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Determination of implementation efficiency of hybrid shunting diesel locomotive, taking into account the type of field operation

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Summary. One of the methods for increase in exploitation efficiency of shunting diesel locomotives is substitution of the existent diesel-generator set to the set of low power with an energy store, i.e. creation of a hybrid drive. The whole world attempts to implement the hybrid power transmission on rail transport [1-5]. However, such locomotives are not exploited in Ukraine. The optimization model for determination of rational technical and economic indexes of the hybrid shunting diesel locomotive has been developed, on the basis of which parameters of hybrid locomotives for different types of field operation have been defined. The efficiency coefficient of the hybrid shunting locomotive on the basis of the diesel locomotive of the ChME3 series has been calculated. It has been proved that implementation of the hybrid shunting diesel locomotive instead of the diesel locomotive of the ChME3 series improves technical, economic and ecological indexes of the locomotive.

Key words: hybrid diesel locomotive, diesel-generator set, energy store, efficiency coefficient, life cycle, technical level, ecological indexes.

INTRODUCTION

Under conditions of decrease in turnover and wear of the locomotive park, it is necessary to decide the problem of providing of effective work of the traction rolling stock (TRS). There arises a need for updating of the traction rolling stock of Ukrzaliznytsia. This task can be fulfilled by purchase of a new rolling stock or by modernisation of the existing one. The latter way is the most effective method for lengthening of life of locomotives, especially under conditions of deficit of finances and high cost of a new locomotive park.

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

Most of the time shunting diesel locomotives work in the idle mode. Use of a powerful diesel-generator is ineffective for shunting works. High nominal power is necessary for shunting-export locomotives, which also transfer the train to nearby stations and junctions, except for shuntings at stations.

One of the methods for increase in exploitation efficiency of shunting diesel locomotives is substitution of the existent diesel-generator set to the set of low power with an energy store, i.e. creation of a hybrid drive. The whole world attempts to implement the hybrid power transmission on rail transport [6-10]. However, such locomotives are not exploited in Ukraine.

The aim of the article is determination of substitution efficiency of the basic hybrid diesel locomotive ChME3 to the hybrid one, created on its basis, for different types of field operation.

OBJECTIVES
THE MAIN RESULTS OF THE RESEARCH

Recently Implementation of the hybrid shunting diesel locomotive instead of diesel locomotive of the ChME3 series must improve technical, economic and ecological indicators of the locomotive.

There has been developed an optimization model for determination of rational technical and economic indexes of the hybrid shunting diesel locomotive, which is the model of nonlinear programming. The implied view of its objective function looks like:

$$\begin{aligned} &Uzag(N_{eng}, E_{ne}) = f(U0, U1(N_{eng}), U2(E_{ne}), \\ &U3(N_{eng}, E_{ne}), U4(N_{eng}, E_{ne}), kzm, kv, kz) \rightarrow \min \end{aligned} \quad (1)$$

where: $Uzag\ (N_{eng,} E_{ne})$ – general costs, related to modernisation; $U0$ – the cost of the basic diesel-generator, UAH; $U1\ (N_{eng})$ – the cost of the diesel-generator, depending on its power, UAH; $U2\ (E_{ne})$ is the cost of energy stores, UAH; $U3\ (N_{eng,} E_{ne})$ – reduce of costs on fuel after modernisation, UAH; $U4\ (N_{eng,} E_{ne})$ – reduce of costs on service and repair after modernisation, UAH; kzm – amount of changes per twenty-four hours; kv – amount of days of use of the locomotive per year; kz – a load coefficient of the locomotive per twenty-four hours.

On the basis of this model calculations were made and corresponding parameters of hybrid locomotives were defined, depending on the type of field operation.

E.g, it was defined for the district, served by the Locomotive depot of Popasna of the Donetsk railway, that performance of easy shunting work requires the hybrid diesel locomotive with the power of the diesel-generator of 150 kW and energy capacity of the energy store of 20 MJ; work on a hump - 200 kW and 50 MJ correspondingly; export work - 530 kW and 50 MJ correspondingly.

In order to estimate how effective implementation of the hybrid shunting diesel locomotive is, it is necessary to use a criterion that would take into account all these indexes. It is suggested to define this index according to the procedure, presented in Fig. 1.

