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Calculation of the parameters of hybrid shunting locomotive

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Abstract

The major part of the locomotives under operation requires increase of the maintenance and repair expenditures by 40-60% in comparison with the modern models. Creating a hybrid shunting locomotive is an effective solution to the shortage of finance and the high cost of a new locomotive fleet. It was the analysis of methods and models for determining the technical and economic parameters of hybrid vehicles, which have been developed by scientists from different countries. It was created a mathematical model to determine the optimum parameters of the motor and energy storage, depending on the operating conditions. It was calculated coefficient of technical level, life cycle and on the basis efficiency ratio is defined hybrid shunting locomotive for different operating modes, which fully confirms the efficiency of introduction this type of locomotives instead of the diesel locomotive series CHME3. Traction calculations confirm the efficiency of proposed solutions.

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Keywords: Hybrid shunting locomotive; rational parameters; model; power plant; storage

1. Introduction

The state of the shunting locomotive stock of Ukrainian railways fails to satisfy the railroad transport needs and to meet European transportation service quality standards in Sergienko N. (2010), Lashko A., Samsonkin V., Goncharov

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A., Konovalov A. (2006) throughout many parameters. The major part of the locomotives under operation requires increase of the maintenance and repair expenditures by 40-60% in comparison with the modern models.

Problem statement. The analysis of the shunting locomotive operation has revealed that they are characterized by sharp changes in the operation mode whereby 50-60% of the operational time is taken by the run at idle speed, 45-70% - under low loads and only 2-5% of the operational time – under the nominal ones.

One of the methods to increase the cost effectiveness of operation of the shunting locomotive is replacement of diesel generator unit with the low power energy storage units. Apart from the economic factor, such a locomotive modernization will allow to improve environmental values.

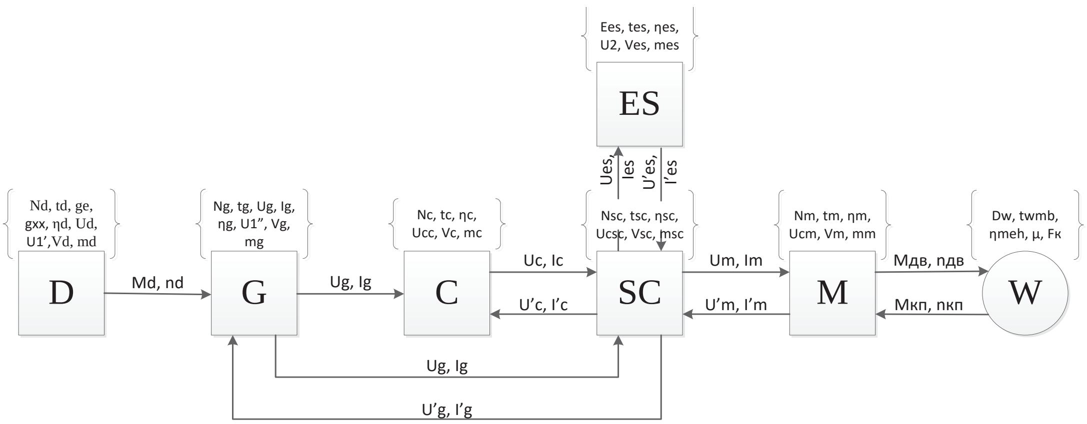
The attempts to implement hybrid power transfer at the railroad transport have been made all over the world in Falendysh A.P., Volodarec N.V. (2010). Nevertheless, all operated shunting locomotives produced in Ukraine use the transmission without energy storage.

Analysis of the recent studies and publications. Many scientists from different countries have been conducting researches to determine the performance parameters of motive power for a long period of time in Wolfs P. (2005), Donnelly, F.W.; Cousineau, R.L.; Horsley, R.N.M. (2004), Akli, C.R.; Sareni, B; Roboam, X; Jeunesse, A. (2009), Lohner, A.; Evers, W. (2004), Yap, H.T.; Schofield, N.; Bingham, C.M. (2004), Cousineau, R. (2006), Liudvinavičius, L. Lingaitis, L.P. (2011), Liudvinavičius L., Lingaitis L.P. (2010). Under the analysis results for the scientists' works, the methods of selection of power unit parameters have been broken down into five categories: the methods based on the average locomotive performance indicators; the methods based on the comparative evaluation of various options with the total power selected under the primary standard depending on the predetermined locomotive operation mode (with and without recuperation); the methods based on loading of the power unit while operated at certain areas (the power unit is selected under the average power and the energy storage –under energy deficiency); the methods under which the energy storage is selected based on the performance indicators of its exploitation.

