13].

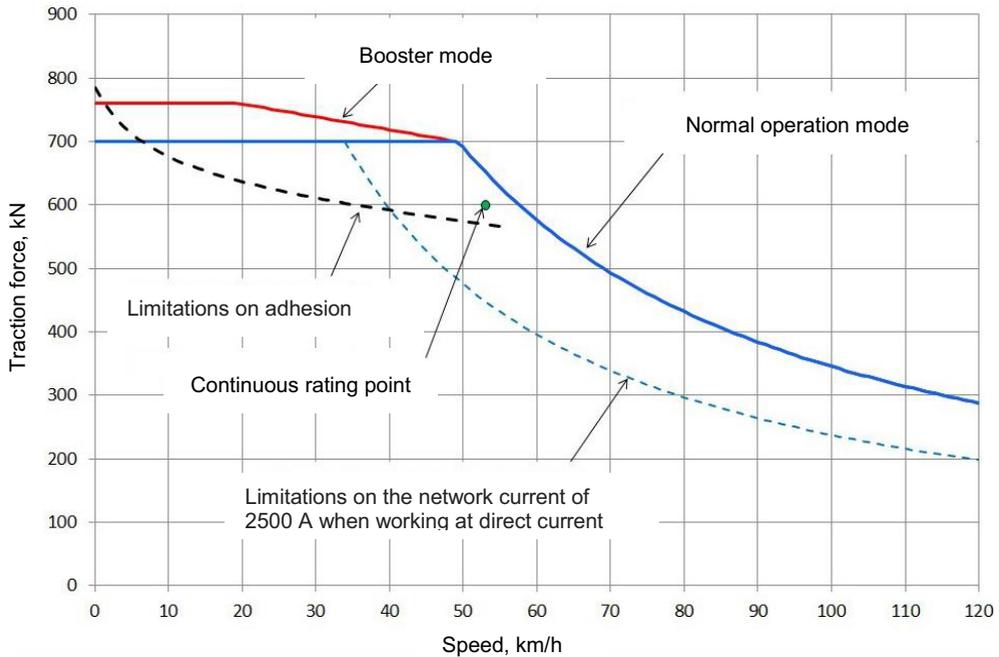


Fig. 2. Traction characteristics of the dual-mode electric locomotive 2EV120.

In the normal operation mode, the traction characteristics of the electric locomotive 2EV120 are limited to a control system at the level of 700 kN in the speed range from 0 to 49 km/h (until the power on the rim of the wheel sets reaches 9600 kW), and the maximum power on the rim of the wheel sets is 9600 kW. The electric locomotive realizes these traction characteristics both on a direct, and on alternating current. As can be seen from the traction characteristics of an electric locomotive, a booster mode is provided in the speed range from 0 to 49 km/h. The control system allows the use of this mode only in case of the removal from the operation of a part of the traction motors due to the failure in order to partially compensate for the loss of traction force of the locomotive. When a single traction motor is removed from the operation, the booster mode allows the traction force of 665 kN (for seven traction motors) to be realized in the speed range from 0 to 20 km/h, which is usually enough to start and accelerate the train of designed mass at the designed lift, if the adhesion conditions allow it [14].

To achieve the necessary indicators in the field of adhesion properties, an asynchronous traction electric drive is installed on an electric locomotive “Knyaz’ Vladimir”. However, the rigid characteristics of such a traction drive are not used. On the electric locomotive, special control algorithms are applied and axle traction regulation is implemented, which allows increasing the coefficient of adhesion. When analyzing the data obtained on the basis of the results of controlled operation in the South Urals, the declared constraints on the adhesion calculated according to the following formula were confirmed [15]:

$$\Psi_k = 0,31 + \frac{4,5}{50+6 \cdot V} - 0,0006 \cdot V, \quad (1)$$

where V – the speed of an electric locomotive, km/h.

When switching to the electric braking mode, the control system first always activates the regenerative mode. As can be seen from the characteristics of electric braking (fig.3), the maximum power at the rim of the wheel sets is equal to the maximum traction power and is

9600 kW. This maximum power of the regeneration mode can be realized both at direct and alternating current.

