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IMPROVEMENT OF THE REGENERATING ENERGY ACCOUNTING SYSTEM ON THE DIRECT CURRENT RAILWAYS

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Abstract: *Purpose. Monitoring of current state of quantitative indices of regenerative energy in the suburban movement, the analysis of the factors influencing its volumes and improvement the principles of the train regenerative energy accounting on the basis of it. Relevance. Development of effective measures of increase the regeneration efficiency of the electric power in system of electric traction demands comprehensive completeness of information on quantitative indices of regeneration energy volumes at all possible levels of its analysis, in particular on the corresponding sections of RS movement that will allow to establish the influence on the level of regeneration of various factors, such as parameters of traction power supply and the organization of train service. As the existing system of the regenerative energy accounting does not allow to consider the specified factors, development of the principles for increasing the efficiency of the analysis of volumes of return energy to a contact line during regenerative braking on DC rolling stock is the actual direction of researches. Collective monitoring of regeneration energy volumes by specialists of locomotive service, power supply and traffic operating departments will be essentially new approach to definition of real factors and taking effective decisions for increasing of using of regenerative energy. Scientific novelty. It's offered to consider the influence on quantitative indices of regenerative energy the parameters of traction power supply and the organization (sizes) of traffic service on sections. Practical importance. Increasing the efficiency of the regeneration energy accounting is an important element in drawing up the balance of energy for electric traction system, development of the effective methods for improvement of the conditions of regeneration in it and in estimation of its power indicators in general.*

Key words: *regeneration, energy accounting system, power consumption, power supply, traffic size*

1. Introduction

One of the main reserves of decreasing power consumption on the electrified railway transport is using of the regenerative modes of energy on train's electric braking. Using of these modes in the suburban traffic and in the fright movement on sections with considerable biases is especially important.

Efficiency of this mode is influenced by a following technical, operational and organizational factors - technical condition of regeneration system of the rolling stock (RS), the traffic volume and train schedules, voltage level on feeder of traction substations, qualification of locomotive drivers, weather conditions, etc. Without favorable train schedules (from the point of view of regenerative energy consumption), devices of braking excess energy reception and the high voltage level at the feeders of traction substations the efficiency of energy regeneration significantly decreases. Increasing of the regeneration energy accounting is an important element in drawing up the energy balance for the traction power supply system, development of effective methods for improvement the conditions for regeneration in it and estimates of its power indicators in general.

2. Relevance and purpose of the work

Development of effective measures for increasing the regeneration efficiency in the traction power supply systems demands comprehensive completeness of information on quantitative indices of regeneration energy volumes at all possible levels of its analysis, in particular on the corresponding section of the movement of Rolling Stock that will allow to establish the indicators of influence on the regeneration level various factors, such as parameters of traction power supply and the organization of train traffic. As the existing system of the regeneration energy accounting does not allow to consider the specified factors, development of the principles of increasing the regeneration

energy efficiency analysis during braking mode on DC line is an actual direction of researches.
Monitoring of current state of quantitative regeneration energy indices in the suburban transportation, the analysis of the influencing factors on its value and improvement on the basis of it the principles of the regeneration energy accounting.