It has been discovered that these methods fail to account for either the cost parameters, the actual operation conditions, the dimension and mass indicators of the energy storage and power unit or these parameters combined. For this purpose, it is necessary to improve the reviewed methods taking into account the gaps hereinabove.

Objective. The objective of the article is to calculate the parameters of hybrid shunting locomotive and elaborate the corresponding models.

Research results. There are many varieties of hybrid locomotive traction drive systems [3-11]. They use various patterns and elements. Based on the analysis of these systems, the generalized schematic structure of power circuit of shunter with hybrid power transmission (fig.1) has been created.



D - diesel; G - traction generator; C- converter; SC - control system; ES - energy storage; M - traction motor; W – wheel set

Fig. 1. Structural diagram of the shunter locomotive power circuit with hybrid transmission.

The energy is transferred to the generator from a diesel, then to a converter, if available, and then to the control system. The control system connects the energy storage, the electric traction and the traction generator. In the traction mode energy from the power-plant is transmitted to the traction motors through the converter, if available, and to the management system. Motors can also powered from energy storage in the case where the power-plant power is not enough. If the locomotive operates in idling and low loads mode, the power-plant replenishes reserve of energy in the energy store. We can use traction motors as generators to charge the energy storage in the event that engines operating in the mode energy recovery during braking train.

To determine the technical and economic parameters of the hybrid locomotive model was prepared in accordance. The objective function model is as follows:

$$Uzag = f\left(U0, \underbrace{F_D, F_G, F_C, F_{SC}, F_{ES}, F_M, F_W}_{F}, U1\left(N_{eng}\right), U2\left(E_{ne}\right), U3\left(N_{eng}, E_{ne}\right), kz\right) \rightarrow \min, \qquad (1)$$

where: U0 – cost of basic locomotive power-plant, UAH.; F – set of hybrid locomotive parameters, which includes diesel parameters set F_D, traction generator parameters set F_G, converter parameters set F_C, control system parameters set F_{SC}, energy storage parameters set F_{ES}, traction motor parameters set F_M, wheel set parameters set F_W; $U_1(N_{eng})$ – dependence of power-plant cost from its power, UAH; $U_2(E_{ne})$ – dependence of energy storage cost from its power intensity, UAH; $U_3(N_{eng}, E_{ne})$ - reducing of fuel costs after modernization, UAH; kz –load factor of locomotive during the year.

The input data for the calculation is: vector of power-plant power Nfi, which was determined during the trip $\Delta\tau$ minutes. Vector Nustj of power plant estimated power is formed based on Nfi. Power intensity of energy store Ei,j is determined at each stage of changing the required locomotive's power in the following way

$$E_{i+1,j} = \begin{cases} E_{i,j} - \left(Nf_{i+1} - Nust_j\right)\Delta\tau, if \ \mathrm{Nf_j > Nust_j}, \\ E_{i,j}, if \ \mathrm{Nf_j = Nust_j}, \\ \begin{cases} E_{i,j} - \left(Nf_{i+1} - Nust_j\right)\Delta\tau, if \ E_{i,j} - \left(Nf_{i+1} - Nust_j\right)\Delta\tau \le Eo, \\ E\hat{\imath}, if \ E_{i,j} - \left(Nf_{i+1} - Nust_j\right)\Delta\tau > Eo, \end{cases} , if \ \mathrm{Nf_j < Nust_j}. \end{cases} \qquad (2)$$

The dependence of power plant power Nengj from power intensity of energy storage Enej is as follows

$$Neng_j = Nust_j = f\left(Ene_j\right), where \ Ene_j = \left|\min\left(E^{\langle j \rangle}\right)\right|. \qquad (3)$$

For valuation diesel generator was obtained dependence prices of diesel generator depending on its power through a long series of discrete values approximating prices in the dealer network on diesel generators manufactured by leading companies. Dependence of diesel-generator setting cost from its power U1(Neng), UAH, is the following

$$U1 = 1,099 \cdot Neng^2 + 943,46 \cdot Neng + 131885 \qquad (4)$$

It was formed the dependence of energy storage cost from its power intensity U2(Ene),UAH:

$$U2 = u2 \cdot Ene, \tag{5}$$

where: u2 – specific cost of energy store, UAH / MJ.

