

Prospective model of the hybrid shunting diesel locomotive

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Abstract. In the article, the studies are performed which confirm dependence of fuel consumption of the shunting locomotive on the train driving mode. Using a hybrid power plant in the shunting diesel locomotive is proposed, which can help significantly reduce fuel consumption, since shunting will mostly be powered by an alternative power source, and provide high environmental cleanliness of the locomotive both with the basic DC motor and the proposed new traction motor type – switched reluctance motor.

1. Introduction

Global trends in transport development show an ecological priority combined with energy efficiency. A particular attention in this matter is given to land transport. As rail transport is energy-intensive, highly demanded and widely used in all developed countries, the relevance of applying advanced technologies in this field is of the utmost importance. The specific operating mode is shunting operation, when the use of electric locomotives is almost impossible and the operating modes differ from the magistral ones. The proposed paper is devoted to the study of these specific problems.

2. Methodology

Figure 1 shows a functional diagram of the hybrid diesel locomotive, which includes diesel D, synchronous generator SG, (diesel-generator set D-GS), rectifier R, energy storage (battery pack BP, capacitor battery CB, supercondensers), static converter SC and traction motor TM [1, 2].

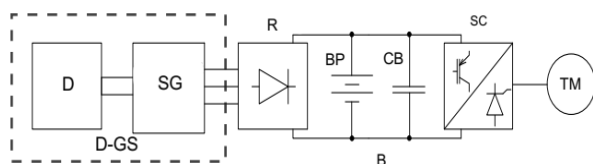


Fig. 1. Functional diagram of the hybrid diesel locomotive.

Using this solution, fuel consumption can be significantly reduced, since shunting will mostly be powered by a traction battery and high environmental cleanliness of the locomotive can be provided.

Since the significant amount of shunting is performed with the ChME3 locomotive, it is advisable to use it as a basis for conducting further studies. The following parameters of the design elements are taken for simulation: K6S310DR diesel, TD-802 DC generator, TE-006 DC traction motor (DCM). The simulation model was used as a tool to obtain the basic oscillograph chart of the locomotive operation.

Specialists of the Ukrainian State University of Railway Transport (Kharkiv) have proposed a mathematical model of the diesel locomotive CHME3, which allows displaying the operation of the locomotive in the real track section with simulation of train driving by the engine driver.

In the study of the train operation using a simulation model, tachograms were set with maximum speeds in the range of 40-70 km/h in 10 km/h increments. Figures 2 and 3 show examples of oscillograph charts of a shunting locomotive with 10 cars during movement, where: 1 – given tachogram; 2 – actual speed of the train; 3 – track profile; 4 – fuel consumption; 5 – number of the engine driver's controller position; 6 – traction motor voltage; 7 – traction motor current.

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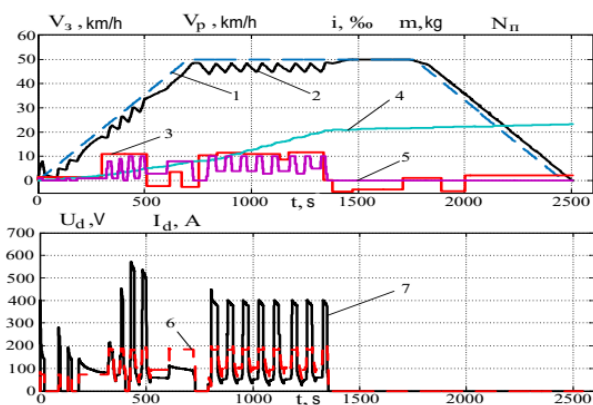


Fig. 2. Oscillograph charts of locomotive operation at maximum speed 50 km/h.