3. Review of literature

In work (Hryakov, 2011) it's discussed the principles of improvement the calculation methods for calculation of traction power consumption on DC current lines in accounting zones on the basis of the devices installed on feeders of a contact line of traction substations and rolling stock (RS). It's offered the method of power consumption calculation for traction of RS with using the navigation system and a database contained the borders of locomotive crews work section. As a result in work it is received the simplified method for calculation the power consumption on accounting zones, determination of unbalance level on traction of trains in borders of sections and in borders of tariff zones, however the proposed method ignores techniques errors of measuring devices and belonging of RS to other railway companies. In works it's formulated (Davydov, 2011; Zhelezniak, 2010) the recommendations about increasing the effectiveness of routes processing system for locomotive drivers (LD) regarding the accounting of power consumption on traction, including the method for calculation of power consumption on traction of trains for a trip taking into account the actual expense of the electric power on cars heating during movement that allows to increase the accuracy and objectivity of rationing of energy consumption. The offered forms of tables in this work differ from existing by the indicators of energy consumption dynamics and results of an energy expenses and regeneration counting on locomotive crew. In Sablin and Kiyko (2011) researchers explained the dynamic errors of measurement of power consumption on traction of RS by methods of the stochastic functions theory. At the sharply variable modes of RS power consumption the dynamic error of measurement of the electric power expenses by direct current meters could increase, therefore their indications can exceed the error regulated for the static mode of a power consumption. In Nerubatsky (2013) it's discussed on the basis of the developed imitating model the algorithm of calculation of traction DC power supply system allowing to carry out the analysis of a current distribution of the regeneration energy and energy coming to traction power supply system from external power supply system. Such approach allows to conduct research of influence of energy regeneration of trains on the main indicators of traction power supply system. In works (Sablin, 2014; William and Nezevak, 2013) it's shown the influence of the traction power supply modes on regeneration energy efficiency under the conditions of restriction or lack of a traction power consumption on zones between substations.

4. The main material

Currently there is a number of the objective and subjective factors constraining use of the modes of regenerative braking in traction of trains. Using of energy regeneration depends on interests of many railway departments – like Traffic Operating, Power Supply, Locomotive, Tracks, Cars and car facilities, Department of the telemechanic, communication and interlocking. Various railway divisions have both positive and negative consequences from using of this type of electric braking on their operational indicators. Tab. 1 shows the main consequences from using the regenerative braking mode on trains for the relevant railway divisions. However, despite all existing negative factors of this mode the system effect from using of regeneration on RS is indisputable; development and improvement of conditions of regeneration braking on trains will be carried out on all further period of the electric tration operation. The analysis of regeneration efficiency according to the driver route sheets (RSh) is based on a comparative assessment of productivity indicators shown the return of the electric power at various levels of data integration at the corresponding level of the railway (fig. 1, a) and at the level of engine shed (fig. 1, b).
The primary data source about operational work, power consumption on traction and regeneration of the electric power is the RSh. Initial processing of these data is carried out in engine sheds in the specialized automated system ЛОКБРИГ then the data come to computer centers of the railway. Data fom ЛОКБРИГ form a basis for drawing up forms for accounting ТХО-1, ТХО-2, ТХО-9 which can be used for the analysis of regeneration efficiency in the directions of given railway line or network of lines.

Table 1. The factors defining the efficiency of the energy regeneration

Railway Divisions	Positive factors	Negative factors
Locomotive service	1. Decreasing the costs on traction; 2. Increasing of the technical speed, average kilometric performance and productivity of RS; 3. Wear decreasing of the equipment on RS.	Big (than in the traction mode) probability of emergence of circular fires on collectors of engines caused by dependence of the braking mode on line voltage
Power supply	1. Decreasing of the energy losses in the lines; 2. Increasing of the voltage level in line	1. Voltage jump in a line; 2. Increasing of voltage in a line up to 4 kV under the absence of consumers
Cars and car facilities	Decreasing of the mechanical brakes equipment wearing of cars	Deterioration of dynamics of the movement of continuous fright trains
Traffic Operating	1. Increasing of traffic safety of trains and capacity of lines; 2. Decreasing in time of train processing after exhaust	
Track maintenance	Reduction of superstructure pollution by metal dust	Creeping of the rails on section with considerable descents
Signalling and interlocking		Increased level of hindrance

