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Study of Performance of RZhFA-6500 Smoothing Reactors



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ABSTRACT

DC traction power supply systems have become widespread in several countries. Electricity consumption by traction power supply systems has pronounced seasonal and daily peaks. The peak nature of consumption leads to additional heating of live parts since time constants of transient thermal and electrophysical processes differ by several orders of magnitude, therefore, reducing ohmic resistance of electrical equipment, other things being equal, is an extremely important task.

Within the framework of solving the problem of increasing energy efficiency of equipment of DC traction substations, smoothing reactor filter devices with an armoured radial-cylindrical magnetic core with low ohmic resistance, named RZhFA-6500, were developed and manufactured.

In 2018, two blocks of RZhFA-6500 smoothing reactors were put into pilot operation at one of the most heavily loaded sections of DC electrified railways, providing traffic of trains weighing up to 9000 tons and traffic volume of about a hundred pairs of trains per day.

To determine comparative indicators of energy efficiency, data on consumption of electric power for traction of trains for the compared periods before and after introduction of smoothing reactors of a new type were requested. The data received from JSC Russian Railways contained information on the traffic volume, type of rolling stock, and weight of the transported goods in accordance with the executed traffic schedule through section under consideration. The resulting set of data served as the basis for development of a multivariate methodology for assessing energy efficiency of reactors of a new type, as well as their contribution to efficiency of train operation over the considered comparative time interval. Since efficiency of power equipment also depends on the ambient temperature, the average integral parameter of average daily temperature was introduced into the calculation methodology, which, as it turned out, during processing initial data and construction of characteristic graphical dependencies, has a comparative difference of less than one percent for the same monitored periods.

Accurate quantitative accounting of the data on consumption of electrical energy provided for traction of trains, exchange of reactive energy with the supply network, volume of transportation allowed to obtain an objective comparison of contribution of smoothing reactors of a new type to increasing efficiency of train operation and reducing consumption of electrical energy for traction of trains.

Keywords: railway, energy efficiency indicators, traffic volume, smoothing reactors, filter device, active energy, reactive energy.

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The topicality of problems of energy efficiency and energy saving is due to the growth in consumption of electrical energy throughout the world. The gradual transfer of transport systems from hydrocarbon fuel to electricity requires both an increase in its generation volumes, as well as raise the requirements for equipment of its transmission and distribution systems in terms of reducing power losses.

The development of new transport corridors and increase in traffic volumes result in a significant increase in electricity consumption by traction power supply systems, which have pronounced seasonal and daily peaks. The peak nature of consumption leads to additional heating of live parts since time constants of transient thermal and electrophysical processes differ by several orders of magnitude, therefore, reducing ohmic resistance of electrical equipment, other things being equal, is an extremely important task.

Within the framework of solving the problem of increasing energy efficiency of equipment of DC traction substations, two sets of smoothing reactor filter devices with low ohmic resistance were developed and then manufactured [1].

Since DC traction power supply systems have become widespread not only in Russia, but also in several European countries, in Italy, Lithuania, Latvia, Estonia, as well as in Poland where 80 % of railways are DC electrified, this reactor can have a high degree of unification.

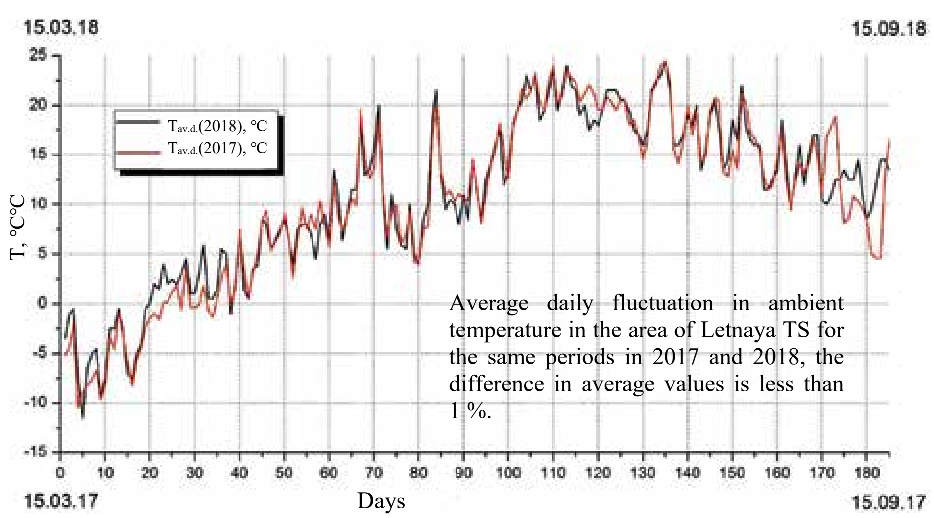
To conduct pilot operation of manufactured reactors, that received the abridged name RZhFA-6500, JSC Transenergo JSC, the branch of JSC Russian Railways, identified two DC sections with heavy-haul traffic of Sverdlovsk and West Siberian railways.