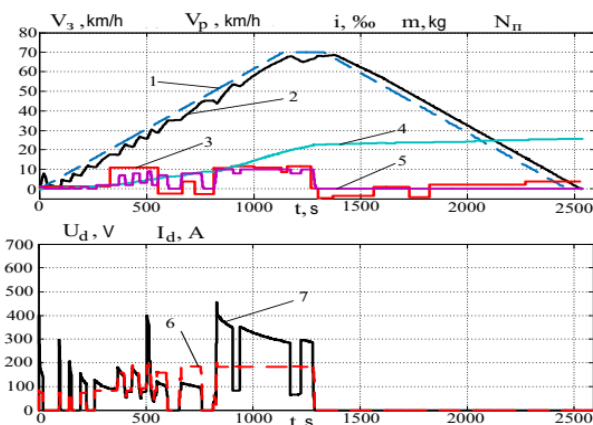


Fig. 3. Oscillograph charts of locomotive operation at maximum speed 70 km/h.

In the obtained oscillograph charts, curve 5 shows the set of positions which changes with different values of maximum speed. Each position corresponds to a change in the voltage and the current rate in the traction motors, which was limited to 600 A. The diagrams also show that the fuel consumption tends to increase with increase of the maximum speed. By changing the maximum speed of the triangular chart in the range of 70-95 km/h in 5 km/h increments, the results were obtained which are presented in table form (Table 1) and as a 3D surface (Fig. 4).

Table 1. Results of fuel consumption

Maximum speed of a triangular tachogram, km/h	Maximum train speed according to tachogram, km/h	Fuel consumption, kg
70	40	30.07
	50	30.96
	60	31.38
	70	31.14
75	40	30.05
	50	30.82
	60	31.69

80	70	30.6
	40	30.06
	50	30.79
	60	31.61
	70	31.87
85	40	31.33
	50	30.35
	60	32.64
	70	33.18
90	50	30.84
	60	34.04
	70	34.02
95	50	32.59
	60	34.4
	70	35.72

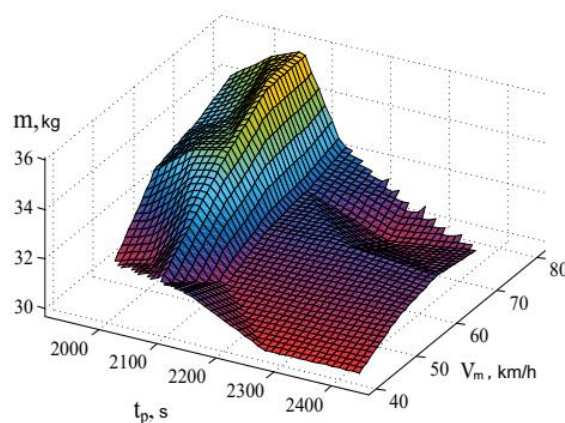


Fig. 4. Change of fuel consumption depending on the maximum speed and the time of movement in the track section.

The obtained surface confirms the dependence of the fuel consumption of the locomotive on the train driving mode (on the time of operation of the locomotive at a certain position and the intensity of the transition from one position to another) when performing the same work, i.e. the same time of movement in the track section. The lowest fuel consumption, namely 29-31 kg, was recorded when the maximum speed was 40-50 km/h.

In the next stage, studies were conducted to consider the possibility of using a hybrid power plant on a shunting locomotive both with basic DCM, and with a switched reluctance motor (SRM).

A generalized functional diagram of a hybrid diesel locomotive is shown in Figure 5.

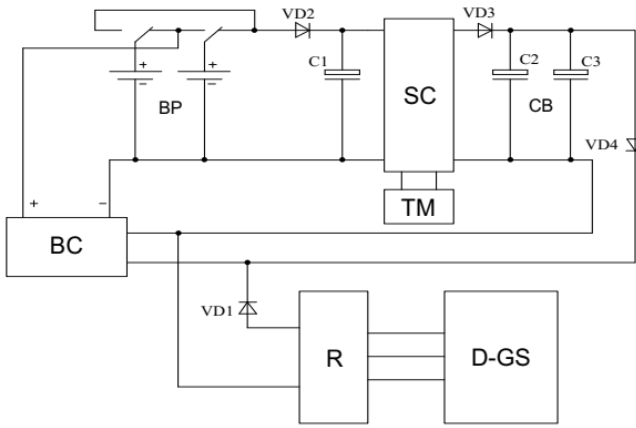


Fig. 5. Generalized functional diagram of the hybrid diesel locomotive.