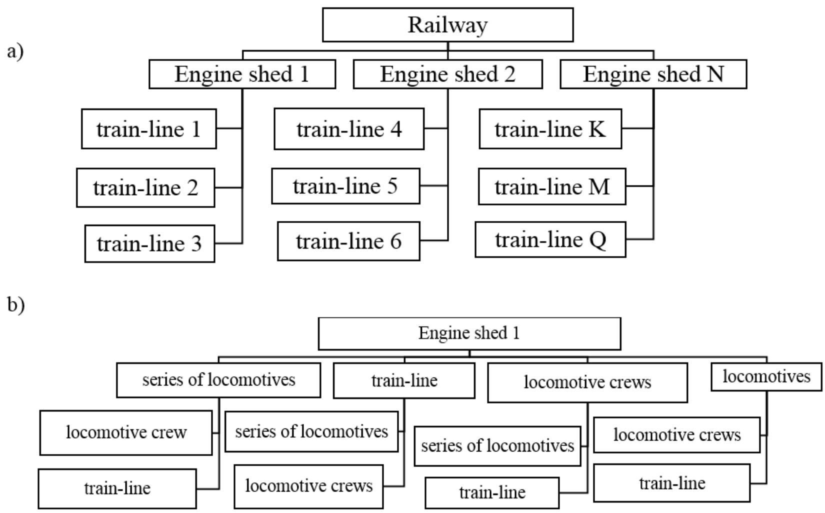

Fig. 1. Levels of the analysis of regeneration efficiency:a) railway; b) engine shed

Modern systems of the accounting of the electric power in the modes of traction and regeneration do not differ and include the following main stages, that are presented at fig. 2.

On the basis of reports of TXO-1 the report of TXO-2 are calculated the electric power expenses at a level of railway, separated by series and types of the movement. In these forms is defined the indicators of expenses on movement on work unit (gross kilometre tonnage), on a unit of weight of the train and percent of economy on separate series of electric locomotives and types of the movement.

This accounting system has the following shortcomings:

1. Mixing of the calculated indicators passing multistage structure of data processing and the measured by meters;
2. Absence of the division on balance zones. During the work of RS on the long traction shoulders relating to various railwas, electric power consumption rates for locomotive crews are culculated on the basis of the train shoulders not taking into account whether this shoulder end within the railway or beyond its limits.

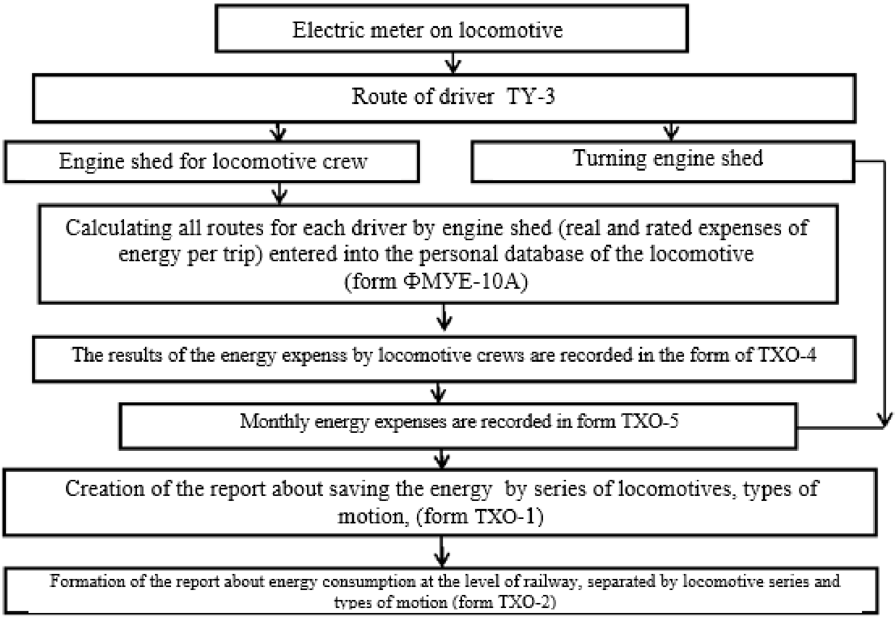

Fig. 2. Structure of the regeneration energy accounting system

In this work monitoring of regeneration energy volumes was executed for local services of the electric trains ЭПЛ2Т which are operated in Dnepropetrovsk engine shed (РПЧ-1) of the Pridnieprovskaya railway and equipped with system of recuperative and rheostatic braking. All main directions of movement of electric trains were observed - namely Pyatikhatki, Chaplino, Lozovaya, Krivoy Rog, Donetsk. In the analysis were processed 2150 driver's sheets during 2014. Doubtful data of traction and regeneration (the faulty meter in the traction or regeneration mode or its absence, casual or intended distortion of indications) in statistical material according to DSh in the analysis were not considered.