The fuel costs reducing after modernization U3, UAH:

$$U3_j = \left(Gekspl - G1(Neng_j)\right) \cdot \mathrm{ct} = \left[\sum_{i=1}^{n}\left(Nf_i \cdot ge0 \cdot \frac{\Delta\tau}{3600}\right) - \sum_{i=1}^{n} G_{i,j}\right] \cdot \mathrm{ct}, \tag{6}$$

where: ct – fuel cost, UAH/kg; ge0 –specific fuel consumption by diesel engines, kg / kW · h.

$$G_{i+1,j} = \begin{cases} Nust_j \cdot gen \cdot \dfrac{\Delta\tau}{3600},\ if\ \mathrm{Nf}_{j+1} > \mathrm{Nust}_j \\ \begin{cases} Nust_j \cdot gen \cdot \dfrac{\Delta\tau}{3600}, if\ E_{i,j} - \left(Nf_{i+1} - Nust_j\right)\Delta\tau \le Eo, \\ 0, if\ E_{i,j} - \left(Nf_{i+1} - Nust_j\right)\Delta\tau > Eo. \end{cases}, if\ \mathrm{Nf}_{j+1} = 0 \\ \begin{cases} Nust_j \cdot gen \cdot \dfrac{\Delta\tau}{3600}, if\ E_{i,j} - \left(Nf_{i+1} - Nust_j\right)\Delta\tau \le Eo, \\ Nf_{i+1} \cdot gen \cdot \dfrac{\Delta\tau}{3600}, if\ E_{i,j} - \left(Nf_{i+1} - Nust_j\right)\Delta\tau > Eo. \end{cases}, if\ 0 < \mathrm{Nf}_{i+1} < \mathrm{Nust}_j \end{cases}, \tag{7}$$

where: gen – specific fuel consumption by new diesel engines, kg / kW · h.

The model was tested for adequacy. The error was about 3%, which is satisfactory for calculations.

The parameters of hybrid locomotives several options depending on the type of work performed. The duration of the life cycle for diesel locomotive shunting CHME3, who works for the export operation is shown in Fig. 2

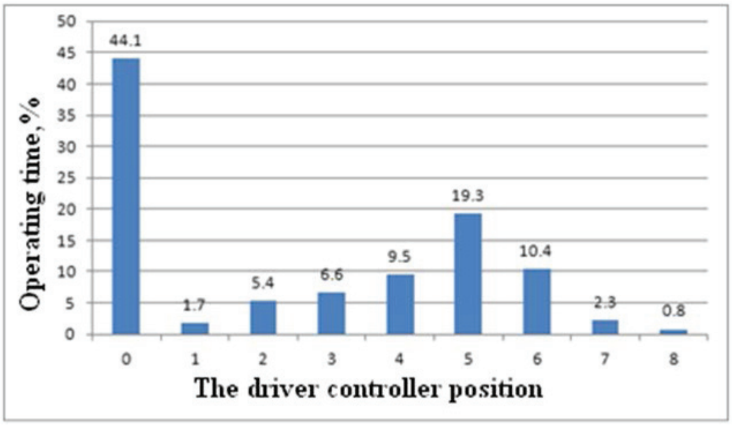


Fig. 2. The dependence of the percentage of the total time of the locomotive on the position of the controller in the performance of the export.

There were estimates of parameters of the hybrid locomotive for this cycle, the results of which are shown in Fig. 3.