The diagram above includes also a battery charger (BC) which is not shown in Figure 1.

Using the general functional diagram and the functional diagrams of the individual blocks, a simulation model of operation of the hybrid locomotive was developed in the Matlab environment, where a traction DSM was used with a control system based on the pulse-width converter (PWC). The proposed model was developed taking into account the possibility of switching traction motors to the generator (regenerative) mode in order to accumulate energy on the supercondensers. Regenerative braking was used up to a speed of 10 km/h with the consequent use of pneumatic brakes [3, 4, 5].

In the study of the operation of a hybrid locomotive using a simulation model, tachograms were set with the maximum speeds in the range of 40-80 km/h in 10 km/h increments. Figures 6 and 7 show examples of oscillograph charts of a shunting locomotive with 10 cars during movement, where: 1 - given tachogram; 2 – actual speed of the train; 3 - track profile; 4 - fuel consumption; 5 - number of the engine driver’s controller position; 6 - traction motor current; 7 – capacitor current; 8 – battery pack current.

To maintain the current speed according to a given tachogram, the engine driver changed the voltage on the traction motors by changing the position of the engine driver's controller [5, 6, 7, 8]. A change of one position corresponds to a 10% change in the output voltage level of the pulse-width converter. In the traction mode, current was limited to 600A. The negative current values on the curve correspond to the recovery mode and the capacitor charge. When the voltage of the supercondenser reached 300 V, charging of the battery pack (BP) began. In order to study the dependence of changing fuel consumption on changing the train driving mode train, fix fuel consumption should be recorded.

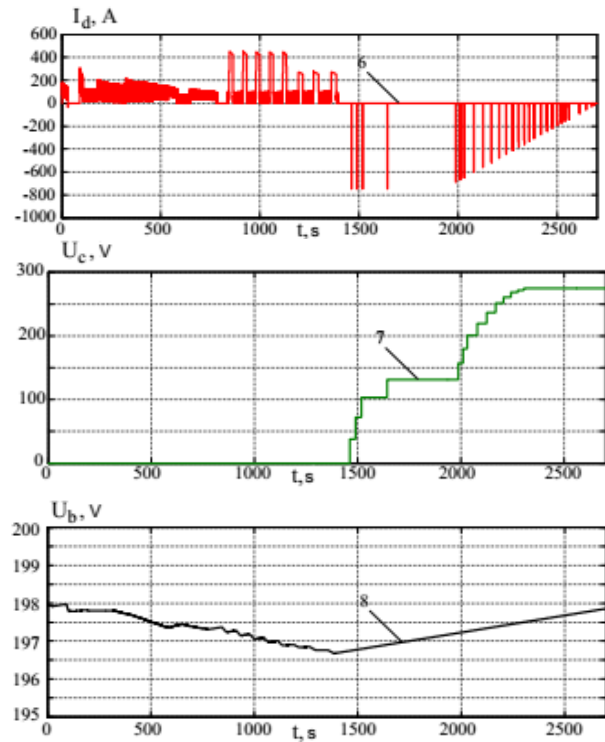
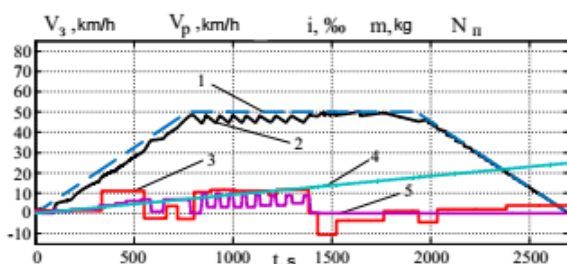


Fig. 6. Oscillograph charts of locomotive operation with DSM at maximum speed 50 km/h.