Installation of meters allows to keep account and control of the electric power on RS, but in the analysis of their indications there are some errors which are connected with the fact that the meter of traction measures in traction mode mesures not only power consumption on traction, but also power consumption for own needs and heating of salons of trains.

As an indicator of using the regeneration mode could be so-called coefficient of regeneration – the relation of regenerative energy on i-m level to the energy spent for traction:

$$k_i^e = \sum_{m=1}^{n} W_{Rm} \Big/ \sum_{m=1}^{n} W_{Am} \qquad (1)$$

where:

W_{Rm} – the volume of the electric power returned according to DSh, kW · h;

W_{Am} – a full expense of the electric power according to DSh, kW · h;

n – number of the studied MM.

Fig.3 shows the statistical distributions and the main probabilistic characteristics of power consumption on traction, regenerated energy and coefficient of regeneration of electric trains of ЭПЛ2Т averaged on all section of engine shed РПЧ-1 during 2014. According to numbers of electric trains of ЭПЛ2Т related to the engine shed РПЧ-1 there is the essential dispersion of regegeration energy values (fig. 4). This fact could be explained by work of these electric trains on the unfavorable sections with adverse conditions for regeneration.

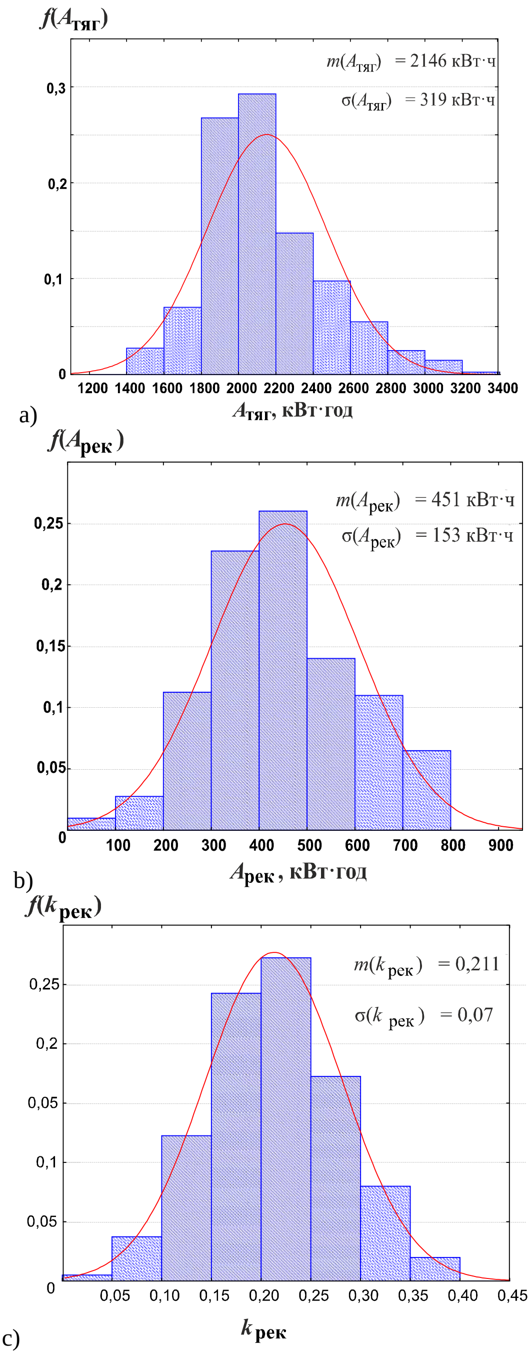

Fig. 3. Statistical distributions of power on traction (a), regeneration energy and regeneration coefficient for electric trains ЭПЛ2Т on engine shed РПЧ-1