Letnaya traction substation of Sverdlovsk railway was selected as the site of introduction of the first set of two smoothing reactors with an armoured radial-cylindrical magnetic core [2]. This traction substation is located at a hill climbing section [where trains should move with the authorised speed], which determines a relatively higher level of load on overhead line feeders.

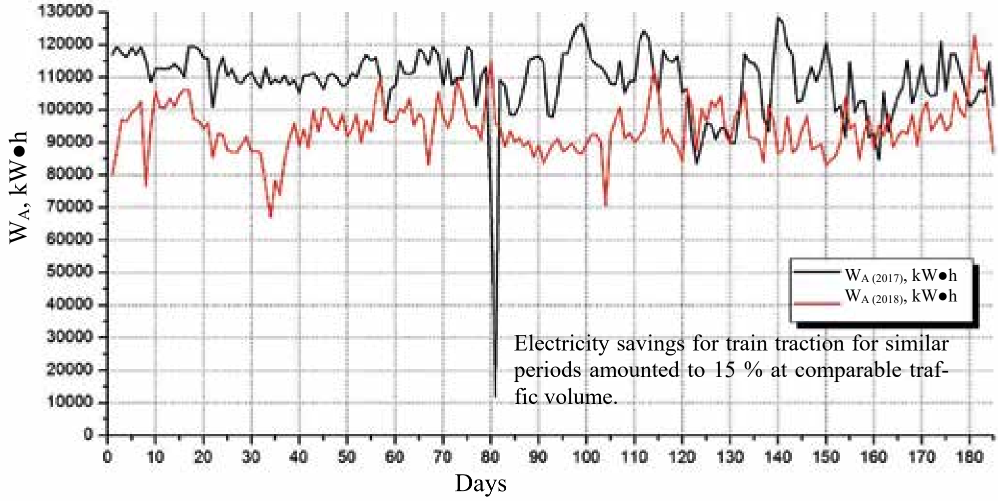
Two RZhFA-6500 units are connected in series and mounted in the second link of the filter device of West Siberian railway circuit without reconfiguring its resonant circuits [1].

The level of psophometric voltage on the buses of DC switchgear of the traction substation in a wide range of traction current values did not exceed 15 V [3–7]. No increase in dangerous or interfering influences on devices of centralized blocking systems (CBS), communications and adjacent lines of longitudinal power supply of 6/10 kV was recorded, significant heating of the structural elements of RZhFA-6500 units during operation did not take place either [8].

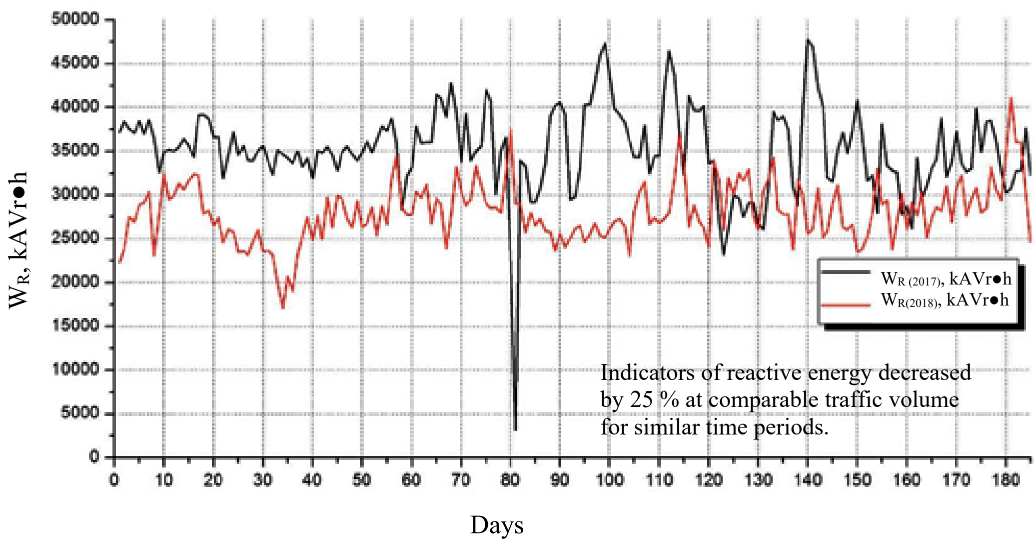
Reactors of RZhFA-6500 type have proven themselves well, including during operation in the summer season, when the ambient temperature in the shade rises to +31ºC [9].