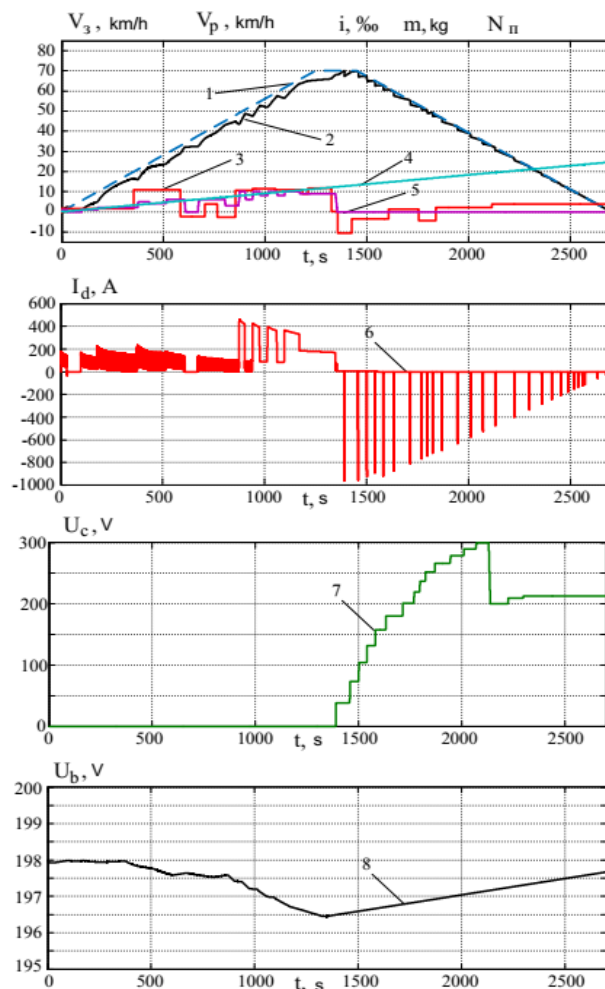


Fig. 7. Oscillograph charts of locomotive operation with DSM at maximum speed 70 km/h.

Table 2. Simulation results

Maximum speed of a triangular tachogram, km/h	Maximum train speed according to tachogram, km/h	Fuel consumption, kg	BP voltage, V	CB voltage, V
70	40	24.48	198	273
	50	24.41	197.9	283
	60	24.24	197.6	234
	70	24.39	197.5	213
75	40	24.43	198	277
	50	24.46	197.9	279
	60	24.37	197.7	228
	70	24.38	197.6	208
80	40	24.58	198	271
	50	24.53	197.8	274
	60	24.47	197.6	221
	70	24.32	197.6	210
85	43	24.98	197.9	278
	50	25.27	197.6	284
	60	24.68	197.8	241
	70	24.73	197.7	253
90	50	25.09	197.3	292
	60	24.82	197.4	240
	70	24.67	197.2	261
95	50	24.64	197.1	298
	60	24.59	197.2	235
	70	24.37	197	242

Using the data of Table 2, dependences were plotted in form of 3D surfaces: fuel consumption (Fig. 8), BP voltage (Fig. 9), capacitor battery (CB) voltage (Fig. 10) on the maximum speed of the tachogram and time of movement in the track section.

The obtained dependence of fuel consumption suggests that a diesel locomotive with a hybrid power plant is more energy efficient than the traditional one [9, 10, 11, 12]. There are two evident maximums at 80 km/h and 50 km/h for the triangular chart with a maximum speed of 90 km/h. These extreme values are 25.11 and 25.09 kg, respectively. The reduction in fuel consumption of the locomotive is in the range of 5.62-11.2 kg compared to the traditional system (Table 1), which is 18.7% to 31.3%.

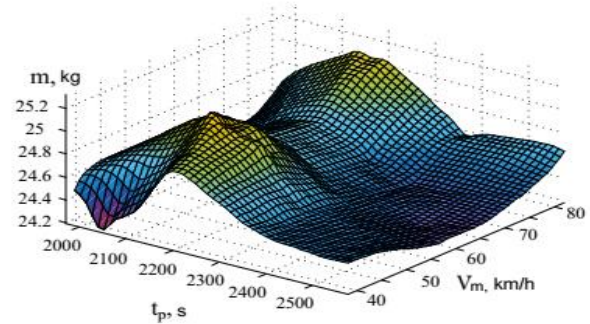


Fig. 8. Change of fuel consumption by a hybrid locomotive depending on the maximum speed and time of movement in the track section.

