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INCREASE OF FUEL ECONOMICAL EFFICIENCY OF MULTI-SECTIONAL DIESEL LOCOMOTIVES BY PERFECTION OF THE ALGORITHMS OF CONTROL BY DIESEL-GENERATORS

Summary. In the article one of the ways of reducing of fuel consumption at railways is explored. It is shown, that now there is possibility of substantial (5-10%) improvement of traction-economical characteristics of multi-sectional diesel locomotives due to the use of the microprocessor systems of control, which correlate diesel-locomotive characteristic and provide the asynchronous condition of operations of Diesel-generators in dependence on the conditions of traffic of train.

ПОВЫШЕНИЕ ТОПЛИВНОЙ ЭКОНОМИЧНОСТИ МНОГОСЕКЦИОННЫХ ТЕПЛОВОЗОВ СОВЕРШЕНСТВОВАНИЕМ АЛГОРИТМОВ УПРАВЛЕНИЯ ДИЗЕЛЬ-ГЕНЕРАТОРАМИ

Аннотация. В статье исследован один из путей уменьшения затрат топлива на железных дорогах. Установлено, что в настоящее время имеется возможность существенного (5-10%) улучшения тягово-экономических характеристик многосекционных тепловозов за счет применения микропроцессорных систем управления, которые корректируют тепловозную характеристику и обеспечивают асинхронный режим работы дизель-генераторов в зависимости от условий движения состава.

1. INTRODUCTION

The tendencies of development of transport network of Ukraine are closely connected with the increase of efficiency of work of railway transport, in particular, with the necessity of the consumption cutting of fuel and energy resources and improvement of traction properties of locomotives. It stipulates high requirements to quality of operation of the system of control by Diesel-generators (DG) of diesel locomotives. It had been ascertained in the first works in which the fuel economy of diesel locomotives was studied [1], that fuel economical efficiency was mainly determined by perfection of operation process of diesel on the operating conditions. It was envisaged thus, that maximum propulsion efficiency (PE) of diesel locomotive was achieved at coincidence of diesel-locomotive characteristic $P_e = f(n_Д)$ with its economic characteristic $P_{ек} = f(n_Д)$. Then it was approved [2-4], that distributing the modes of operation on hours and coincidence of base region of the most PE of diesel according to its economic characteristic with the region of the primary modes of loading in operation influenced substantially on the diesel locomotives operating characteristics. The number of the works [2, 3, 6, 7, 9] directed on rapprochement of the characteristic $P_e = f(n_Д)$ to economic one was also carried out.The experience of usage of diesels with various velocity characteristics had shown that diesel locomotives, at which the diesels have higher capacity according to characteristic $P_e = f(n_Д)$, are more effective in operation at equal effective values of the PE [6, 9].

It is very important, that its level would be low not only at rated power (P_{eH}), but also on the intermediate conditions (fig. 1).

It is necessary also to note that from all locomotive diesels the Diesel-generator 1A-5Д49 has the least range of capacity, in which the specific effective fuel consumption changes in relation to its minimum magnitude insignificantly ($g_{e\ \min} = 214{,}1$ g/kW*g). The investigations on the special methodology with the use of regime meters of working hours [9] were conducted by the All-Russian Research Institute of Railway Transport to determine the magnitudes of average specific fuel operation consumptions for the most loaded areas of the railway network.