Pic. 1. Average daily temperature fluctuation during most distinctive monitored periods (compiled by the authors).



Pic. 2. Average daily consumption of active energy for traction of trains during distinctive monitored periods (compiled by the authors).



Pic. 3. Average daily indicators of reactive energy for the distinctive monitored periods (compiled by the authors).

The graph of fluctuations in the average daily temperature for the period of experimental field operation is shown in Pic. 1.

To assess energy efficiency of new reactors, the readings of active and reactive energy meters for the inputs of converter transformers of Letnaya TS for a six-month period (from 15.03.2018 to 15.09.2018) of the experimental field operation of RZhFA-6500 reactors and for the comparable period of the previous year (from 15.03.2017 to 15.09.2017) were officially requested at Shartashskaya power supply distance unit (EChE-232). Based on the results of processing the obtained data, graphs of daily average values of active energy (Pic. 2), consumed for traction of trains, and of reactive energy which characterised energy exchange with the supply network (Pic. 3) were constructed.

Average values of active $W_{\text{A av}}$ and reactive $W_{\text{R av}}$ energy over the half-year period were determined using the following expressions:

$$W_{\text{A av}} = \frac{1}{n}\sum_{0}^{n} W_{Ai}, \ \text{kW} \bullet \text{h}, \quad (1)$$

$$W_{\text{R av}} = \frac{1}{n}\sum_{0}^{n} W_{Ri}, \ \text{kvar} \bullet \text{h}, \quad (2)$$

where W_{Ai} and W_{Ri} are average daily readings of active and reactive energy;

Table 1

Series of ERS	Months of 2017						
	03	04	05	06	07	08	09
2ES10	0	0	0	0	0	42	0
2ES6	44 854	38 510	41 825	40 586	33 436	42 834	39 869
VL10	12 531	12 240	9 644	7 323	8 197	10 841	10 020
VL10K	2 197	2 217	1 942	1 327	630	714	1 147
VL10U	187	203	0	0	0	0	44
VL10UK	0	0	0	0	0	0	0
VL11	3 289	2 934	3 315	3 000	2 317	2 305	1 975
VL11K	391	436	55	660	235	505	567
VL11M	1 329	1 333	485	707	442	576	279
Total	64 779	57 872	57 266	53 603	45 257	57 818	53 900
Total for the period under consideration 2017						390 495	
Series of ERS	Months of 2018						
	03	04	05	06	07	08	09
2ES10	69	0	58	0	286	264	69
2ES6	40 112	38 118	33 938	34 567	36 756	37 899	34 967
VL10	9 318	8 446	8 528	7 074	7 116	9 868	7 045
VL10K	1 425	2 312	1 659	1 235	2 135	2 565	1 971
VL10U	831	579	69	197	1 073	2 042	2 146
VL10UK	0	0	0	69	0	0	0
VL11	1 688	1 080	1 018	926	1 154	1 624	910
VL11K	553	650	339	400	619	891	612
VL11M	550	304	221	385	315	332	283
Total	54 546	51 489	45 830	44 852	49 455	55 485	48 003
Total for the period under consideration 2018						349 659	

n is the number of days in the period under consideration.

For adjustment of average values of active and reactive energy average daily temperature is calculated in a similar way for the periods under consideration:

$$T_{av} = \frac{1}{n}\sum_{0}^{n} T_i, {}^{\circ}\mathrm{C}. \quad (3)$$

Using the obtained average temperatures for the same periods in 2017 and 2018 the temperature correction factor is calculated:

$$\eta_T = \frac{T_{av(2017)}}{T_{av(2018)}}. \quad (4)$$

The volume of operations performed by electric rolling stock (ERS) of various types for March–September 2017–2018 for Shartashskaya power supply distance along odd tracks is shown in Table 1, and along even tracks – in Table 2 (units of measurement are equal to 10 thousand t • km gross). Based on the total traffic volumes on both tracks for the same periods in 2017 and 2018, the correction factor was calculated:

$$\eta_V = \frac{\Sigma V_{2017}}{\Sigma V_{2018}}. \quad (5)$$

To assess energy efficiency of introduction of RZhA-6500 reactors the calculation is as follows:

$$\varepsilon = \frac{\eta_V W_{av(2017)}}{\eta_T W_{av(2018)}}. \quad (6)$$

Specific energy consumption for transportation of 1 ton gross per 1 km is:

$$w_0 = \frac{\sum W_A}{\sum V}. \quad (7)$$

If the operating efficiency of RBFA-U-6500/3250 is taken equal to 100 %, then with the known factors η_T = 0,967 and η_V = 1,041, as well as with the average daily power consumption for the monitored period $W_{A\ av(2017)}$ = 108781,91 kW • h; $W_{A\ av(2018)}$ = 94332,68 kW • h and its reactive component $W_{R\ av(2017)}$ = 35168,18 kvar • h, $W_{R\ av(2018)}$ = 28080,71 kvar • h, efficiency of introduction of RZhFA-6500 reactors regarding active energy consumed for traction of trains will be ε_A = 1,241, for reactive energy it will be ε_R = 1,348.