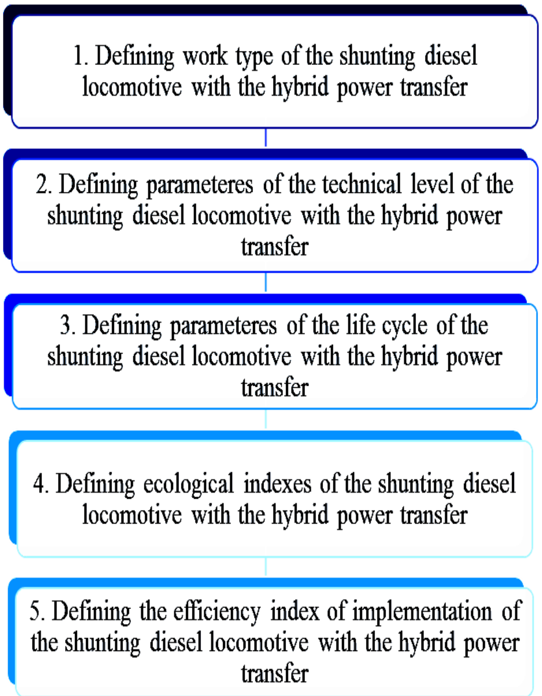

Fig. 1. Estimation procedure of implementation efficiency of the shunting diesel locomotive with the hybrid power transfer

We use the efficiency coefficient of implementation of the shunting diesel locomotive with the hybrid power transfer as such an index. We will calculate this coefficient by the formula:

$$K_{ef} = \frac{\sum_{i=1}^{i=3} K_i \varphi_1(i)}{\sum_{i=1}^{i=3} \varphi_1(i)}, \qquad (2)$$

where: K_{ef} – the efficiency coefficient of implementation of the hybrid shunting diesel locomotive; K_1 – a coefficient of the technical level of the hybrid shunting diesel locomotive; K_2 – a coefficient of the life cycle of the hybrid shunting diesel locomotive; K_3 – a coefficient of ecological indexes of the hybrid shunting diesel locomotive; $\varphi_1(i)$ – a function that regulates weight of parameters in the ranged sequence for determination of the efficiency coefficient of implementation of the hybrid shunting diesel locomotive.

Criterion of the technical level K_1 characterizes a new design and engineering development, regarding the existent technological objects of the same productive application, and according to the method of weight coefficients. It is calculated by the formula [2, 3]:

$$K_1 = \frac{\sum_{i=1}^{i=s} K_p \varphi_2(i)}{\sum_{i=1}^{i=s} \varphi_2(i)}, \qquad (3)$$

where: K_1 – a criterion of the technical level; k_p – a parameter that is a ratio of numerical parameters of a new development to parameters of the existing objects for rational categories (decrease in a parameter corresponds to technological progress) and irrational categories (decrease in a parameter does not correspond to technological progress); $\varphi_2(i)$ – a function that regulates weight of parameters in the ranged sequence for determination of the efficiency coefficient of the technical level.

The greater value of coefficient K_1 corresponds to the best of the compared locomotives.

The evaluation method for the technical level of the hybrid shunting diesel locomotive is proposed, the algorithm of which is presented in Fig. 2.

According to the presented algorithm there was calculated the technical level of the designed hybrid locomotive on the basis of ChME3 for different types of field operation. Results are presented in Table 1.

Table 1. Coefficient of the technical level K_1 of hybrid shunting diesel locomotives on the basis of ChME3

Type of locomotive	Coefficient of the technical level K_1
Hybrid ChME3 for work at the station	1,1
Hybrid ChME3 for work on a hump	1,18
Hybrid ChME3 for the export work	1,23

The coefficient K_2, included into the formula (2), is determined as a ratio of the life cycle cost of the basic locomotive to the hybrid one, i.e.:

$$K_2 = \frac{LLC_{Tb}}{LLC_{Tg}}, \qquad (4)$$

where: LLC_{Tb} – the cost of the life cycle of the basic shunting diesel locomotive, UAH; LLC_{Tg} – the cost of the life cycle of the hybrid shunting diesel locomotive, UAH.