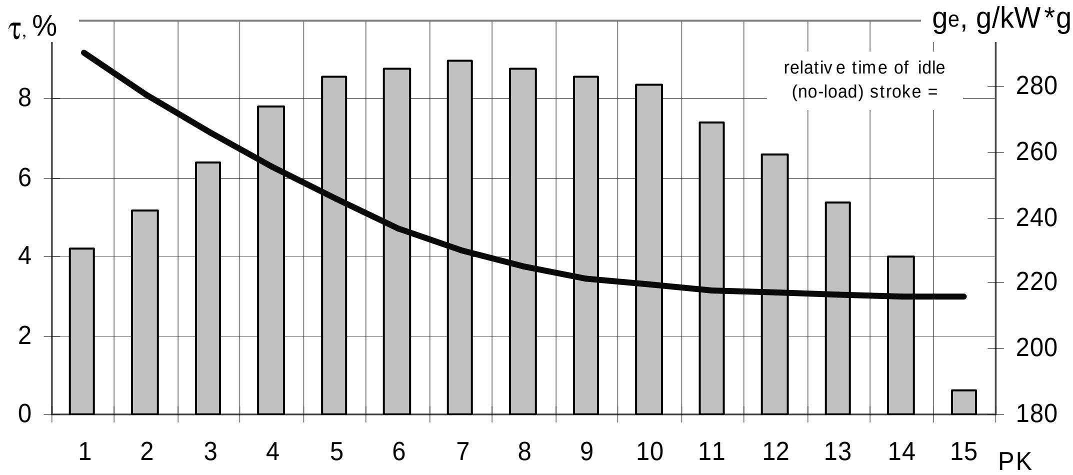

Fig. 1. Consumption characteristic of Diesel-generator 1A-9DG and distributing of under-load operation conditions of diesel locomotive power-plant: τ – relative time of operation of the DG; PK – position of controller-engine-driver

Рис. 1. Расходная характеристика дизель-генератора 1А-9ДГ и распределение режимов нагружения силовой установки тепловоза: τ –относительное время работы DG; PK – позиция контролера машиниста

The results of these researches for a main diesel locomotive 2TE116 with the power-plant by capacity $P_{ен} \approx 2200$ kW have shown that diesels tick over in the average about 62% of time. Time of work under loading was distributed in this way: over 58% of time were set the conditions of the middle loading, about 32% – small loading (1…5 positions of controller), 4,5% – condition near to nominal (13..15 positions), and only 0,5% – nominal condition.

Consequently it is possible to draw conclusion, that time of diesel operation on low positions of controller-engine-driver (both main-line and yard diesel locomotives are operating mainly on such conditions) influences most substantially on the average fuel operation consumption. That is the basic work of the DG (84,5%) occurs in the range of capacities which do not coincide with the region of maximal PE.

It is visible from the conducted analysis, that there is the real possibility of perfection of algorithms of loading of the DG diesel locomotives during their work on the operation average conditions and, as a result, to achieve economy of diesel fuel in the order of 5-15%.

2. SUBJECT OF STUDY

It is generally known, that the reduction of consumption characteristic $g_e = f(P_{e)}$ can be attained by the rise in this zone of diesel locomotive characteristic $P_e = f(n_Д)$, that is by the increase of diesel capacity at the lesser rotational speeds of crankshaft. Thus a curve $P_e = f(n_Д)$ will be approached to economic characteristic. However the rise of diesel locomotive characteristic is not always possible because of its proximity to the restrictive curve. In transitional processes the capacity of diesel can attain a restrictive characteristic or even surpass it, that will result not only in the increase of smoking (fuming) of exhaust and increase of fuel consumption because of decrease of the excess-air coefficient, but also to the increase of the thermal loading on the details of cylinder-piston group and, as a result, to the reduction of reliability of diesel.

Therefore, the main ways of the operation average consumption of fuel by main diesel locomotives during work under loading are the following:

change of consumption characteristic of diesel $g_e = f(P_e)$;

improvement of algorithms of work of the system of the incorporated control by a diesel and electricity transmission in transient conditions;

introduction of asynchronous method of loading of Diesel-generators of multi-sectional diesel locomotives.

For evaluation of effectiveness of the offered changes the data of rheostat tests of 2TE116 diesel locomotives were used. THE tests were executed in the Colomensk diesel locomotive building works [9]. Then, consumptions of energy on proper needs $\Delta P_{вп} = f(n_д)$ were determined in the electric transmission ΔP_{en} for several current points n_{di}, g_{ei} on one of consumption curves $g_e = f(P_д, n_д)$ and traction (tangent) capacity of diesel locomotive $P_к$ was calculated according to the following dependence:

$$P_к = [P_e \cdot \eta_{тг} - \Delta P_{вп}] \cdot \eta_{ву} \cdot \eta_{тд} \cdot \eta_р \quad (1)$$

where: $\eta_{кп}$ – accordingly: the PE of the traction generator, rectifier set, traction engines, traction reducing gears and realization of traction efforts in the contact of "wheel-rail".