If the specific energy consumption for carriage of 1 ton gross per 1 km for 2017 is taken as 100 %, then efficiency of locomotive work *E* for the same period monitored in 2018 with

Table 2

Series of ERS	Months of 2017						
	03	04	05	06	07	08	09
2ES10	0	0	0	0	0	0	0
2ES6	22312	21786	21294	20817	24649	25684	24973
VL10	8595	6925	6703	5506	7146	9074	7656
VL10K	1581	1265	1399	655	348	621	1236
VL10U	176	103	20	0	42	104	64
VL10UK	0	0	0	0	0	0	0
VL11	1412	1051	1211	1186	391	1082	861
VL11K	111	80	63	97	87	140	122
VL11M	297	271	102	116	215	312	163
Total	34485	31481	30792	28376	32878	37018	35075
Total for the period under consideration 2017						230106	
Series of ERS	Months of 2018						
	03	04	05	06	07	08	09
2ES10	0	0	0	0	0	0	0
2ES6	20587	22723	23326	22990	23723	26790	24339
VL10	8001	6918	8228	6794	8152	8693	7962
VL10K	1363	2098	1707	1406	1777	2239	2540
VL10U	412	606	199	148	988	1625	2157
VL10UK	0	0	0	29	0	0	0
VL11	1033	556	284	487	693	884	717
VL11K	232	398	129	101	243	526	365
VL11M	132	108	106	185	122	249	354
Total	31760	33406	33978	32139	35698	41006	38433
Total for the period under consideration 2018						246421	

known factors η_T, η_V, total electricity consumption $\Sigma W_{A\,(2017)}$ = 20124653 kW • h; $\Sigma W_{A\,(2018)}$ = 17451546 kW • h for train traction, and with figures calculated using the expression (7) $w_{0\,(2017)}$ = 3,243 W • h/t • gross km, $w_{0(2018)}$ = 2,928 W • h/t • gross km will be: E = 9,71 %.

The introduction of the new type of reactors took place also at the second facility which was the Uglerod traction substation of West Siberian railway, which feeds the section with intensive freight traffic of trains weighting up to 6000 tons and with a traffic volume of up to 120 pairs of trains per day. However, it is not possible to carry out an objective assessment of the parameters of energy saving [10] and the level of monetization of the energy efficiency of a two-unit RZhFA-6500 reactor according to the existing standards [11], since there is a docking station located in the immediate vicinity of Uglerod TS, which, while supplying power to a powerful single-phase traction load, causes voltage asymmetry in the phases of the longitudinal power supply line and, consequently, asymmetry of even harmonics on the rectified voltage side [12]. Moreover, RZhFA-6500 reactor is included in the traction current return circuit in series with RBFA-U-6500/3250 reactor behind the connection point of the aperiodic capacitor and of 100 Hz resonant circuit, and therefore, its contribution to operation of the L-shaped filter device is mainly devoted to the current-limiting action.

Conclusion. The proposed method for assessing operational efficiency of RZhFA-6500 reactor makes it possible to consider impact of the ambient temperature, contact and track circuits, scheduled and then executed operation of one or another type of electric rolling stock during calculation of the efficiency of a traction substation. At the same time, the calculations used the average integral values of the traffic volume and of consumption of electric energy for traction of trains for the comparable monitored periods before and after introduction of the new type of reactors into pilot operation. The calculation results clearly illustrate the comparative advantages of RZhFA-6500 reactor when it is used in the traction current return circuit instead of the old-type reactors, which makes it possible to increase the efficiency of locomotive work by almost 10 %. The latter suggests that sectional speeds can be raised, as well as energy-efficient modes of driving locomotives of trains of the standard mass at the entrance to the hill climbing sections and further on.

In general, the RZhFA-6500 reactor is an authentic and reliable design with attractive energy efficiency parameters for its further implementation on the Russian railway network as part of implementation of the Energy Strategy of JSC Russian Railways Holding company for the period up to 2015 and for the future until 2030 [13], as well as of the provisions of the Federal Law of 23.11.2009, No. 261-FZ on Energy Saving and Increasing Energy Efficiency.

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