As for railroads of Ukraine, the cost of the life cycle of the traction rolling stock, being purchased or modernised, is the sum of all the costs – one-time and current on all the stages, and is determined, taking into account the discount factor by the formula [11-16]:

$$LCC_T = \sum_{t_p}^{t_n+T} (K_t \cdot \alpha_t + I_t \cdot \alpha_t - L_t \cdot \alpha_t) = \sum_{t_p}^{t_n+T} (K_t^p \cdot \alpha_t + K_t^e \cdot \alpha_t + I_t^p \cdot \alpha_t + I_t^e \cdot \alpha_t - L_t \cdot \alpha_t) \qquad (5)$$

where: K_t – capital (one-time) investments in a year t of the life cycle in the production field (K_t^p) and exploitation (K_t^e) of the traction rolling stock, UAH; I_t – current costs in a year t of the life cycle in the production field (I_t^p) and exploitation (I_t^e) of the traction rolling stock, UAH; L_t – the depreciated cost of capital funds, that are taken out in a year t of the life cycle, UAH; T – duration of the life cycle

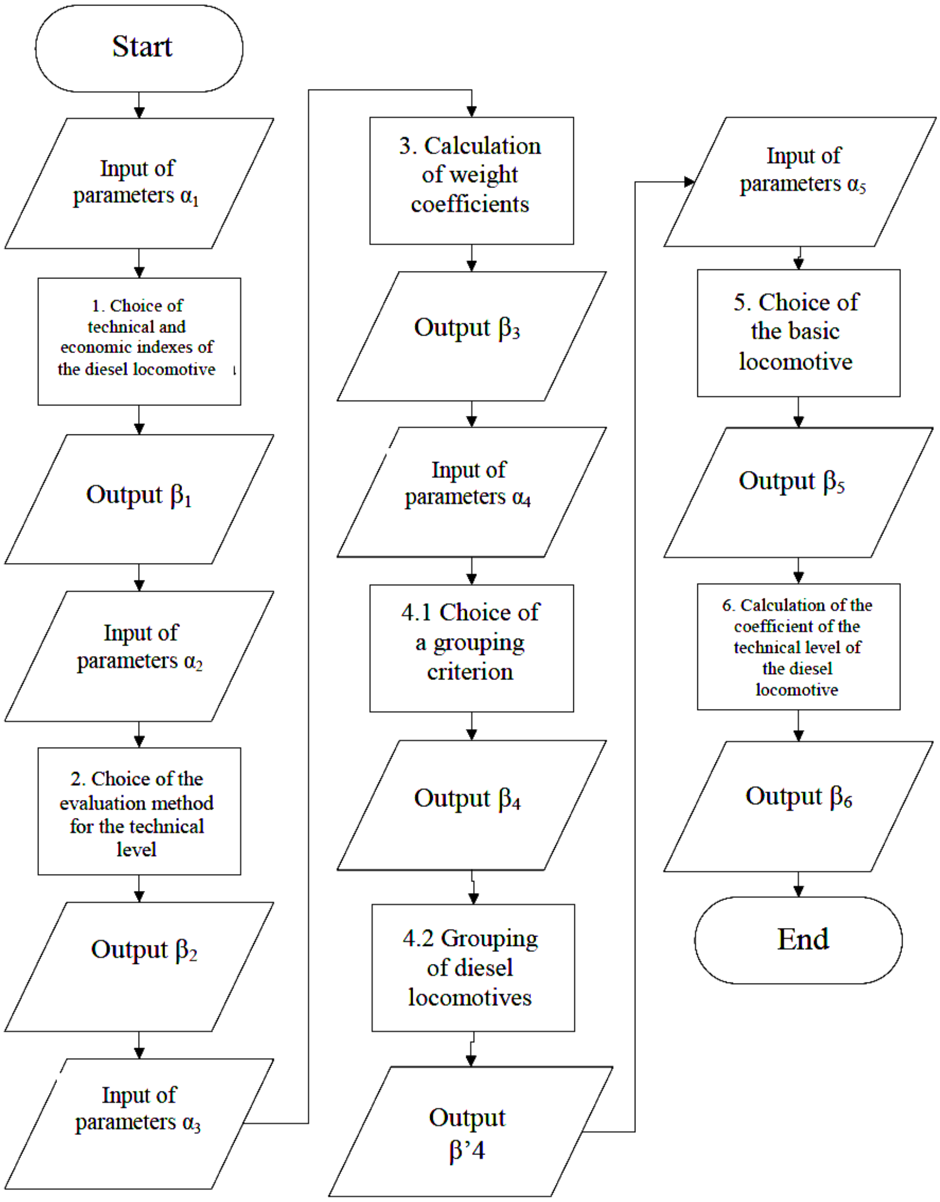

Fig. 2. Algorithm of the evaluation method of the technical level of the hybrid shunting diesel locomotive