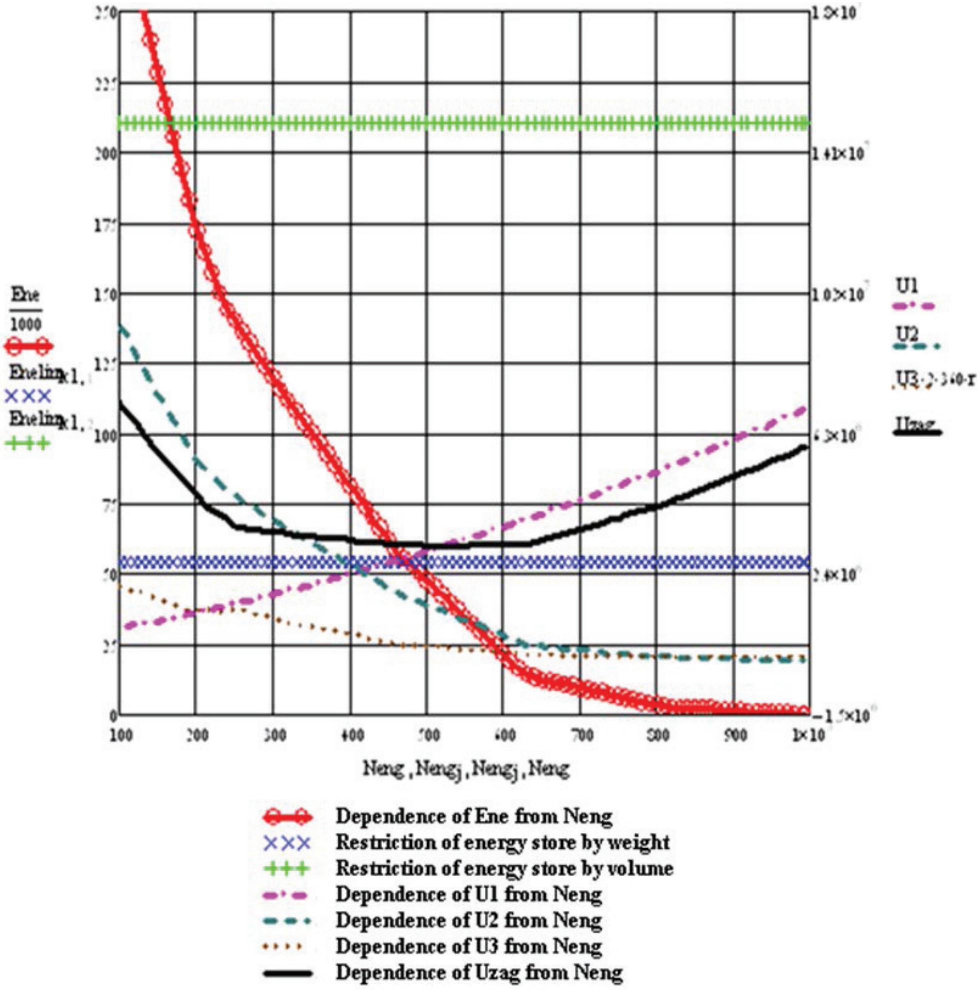


Fig.3. The energy storage device with the restrictions and cost parameters for the modernization of the export performance.

It was chosen the appropriate parameters of hybrid locomotives: Nengopt - optimum power of diesel-generator setting and Ene - optimal power intensity of energy storage depending on the type of executable their work, namely:

- For shunting operations: Nengopt = 150 kW; Ene = 20 MJ;
- For working on marshalling yard: Nengopt = 200 kW; Ene = 50 MJ;
- For the export operations: Nengopt = 530 kW; Ene = 50 MJ.

It was the comparative analysis of two locomotives for basic diesel locomotive CHME3 and hybrid at its base. Calculations made using Mathcad software for the export operation to the section of Stakhanov-Popasna with train weighing 500 tons. Locomotive rezultatativ parameters taken from the previous calculations for the export operation.

Results traction calculations are presented in Table 1.

Table 1. Results of traction calculations.

Index	CHME3	Hybrid CHME3	Difference, %
Total fuel consumption per trip, kg	166	120	-27,7
Specific fuel consumption, kg / 104 tkm gross	83,1	60,1	-27,7
Specific coal equivalent consumption, kg / 104 tkm gross	118,9	86	-27,7
Time of train movement in the mode of traction, min	36	36	0
Time of train movement in the modes of idling add braking, min	19	19	0
Total time of train movement on the section	55,2	55,2	0
Average energy conversion efficiency, %	19,3	26,7	38,3
Maximum energy conversion efficiency, %	20,5	28,3	38,0
Energy conversion efficiency per trip, %	14,9	20,6	38,3

It was improved method of determining technical level of diesel locomotives, selected range of indicators characterizing the hybrid drive and calculated rate technical level of hybrid shunter locomotive based on CHME3 compared to the prototype. It is equal to 1,1, which proves the effectiveness of the technical operation of the locomotive.

It was designed life cycle cost indicators of CHME3 and of hybrid locomotive at its base. It was found that the use of hybrid locomotive based CHME3 on the operation the overall economic effect of one diesel locomotive will be 2.2 mln. UAH.

Calculated efficiency factor of the introduction of hybrid shunting locomotive diesel instead CHME3 series which takes into account technical, economic and environmental performance locomotive.This coefficient has the following values:

- For shunting operations – Кef(shunt.)=1,7
- For working on marshalling yard – Кef(hill.)=1,9
- For the export operations – Кef(exp.op.)=2,4

It fully confirms the efficiency of the implementation of this type of locomotive instead CHME3 for all operating modes.

2. Conclusions

1. It was analyzed the technical conditions of the shunter locomotives park of Ukrzaliznytsia.
2. An Analysis of the choice of parameters of the hybrid locomotive was made.
3. Model selection of technical and economic parameters of hybrid shunting locomotive was built.
4. There have been calculations and selected parameters of hybrid locomotives for different modes of operation based on the model.
5. Traction calculations confirm the effectiveness of proposed solutions. Fuel consumption hybrid engine compared to the base has been reduced by 27.7%.
6. Odds technical level and life cycle was calculated. Efficiency ratio hybrid shunting locomotive for different modes of work were identified. The results fully confirm the effectiveness of this type of locomotives instead CHME3 series.

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