The general losses of power on own needs at normal atmospheric terms were accounted on empiric dependence of such form:

$$\Delta P_{вп} = 5 \cdot 10^{-4} n_d^{\ 2} - 0{,}29 n_d + 65{,}7 \text{, kW} \quad (2)$$

That is, if to consider not separate DG, and all system "locomotive- train-track", it becomes obvious that well-known economic characteristic will not be the most effective. Such effective characteristic will be some other one which is located more left serial and nearer to restrictive characteristic of DG. Additionally it is needed to emphasize that it is possible to realize a new rational adjustment of diesel locomotive characteristic only subject to the conditions of the use of the microprocessor system of control by the DG, because at the change of atmospheric conditions of traffic and loading of the DG it is necessary to conduct its correction with the purpose of non-admission of increasing the temperature of exhaust gases on the conditions of 35-70% from $P_{e\,N}$

3. RESULTS AND DISCUSSION

The results of modeling of the DG operation with the improved diesel locomotive characteristic are shown in table 1.

Except for the offered change of diesel locomotive characteristic $P_e = f(n_Д)$, it is necessary to analyze the possibility of reduction of running operation consumptions of fuel at the expense of introduction of asynchronous methods of loading of the DG multi-sectional diesel locomotives. That is, it is necessary to determine the ranges of capacity relatively the effective use of this method by comparison of weather consumptions of fuel at synchronous (serial) and asynchronous loading of the DG.

Additionally we will compare power balances at various methods of control by the power systems of diesel locomotives on condition of equivalent of both variants of realization of tangent capacity $P_к$ and work of driving section on idling.

Table 1

The results of modeling

Capacity of the DG, kW	157	257	354	456	558	711	862	1003	1142	1298	1453	1638	1823	1992	2160
Rotational speed of crankshaft, rpm	350	390	421	452	485	528	567	600	634	668	700	740	778	806	835
Specific fuel consumption g_e ,g/kW*g	319	297	283	273	264	254	247	243	239	236	234	233	232	232	233
Reduction of specific fuel consumption in percents to serial characteristic	8,9	8,2	7,9	8,0	8,0	7,5	7,3	6,9	7,1	7,5	8,0	8,2	8,7	8.9	9,2

Power balances at serial synchronous and asynchronous loadings of the DG of two-sectional diesel locomotives 2TE116 by the c (1) and (2) can be described in such form:

$$P^{C}_{к} = [(P'_{e} + P''_{e})\cdot\eta_{тг} - \Delta P'_{вп} - \Delta P''_{вп}]\cdot\eta_{ву}\cdot\eta_{тд}\cdot\eta_{р}\cdot\eta_{зч} \quad (3)$$

$$P^{A}_{к} = (P'_{e}\cdot\eta_{тг} - \Delta P'_{вп} - \Delta P''_{вп} - \Delta P''_{мх} - \Delta P''_{р})\eta_{ву}\cdot\eta_{тд}\cdot\eta_{р}\cdot\eta_{зч} \quad (4)$$

where: $P^{A}_{к}$ – total traction tangent capacity of two-sectional diesel locomotive accordingly at synchronous and asynchronous loading of the DG; P'_{e}, P''_{e} – effective capacity of the DG first and second sections; $\Delta P'_{вп}$, $\Delta P''_{вп}$ – losses of power on own needs in the driving and driven sections; $\Delta P''_{мх}$, $\Delta P''_{р}$ – mechanical losses of power in traction engines and reducing gears at motion of the driven section in the shutting off state; $\eta_{ву}$, $\eta_{тд}$, $\eta_{р}$, $\eta_{зч}$ – accordingly: PE of traction generator, rectifier set, traction engines, traction reducing gears and realization of traction efforts in the contact of "wheel-rail".

_Thus, it is necessary to note that the PE of the elements of the power system of diesel locomotive can be determined by known dependences:

$$\eta_з = \frac{V_л}{V_л + U_s}; \ \eta_т = \frac{UI}{UI + \Delta P_т}; \ \eta_{тд} = \frac{UI_{тд} - \Delta P_{тд}}{UI_{тд}};$$

$$\eta_p = \frac{1}{1{,}015 + 0{,}05\left(\frac{M_н}{M_к} - 1\right)}; \qquad \eta_{ву} = \frac{UI}{UI + \Delta P_{ву}} \tag{5}$$

where: U, I – voltage and current on the outlet of the rectifier set; $\Delta P_{ву}$ – accordingly the losses of power in a traction generator, traction engines and rectifier set; $V_л$ – speed of movement of locomotive; U_s – speed of sliding of the wheel pairs; $I_{тд}$ – current in a traction engine; $M_{н}$, M_k – nominal and current values of traction engine torque.