of the life cycle of the traction rolling stock, year; T^p – duration of the production stage of the traction rolling stock, year; T^n – duration of the exploitation stage of the traction rolling stock, year; t_n – an initial year of the life cycle of the traction rolling stock; t_p – a year of purchase of the traction rolling stock.

A discount α_t factor is calculated by the formula:

$$\alpha_t = (1+E_d)^{t_p - t} \tag{6}$$

where: E_d is a discount norm,
t_p is a calculated year of the life cycle,
t is a year of the life cycle, costs of which are given according to a calculated year.

A calculated year is a year, for which costs of other years of the life cycle are given.

Creation and exploitation of the locomotive require certain capital and exploitation costs during the life cycle that is divided into three stages: development; exploitation, repair and modernisation; utilization.

Fig. 3 presents results of calculation of the life cycle of the hybrid diesel locomotive on the basis of ChME3 and the basic locomotive for implementation of shunting work at stations.

Calculations are executed for a period of 20 years – it is time from modernisation (or capital repairs) of the locomotive to its complete take-out of exploitation. Fig. 4 presents the change of economic effect from hybridization during the calculated period.

Thus, total economic effect from one diesel engine will be 3,5 million UAH, while using the hybrid diesel locomotive on the basis of ChME3 during exploitation.

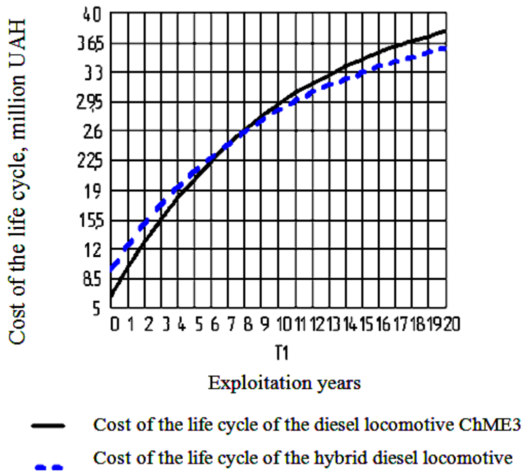

Fig. 3. Cost of the life cycle of diesel locomotives ChME3 and the hybrid one on its basis

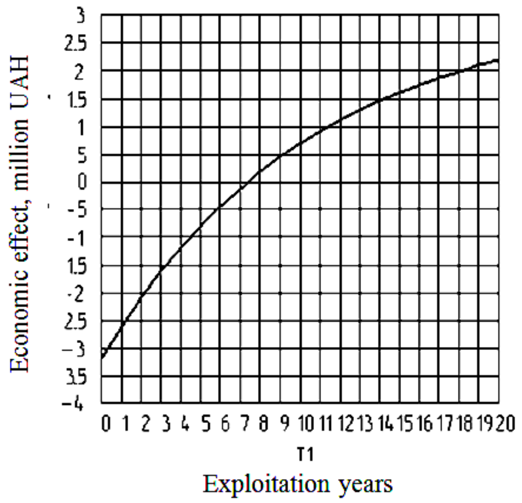

Fig. 4. Economic effect from implementation of the hybrid shunting diesel locomotive on the basis of ChME3

The coefficient of K_3 is calculated as a ratio of losses assessment due to natural environment pollution in a year t during exploitation of the basic locomotive to the hybrid one:

$$K_3 = \frac{Yb_t}{Yg_t}, \qquad (7)$$

where: Yb_t – is losses assessment due to natural environment pollution in a year t during exploitation of the basic locomotive, UAH [5, 17-20]; Yg_t – is losses assessment due to natural environment pollution in a year t during exploitation of the hybrid locomotive, UAH.