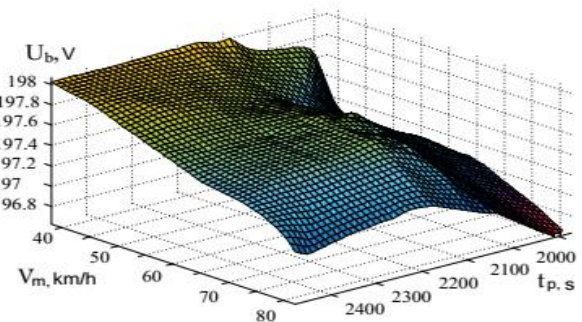


Fig. 9. Change of BP voltage depending on the maximum speed and time of movement in the track section.

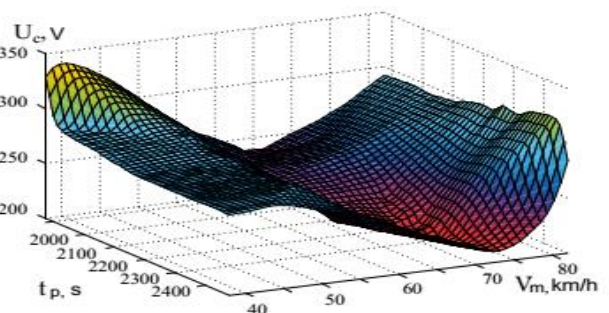


Fig. 10. Change of BP voltage depending on the maximum speed and time of movement in the track section.

Analysis the dependence of the voltage BP revealed a tendency of the increasing charge of BP when the maximum speeds of movement in the track section reduce.

In the surface (Fig. 10) there is a minimum BP voltage area (208-261 V) in the speed range 55-75 km/h, which corresponds to switching to the BP charge mode. In the same speed range, a minimum value area is recorded on the fuel consumption surface as a result of the reduced load on the diesel.

3. Analysis of the results

In the next stage, a simulation of the electric drive of the locomotive was performed on the basis of switched reluctance motors (SRM).

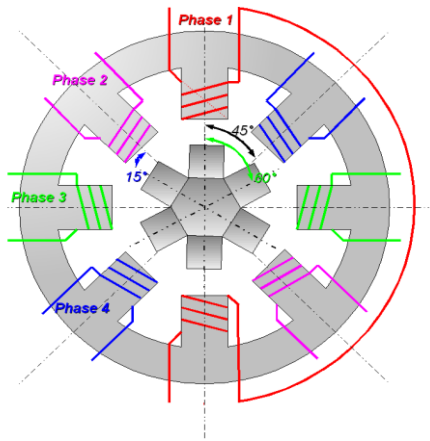


Fig. 11. Four-phase SRM in 8/6 configuration.

Table 3. Technical specification of the motor DVI-165

Electrical mechanical parameters	
U_H, V	200
I_H, A	850
M_H, Nm	875.5
$n_H, t/h$	1800
$R\phi, \Omega m$	0.135
Ld, mGn	1.72
Lq, mGn	0.36

As a result of the simulation, basic oscillograph charts of locomotive operation were obtained, examples of which are shown in Fig. 12-13, where: 1 - given tachogram; 2 – actual speed of the train; 3 - track profile; 4 - fuel consumption; 5 - number of the engine driver’s controller position; 6 - traction motor current; 7 – capacitor current; 8 – battery pack current.