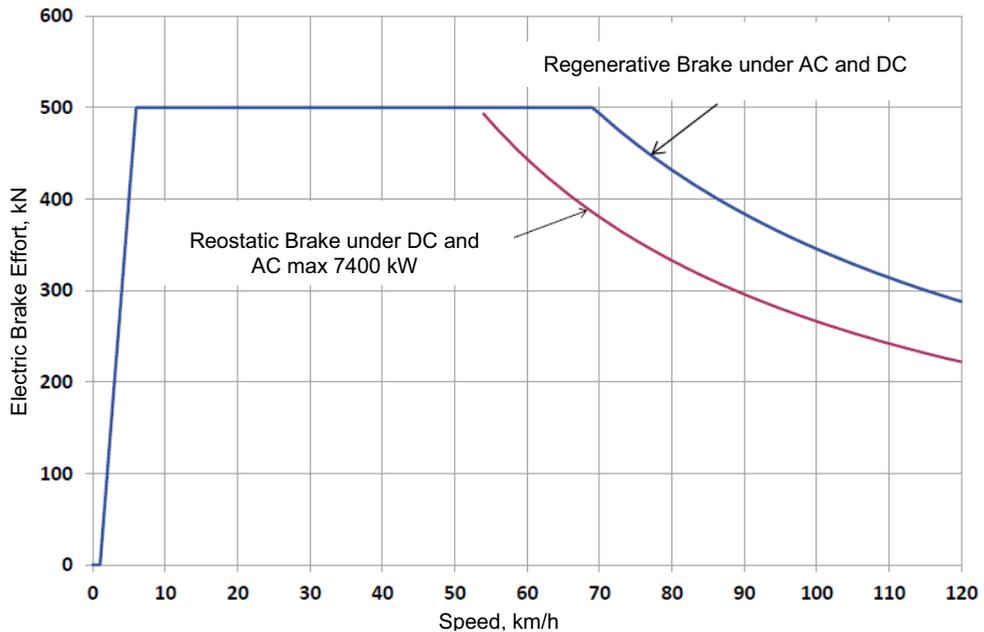


Fig. 3. Characteristic of electric braking of a dual-mode electric locomotive 2EV120.

Gradual proportional automatic replacement of regenerative power by energy dampening in braking rheostats takes place in the voltage range at the current collector: direct current - from 3.6 to 3.9 kV, alternating current - from 28 to 29 kV. Thus, with a voltage on the current collector from 3.9 kV DC and above or from 29 kV AC and above, only an electric rheostat brake with a power limitation on the rim of the wheel sets of 7400 kW is always effective. At the same time, the electric rheostat brake with the maximum power on the rim of the wheel sets of 7400 kW operates without power drops up to the voltage level at the current collector at which the main switches automatically switch off.

2.3 Design of mechanical components

Bombardier Company used the FlexyFloat car trucks on the electric locomotive 2EV120. This family includes a variety of configurations of two- and three-axis locomotive trucks, which are united by one basic design feature - the transverse-elastic connection between the frame of the truck and the axle boxes. The frame of the truck has not only vertical but also transverse springing relative to wheel sets. This is implemented due to the use of FlexyCoil springs in the first (axle box) stage of spring suspension, which allow not only axial (longitudinal) but also radial (transverse) elastic deformation (fig. 4).

The links themselves are located only on one side of the axle box and have a relatively large length, for this, the silent blocks of links of the axle boxes are spherical, not cylindrical. In general, the elastic play of the wheel set relative to the frame of truck is approximately ± 15 mm. Reduction of dynamic side impacts on the track is achieved by means of installed transverse springs (fig. 5).

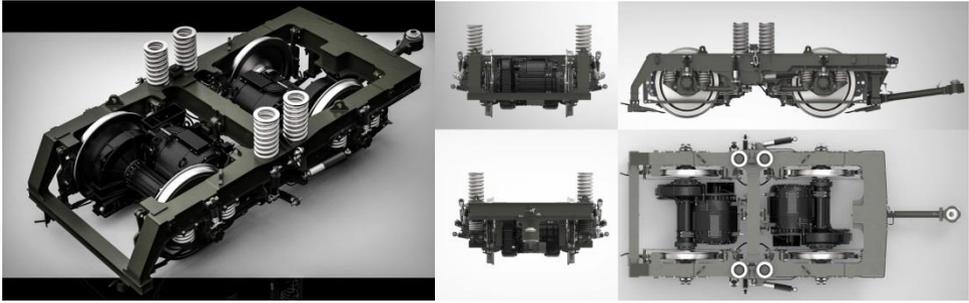


Fig. 4. Truck of dual-mode electric locomotive 2EV120.

The welded construction of the truck's frame is made in the form of a box section. It uses Russian bridge steel 15ChSND2. The structure of the frame is fully adapted to the specifics of the Russian standards for fatigue strength with a safety factor of at least 2.0. The frame of the truck successfully passed all the tests provided by the Russian standards.

Completely identical trucks of one locomotive section are structurally different only by the position of a handbrake, which is used on the truck from the side of the driver's cab. The second stage of spring suspension is also equipped with springs of the FlexyCoil type [12-15].