Except for it, the losses of power in traction engines and reduction gears on friction in bearings, friction of brushes on a collector and friction in the engine-axles bearings of the wheel pair at motion of the driven section in the shutting off state can be computed by such empiric dependences:

$$\Delta P''_{мх} = \frac{(V_л \cdot \mu_p D_{кт})^{1,4}}{33\eta_p}; \ \Delta P''_{мх} = 15{,}4\omega_{тд} \tag{6}$$

where: μ_p – gear ratio of reduction gear; $D_{кт}$, $\omega_{тд}$ – diameter of collector of traction engine and angular velocity of its rotation.

For the preliminary evaluation of rational zone of the asynchronous loading of the DG of multi-sectional diesel locomotives we will assume that the magnitude of additional power of driving section on compensation of mechanical losses in the driven section is determined by the mechanical losses in traction reduction gears and traction engines for the average statistical speed of movement of freight train in the order of $V_л$=41.5 km/h [9]. It should be noted that the consumptions of fuel were calculated in pursuance of the method, offered by E. Kossov [6]. The results of computations and rational distributing of capacity between the Diesel-generators of two-sectional diesel locomotive 2TE116 are demonstrated accordingly on fig. 2 and in table 2.

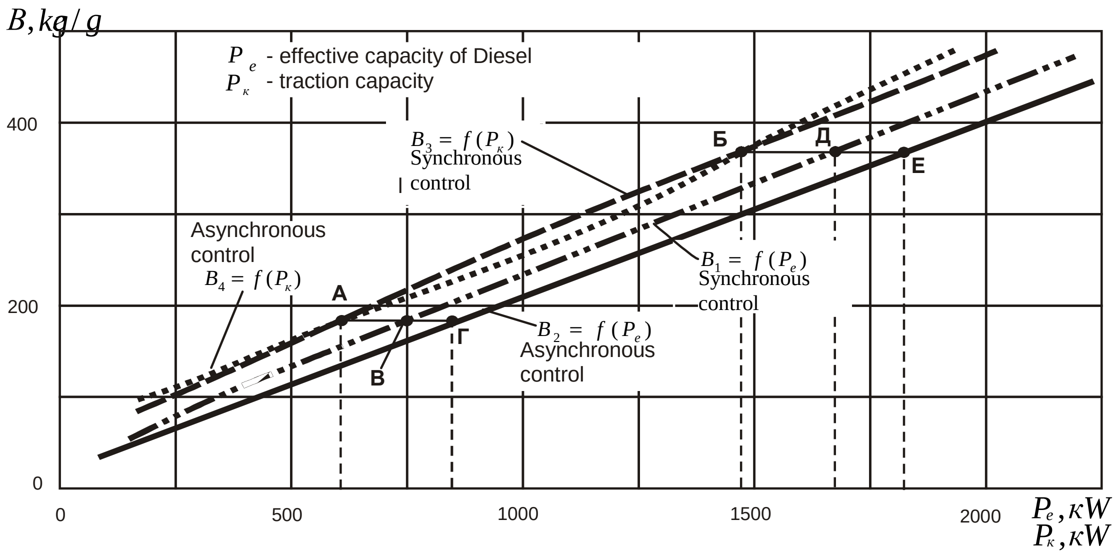

Fig. 2. Hourly consumption of fuel at the synchronous and asynchronous control by Diesel-generators
Рис. 2. Часовой расход топлива при синхронном и асинхронном управлении дизель-генераторами

4. CONCLUSIONS

The results of mathematical simulation and operating tests of diesel locomotives 2TE116 shows:

1. Nowadays there is possibility of substantial (5–10%) improvement of traction-economical characteristics of multi-sectional diesel locomotives of type 2TE116, 2TE121, 2TE10V, 3TE10M due to the use of the microprocessor systems of control, which corrects the diesel-locomotive characteristic and provide the asynchronous condition of operations of Diesel-generators in dependence on the terms of traffic of train.