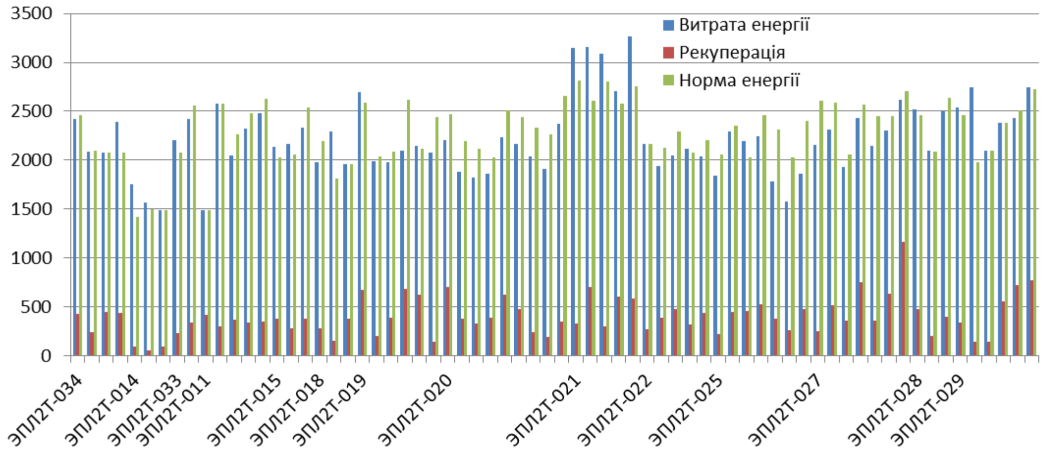

Fig. 4. Chart of the energy expense and energy regeneration of electric trains and their rated values

Efficiency analisys of the accounting of regeneration energy in a suburban movement is complicated because very often one locomotive crew could be related to many routes. Thus, readings of meters are carried out in general for all trips. Definition of the influence of the direction on quantitative indices of energy regeneration is in that case complicated.

Existence of cases of these doubtful results on DSh (the faulty meter or its absence, casual or deliberate distortion of its indications) can lead to obtaining incorrect values of this indicator and to incorrect results of the analysis. Therefore more rational indicator of regeneration efficiency during regenerative braking is (Davydov, 2011) so-called specific regeneration – the relation of the return volume of the electric power to the gross kilometre tonnage:

$$k_i^{QL} = \sum_{m=1}^{n} W_{Rm} \Big/ \sum_{m=1}^{n} (QL)_m \qquad (2)$$

where:

$(QL)_m$ – gross kilometre tonnage, 10^4 tkm gross.

Also in Davydov (2011) it is offered to estimate a volume indicator of application of regenerative braking in general on structural division (railway) according to the gross kilometre tonnage work from DSh with regeneration classified by the traction mode as the relation

$$\gamma_p = \sum_{m=1}^{n_p} (QL)_m \Big/ \sum_{m=1}^{n} (QL)_m \qquad (3)$$

where:

n – number of DSh in general classified by the traction mode;

n_p – number of DSh with regeneration.

According to the TXO-1 forms could be made the retrospective statistical analysis of energy consumption on rated levels in the decreasing order: type of the movement → locomotive series → train-section → category of trains.

The analysis of efficiency of the accounting of regenerative energy includes the following main stages:

– at a preparatory stage organizational issues are resolved, acquaintance with sites of work of locomotive crews and structure of energy consumption on traction is carried out;

– direct power inspection during which it is carried out collection of information about work of locomotives and consumption of energy on traction in engine shed, and also drawing up cards of energy consumption on traction classified on series of locomotives and types of the movement, on unproductive expenses of energy resources and the main operational indicators which influence traction energy consumption (Nerubatsky, 2013).