Fig. 5. Tests of the truck of the electric locomotive 2EV120 during the controlled operation.

The inclined tractions are used to transfer the braking force and traction force from the frame of the truck to the body frame. The brakes are made as a traditional shoe with two-sided pressing and a classic brake gear scheme. Each wheel has an individual brake unit (brake cylinder) pictured in fig. 6. When calculating the economy of an electric locomotive, disc brakes were not used because of their high cost and low coupling properties of the locomotive when they are used.

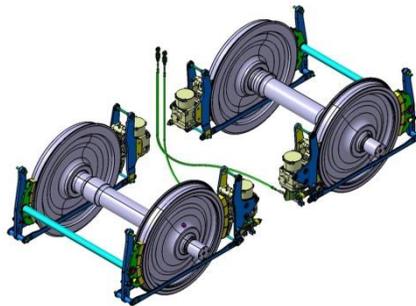


Fig. 6. Brake equipment for the wheel set of the dual-mode electric locomotive 2EV120.

Periodic use of a block brake with increased phosphorus content removes the polished microlayer of metal from the wheel surface and increases the roughness, which in turn significantly increases the coefficient of adhesion of the wheel to the rail. This is important for a main freight electric locomotive having such a large traction force.

The electric locomotive “Knyaz’ Vladimir” is equipped with a traction drive of the axle suspension “Mitrac DR3800N” (fig. 7), it includes: an asynchronous traction motor with forced air cooling of the family “Mitrac TM3800F”; single-stage cylindrical transmission “Mitrac GB3800S” with axial bearings. The technical version of the one-side reduction gear is applied. It is important to note that the teeth on the reduction gear and the gear wheel are made with a slight angle of inclination of 110. The geometry of the tooth has a feature: a thickening in the center part of the tooth of the gear wheel. This is done for a more even load of the teeth taking into account their elastic deformation when applying high forces. This generally increases the life of the gears. In the traction motor, insulation class S200 is applied with the maximum permissible temperature rise of the winding above the cooling air temperature equal to 200 degrees Celsius [12-15].



Fig. 7. Traction drive of dual-mode electric locomotive 2EV120.

The winding of the traction motor is four-pole. The power of the clock mode of the motor on the shaft is declared by the designers - 1225 kW. But due to the fact that the scheme of a power circuit of “direct” power of inverters from a contact network is used on a direct current, the voltage at the input of the inverters can reach 4000 V. To ensure that this mode of operation does not lead to overheating of the motors, they have a power reserve in their design. In other words, clock mode with a power of 1225 kW in thermal terms is provided not only at the nominal voltage in the contact network and at the input of the inverters but also at an increased voltage. If such a motor is powered from an inverter with an input voltage of 2800 V, then its hourly power on the shaft will be about 1600 kW.

3 Results

The conducted studies allow saying that the dual-mode electric locomotive 2EV120 is an innovative, promising locomotive that could replace the outdated electric locomotives. Technical and economic introduction will be beneficial on the sections with jointing stations.

Based on the technical data and the analysis of the test trips, it is possible to evaluate the capabilities of the doubly-fed electric locomotive during operation. The speed of the electric locomotive 2EV120 with trains weighing from 5 to 7 thousand tons is on average higher than with electric locomotives 2ES6 and 2ES5K. In particular, the speed is 10 km/h higher on the ruling gradient, and the total travel time is much less. The specific power consumption of 2EV120 is 3-5% lower than the established norms for comparative electric locomotives.

It is important to note the possibility of using the booster operating mode on the innovative electric locomotive “Knyaz’ Vladimir”. In this case, as can be seen from the traction characteristic in fig. 2, the starting traction force of an electric locomotive and in the

speed range from 0 to 25 km/h rises from 700 to 760 kN. Due to this mode, the probability that the resulting malfunction in the system will lead to a stop on the ruling gradient is reduced, i.e. a backup locomotive will not be required.

4 Conclusions

To implement the introduction of the dual-voltage 2EV120 electric locomotive, it is necessary to perform the following step-by-step work:

a) systematize the methods of the existing operating systems for rolling stock at the regional level;

b) examine in more detail the traction properties and operational limitations for determining the parameters of the train operation, taking into account the specifics of the proposed areas of operation;

c) create a simulation model for assessing the efficiency of the locomotive complex when introducing doubly-fed electric locomotives;

d) calculate the economic efficiency and life cycle including the technology of repair of electric rolling stock.

With the equivalent use of traction power, in terms of power consumption for traction, the doubly-fed electric locomotive 2EV120 has an advantage in the field of energy efficiency in the range of 3-14% in comparison with the other electric locomotives of the new series.

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