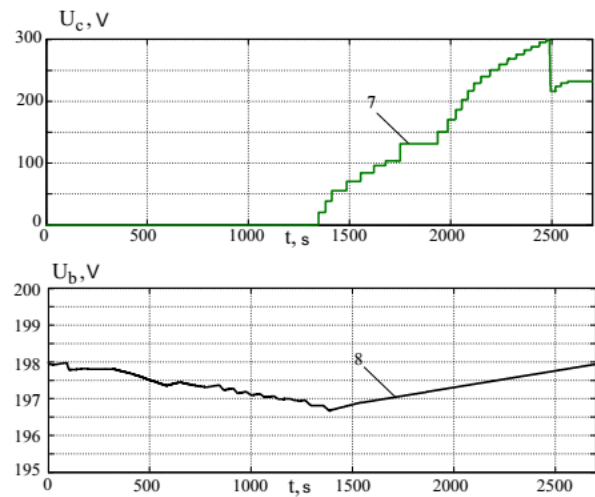
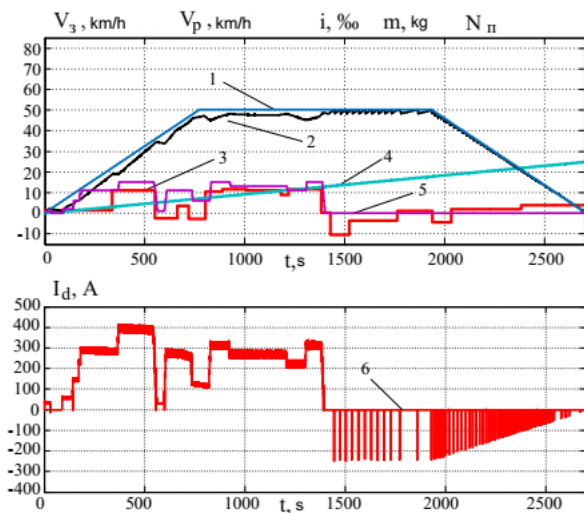


Fig. 12. Oscillograph charts of locomotive operation with SRM at maximum speed 50 km/h.

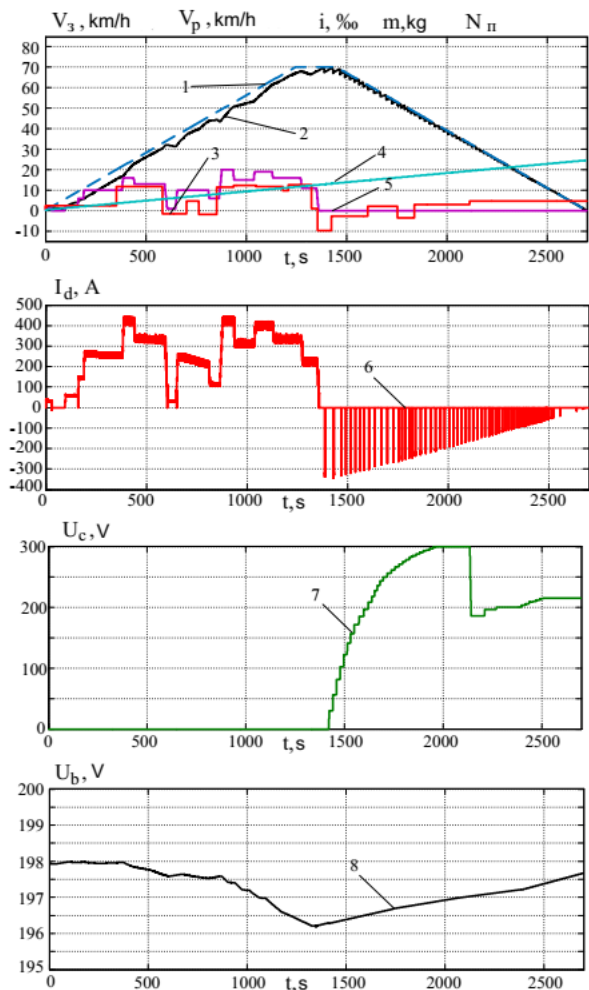


Fig. 13. Oscillograph charts of locomotive operation with SRM at maximum speed 70 km/h.

The results of the analysis of the obtained characteristics are summarized in Table 4.