Based on this it is possible to tell that system of the accounting of regenerative energy is a comparison tables in the Excel program, where the coefficients for calculations are received directly from head department of Ukrzaliznytsa.
During research of this problem the following data on DSh of the engine shed РПЧ-1 were obtained:
– direction (section);
– date of a trip;
– series, number of the electric train;
– Driver's full name;
– amount of the consumed and regenerated energy for a trip;
– consumption and regeneration of energy on a section.
Electric power expenses on traction on Pridnieprovskaya railway for 12 months in 2014 on a section of multiple-unit engine shed according to the ТХО-2 form are presented in tab. 2.
According to the tab. 2 the work in relation to last year decreased by 15,47%, but the expenses of the electric power were reduced by 19,04%. The planned specific norm is reduced upon last year by 3,95%. The actual specific losses decreased till last year by 3,75% and to the plan for 0,7%.
Regeneration according to plan for 2014 was 4264,0 10^3 kW · h (РПЧ-1 – 4143,0 10^3 kW · h; РПЧ-3 – 121,0 10^3 kW · h) actually value was 4256,94 10^3 kW · h (РПЧ-1 – 4137,9 10^3 kW · h; -3 – 117,8 10^3 kW · h; РПЧ-4 – 1,24 10^3 kW ·h). Underfulfilment of the plan made 7,1 thousand kW · h. In РПЧ-1 specific regeneration increased in comparison of the past (2013) years by 2,38 kW · h / 10^3.tkm.br. In РПЧ-3 specific regeneration compared to last year decreased on 0,11 kW · h / 10^3.tkm.br. (from 1,94 kW · h / 10^3.tkm.br. in 2013 to 1,83 kW · h / 10^3.tkm.br. in 2014). The cause of the decreased level of regeneration was high level of voltage in a contact line (up to 3,8 ... 3,9 kV) on a section Akimovka-Sivash at which the scheme of regeneration didn't not gather. This section is one of the main for implementation of regenerative braking due to existence of a considerable bias.

5. Conclusions

The analysis of documentation showed that the system of the accounting of regenerative energy on railway transport is imperfect regarding estimation of regenerative energy efficiency on section of operation of RS as quantitative indices of regenerative energy are influenced significantly by a number of operational and technical factors such as the traffic volume and the organization of train service, voltage level on substations etc. Using of proposed additional indicators will give the chance to solve this problem, to improve the system of estimation of the quality of regenerative energy, and, above all – to increase the energetic and economic efficiency of regenerative braking.

Table 2**Electric power expense on draft of trains on Pridnieprovskaya railway**

Engine shed	Work, million tkm br	Rated regenerative energy, kW of h / 10^4 tkm. br	Electric power expense, 10^3 kW h		Actual expense, 10^3 kW h		Specific expense, kW h / 10^4 tkm br.	Economy (-) an surcharge (+)			
								with losses		without losses	
			with losses	without losses	with losses	without losses	10^3 tkm. br	10^3. kW h	%	10^3. kW h	%
RPCH-1	1660,07	209,53	34783,5	29601,14	34700,4	29400	209,03	- 83,58	- 0,3	- 201	- 0,7
RPCH-2	293,85	173,78	5106,61	4343,52	4844,24	4104	164,85	- 262,4	- 5,1	- 239	- 5,5
RPCH-3	644,71	207,9	13403,5	11417,18	13218,9	11211	205,04	- 184,6	- 1,4	- 206	- 1,8
RPCH-4	91,29	238,01	2172,79	1812,11	2114,40	1792	231,61	- 58,39	- 2,7	- 20,1	- 1,1
NRP 2014	2689,92	205,53	55285,4	47016,3	54877,9	46507	204,01	- 407,5	- 0,7	- 509	- 1,1
NRP 2013	3182,21	213,977	68092,2	58532,8	67447,5	57447	211,95	-	-	-	-

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