2. The transition on the asynchronous loading of diesels at the temperature of surrounding air of t<30°C is recommended to execute at $P_e \approx 375$ kW in every section to achieve the best fuel economy of the DG of model of A-9DG (16ЧН26/26) and non-admission of sharp change of traction efforts. Thus, the DG of driving section must work with capacity $P_e \approx 840$ kW for conservation of the traditional distribution of tangent capacity of the whole locomotive relatively position of controller-engine-driver. That is, at the traditional 15-positional control the transition on the asynchronous loading of the DG must be carried out in the case of switching of controller with N=3 on N=4 position and be maintained in this condition to N=7.

3. At the temperature of surrounding air of t>30°C the microprocessor system of control by the DG must automatically increase the level of diesel locomotive characteristic in the range off rotational speed of diesel crankshaft n_∂ =850-:-1000 rpm.

Table 2

Distributing of capacity at Diesel-generator relatively positions of controller-engine-driver

№ of position	synchronous control	asynchronous control	
	Capacity of two-sectional diesel locomotive	Capacity P_e of driving section	Capacity P_e of driven section
1	314 (157 x 2)	157	157
2	514 (257 x2)	565	0
3	708 (354 x 2)	786	0
4	912 (456 x 2)	1020	0
5	1116 (558 x 2)	1240	0
6	1422 (711 x 2)	1562	0
7	1724 (862 x 2)	1840	0
8	2006 (1003 x 2)	1003	1003
9	2284 (1142 x 2)	1142	1142
10	2596 (1298 x 2)	1298	1298
11	2906 (1453 x 2)	1453	1453
12	3276 (1638 x 2)	1638	1638
13	3646 (1638 x 2)	1823	1823
14	3984 (1992 x 2)	1992	1992
15	4320 (2160 x 2)	2160	2160

4. The economy of fuel about 1-:-3.2% is additionally provided at the expense of regulation of amount of the connected traction engines in dependence on the operating conditions of electric transmission and decreasing the losses of power on the drive of ventilators of the cooling systems.

5. At the offered system of control during operation of diesels in a range from 35 to 70% of nominal power, the temperature of exhaust gases is increased on 20–70^{o}C only, that does not exceed a permissible norm and does not result in the reduction of reliability of work of cylinder-piston group.

Bibliography

1. Глаголев Н.М.: Тепловозы. Москва, Гос. трансп. ж.-д. изд-во, 1948, с. 388.
2. Володин А.И., Фофанов Г.А.: Топливная экономичность силовых установок тепловозов. Москва, Транспорт, 1979, с. 126.
3. Кудряш А.П.: Резервы повышения экономичности тепловозов. Москва, Транспорт, 1975, с. 275.
4. Грищенко А.В.: Повышение производительности и топливной экономичности тепловозов. средствами микропроцессорной техники. Дисс. доктора техн. наук. Санкт-Петербург, Петербургский государственный университет путей сообщения – 1995, с. 420.
5. Коссов Е.Е., Шапран Е.Н., Фурман В.В.: Совершенствование режимов работы силовых энергетических систем тепловозов. Монография. Луганск, Изд. ВНУ им. В.Даля, 2006, с. 280.
6. Flinn F., Mizusawa M., Uychara O. and Myers P.: An Experimental Determination of the Instantaneous Potential Radiant Heat Transfer Within an Operating Diesel locomotive. SAE Trans, 81, SAE Paper 720022, 1972.
7. Гриневич В.П., Гундоров А.В., Родионов И.Н. и др.: Энергетические показатели тепловозов, режимы эксплуатации и затраты топлива на тягу. Труды ВНИИТИ, Коломна, 2003, вып. 79, с. 298–322.
8. Бычков Д.А.: Снижение эксплуатационного расхода топлива тепловозами 2 ТЭ116 путем применения микропроцессорной системы управления дизель-генератором. Дисс. канд. техн. наук. – Москва, 2005, с. 240.
9. Шапран Є.М.: Удосконалення систем керування тяговими електродвигунами тепловозів, Вісник Дніпропетровського нац. ун-ту залізничного транспорту ім. академіка В. Лазаряна, 2005, вип. 8, с. 122-128.
10. Шапран Є.М.: Удосконалення систем керування тяговими електродвигунами тепловозів. Зб. наук. праць. Харків, Укр. ДАЗТ, 2005, вип. 68, с. 198-209.

Received 18.04.2008; accepted in revised form 03.11.2008