Table 4. Simulation results

Maximum speed of a triangular tachogram, km/h	Maximum train speed according to tachogram, km/h	Fuel consumption, kg	BP voltage, V	CB voltage, V
70	40	24.39	197.9	252
	50	24.41	198	235
	60	24.24	197.5	234
	70	24.43	197.8	292
75	40	24.36	197.9	251
	50	24.42	197.9	234
	60	24.37	197.6	237
	70	24.45	197.7	294
80	40	24.57	197.9	250
	50	24.53	197.8	231
	60	24.47	197.7	239
	70	24.32	197.6	215
85	43	24.56	197.8	254
	50	24.89	197.5	233
	60	24.43	197.9	241
	70	24.54	197.5	221
90	50	24.86	197.2	263
	60	24.62	197.5	240
	70	24.47	197.3	227
95	50	24.41	197.2	268
	60	24.49	197.3	235
	70	24.44	197.1	229

Using the results of Table 4, 3D dependences were plotted in form of surfaces: fuel consumption, BP voltage, CB voltage on the maximum speed of the tachogram and time of movement in the track section.

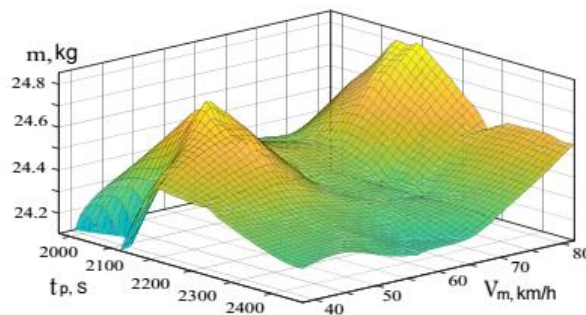


Fig. 14. Change of fuel consumption by a hybrid locomotive with SRM depending on the maximum speed and time of movement in the track section.

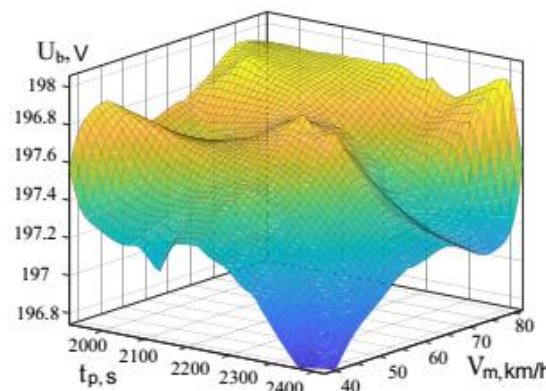


Fig. 15. Change of BP voltage depending on the maximum speed of the triangular chart.

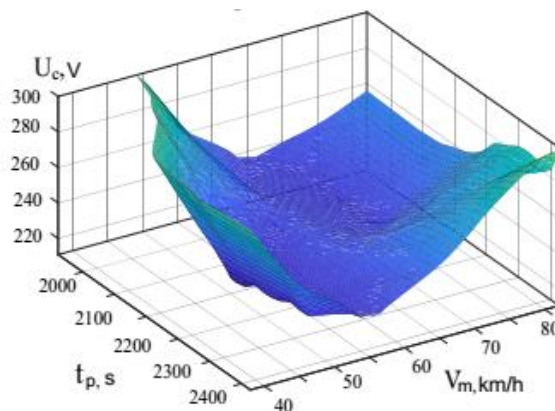


Fig. 16. Change of BP voltage depending on the maximum speed of the triangular chart.

4. Conclusion

The analysis of the obtained surfaces shows their similarity to the dependences observed when DSM were used (Fig. 8-10), but for SRM compared to DSM, the reduction of fuel consumption tended to reduce more intensively as the maximum speeds of the triangular tachograph increased (movement in the line) in the range of 80- 95 km/h. The reduction in fuel consumption in this range is 0.5-1.5%.

Extreme values at speeds of 80 km/h and 50 km/h with the maximum speed of the triangular chart of 85 km/h are 24.92 and 24.89 kg, respectively.

I.e. the above dependences suggest that a diesel locomotive with a hybrid power plant is more energy efficient than the traditional one, and using SRM as a

traction motor is much more efficient than the existing DSM. However, based on the conducted analysis, the dependence of fuel consumption by the locomotive the train movement mode is determined, so an automatic control system should be developed using a speed controller that would follows the given tachogram more accurately.

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