The value of Yb_t is calculated by the formula:

$$Yb_t = \gamma' \delta f \sum_{i=1}^{n} A_i' m_{bi}, \qquad (8)$$

where: γ' –a norm of specific costs, UAH/oil equivalent; δ –an index of relative insecurity of atmospheric air pollution above territories of different types; f –a coefficient that takes into account character of admixtures dispersion in the atmosphere; $A'i$ –an index of relative activity of admixtures of the i[th] kind; m_{bi} –average annual masses of a polluting substance of the i[th] kind, that get into the atmosphere in a year t during exploitation of the basic locomotive, kg/h per one section.

The value of Yg_t is calculated by the formula:

$$Yg_t = \gamma' \delta f \sum_{i=1}^{n} A_i' m_{gi}, \qquad (9)$$

where: m_{gi} – average annual masses of a polluting substance of the i[th] kind, that get to the atmosphere in a year t during exploitation of the hybrid locomotive, kg/h per one section.

Taking into account formulas (8), (9) we get:

$$K_3 = \frac{\sum_{i=1}^{n} A_i' m_{bi}}{\sum_{i=1}^{n} A_i' m_{gi}}, \qquad (10)$$

We will consider that parameters K_i identically influence the efficiency coefficient K_{ef} [20-24].

Then a general formula for determination of the efficiency coefficient of the hybrid shunting diesel locomotive, comparing to the basic locomotive, will look like:

$$K_{ef} = \frac{\frac{\sum_{i=1}^{i=s} k_n \varphi(i)}{\sum_{i=1}^{i=s} \varphi(i)} + \frac{LLC_{Tb}}{LLC_{Tg}} + \frac{\sum_{i=1}^{n} A_i' m_{bi}}{\sum_{i=1}^{n} A_i' m_{gi}}}{3}, \qquad (11)$$

Taking into account the above-mentioned calculations, and the declared ecological indexes of diesels for shunting work, there was calculated the efficiency coefficient of use of the hybrid shunting diesel locomotive. It turned out to be equal to $K_{ef(man.)}$=1,7, that fully confirms implementation efficiency of this type of locomotives instead of diesel locomotives of the ChME3 series. [25-26].

Analogical procedure was conducted for work on a hump and export work for parameters of the hybrid locomotive, calculated in the previous section. Corresponding coefficients are equal to $K_{ef(gor.)}$=1,9 and $K_{ef(vyv.)}$=2,4.

CONCLUSIONS

1. The optimization model for determination of rational technical and economic indexes of the hybrid shunting diesel locomotive has been developed;
2. On the basis of the model calculations have been made and parameters of hybrid locomotives for different types of field operation have been defined;
3. The efficiency coefficient of the hybrid shunting locomotive on the basis of the diesel locomotive of the ChME3 series has been calculated for different types of field operation. On this basis implementation efficiency of this type of locomotives instead of basic diesel locomotives has been proved.

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ОПРЕДЕЛЕНИЕ ЭФФЕКТИВНОСТИ ОТ ВНЕДРЕНИЯ ГИБРИДНОГО МАНЕВРОВОГО ТЕПЛОВОЗА С УЧЕТОМ ВИДА ЭКСПЛУАТАЦИОННОЙ РАБОТЫ

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Ю. Белецкий

Аннотация. Одним из способов повышения эффективности эксплуатации маневровых тепловозов является замена существующей дизель-генераторной установки на установку малой мощности с накопителем энергии, то есть создание гибридного привода. Во всем мире предпринимаются попытки внедрить гибридную передачу мощности на железнодорожном транспорте, однако в Украине такие локомотивы не эксплуатируются. Разработана оптимизационная модель определения рациональных технико-экономических показателей гибридного маневрового тепловоза, на основе которой определены параметры гибридных локомотивов для различных видов работ. Рассчитан коэффициент эффективности гибридного маневрового локомотива на базе тепловоза серии ЧМЭ3. Доказано, что внедрение гибридного маневрового тепловоза вместо тепловоза серии ЧМЭ3 улучшает технические, экономические и экологические показатели локомотива.

Ключевые слова: гибридный тепловоз, дизель-генераторная установка, накопитель энергии, коэффициент эффективности, жизненный цикл, технический уровень, экологические показатели.