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Analysis of operation modes of shunting diesel locomotives when performing shunting work

An overview of modern trends in updating shunting locomotives, which are based on the installation of on-board energy storage devices, multi-diesel propulsion power plants, and power plants operated on hydrogen energy sources, was carried out. The necessity to take into account the operating conditions of a shunting diesel locomotive when choosing an upgrade option is shown. The operation modes of shunting diesel locomotives during shunting operations at the Козятин-І freight station during three shifts were considered. By analyzing the data of the BIC-P onboard system and processing the route sheets, the parameters of the operating modes were determined. Calculations of diesel engine power utilization indicators were performed, according to which it was determined that the full use of the installed diesel generator power is 7.5...8.4%, and the maximum diesel power recorded under the studied operating conditions is about 50%. The duration of work with traction loads is 49.5...68.8% of the shift time. The longest - 55...60% of the total duration of work under traction - are modes with a power of 0...50 kW. The duration of work without load is 18.1...36.9% of the duration of the shift. The shunting work performed is related to the formation and disassembly of trains, including the use of a sorting slide, as a result of which the traction power transmission operates with a low efficiency. In order to reduce the consumption of fuel and energy resources when performing shunting work, it is necessary to update the fleet of locomotives for shunting work, the characteristics of which are adapted to the operating modes.

Key words: hybrid locomotive, modernization, shunting, energy efficiency, energy storage

Introduction. Maneuvering is an integral part of the transportation process. JSC "Ukrzaliznytsia" uses ChME3 series diesel locomotives for shunting operations, the inventory of which is more than 1,200 units [1] with 100% actual wear. For diesel locomotives that are in operation, there is a steady trend of increasing maintenance costs. According to [1], the priority way to improve the situation with shunting diesel locomotives is to restore them through major repairs and modernization of individual units. These works are planned to be carried out on the entire fleet required for shunting operations

(estimated at 870 diesel locomotives in 2033). Arguments for choosing this option are relatively small capital investments and the presence of a developed repair and technological base at all regional branches. At the same time, it is noted that during major repairs it is impossible to restore the passport characteristics of diesel locomotives, therefore significant costs for their current maintenance will remain, and due to the low quality of repairs, an increase in unplanned repairs is predicted. Alternative options for updating the fleet of shunting diesel locomotives, which are indicated in [1], are their complex modernization with remotorization (as well as the purchase of new diesel locomotives). The use of these options allows to improve the traction and energy characteristics of diesel locomotives, it is predicted that the cost of maintenance, repairs and fuel and lubricants will decrease, which will ultimately ensure a decrease in the cost of transportation. Taking into account the possibility of extending the service life of ЧМЕ3 diesel locomotives for 10...15 years [2], it is considered urgent to work out options for comprehensive modernization of these diesel locomotives to improve their traction and energy characteristics.

Analysis of recent research and problem statement. In Ukraine, remotorization of ChME3 diesel locomotives was carried out using the 4Д80Б diesel, in the CIS countries - using the 1-PD4B and 4-36DG diesel generators [3]. A deep complex modernization using a Caterpillar diesel engine, AC-DC power transmission (the traction motors were not changed), an electric drive for cooling fans and a compressor, and a microprocessor control system was carried out in Ukraine at Poltava Tractor Repair Plant, where diesel locomotives were modernized according to the designs of the ZOS company Zvolen (Fig. 1a) and CZ LOCO (Fig. 1b) [4]. The latter company's project was also used in the modernization of ЧМЕ3 diesel locomotives in the CIS and Baltic countries.



a)



b)

Fig.1. Modernized ChME3 diesel locomotives

The paper [5] analyzed the fuel consumption of serial diesel locomotives ChME3 and modernized diesel locomotive ChME3P-№1744. It was established that the modernized diesel locomotive, despite the use of a more powerful diesel engine with a capacity of 1455 kW, consumes 29.4% less fuel than a serial diesel locomotive. Similar results were obtained during the operation of TEM2 diesel locomotives, which are modernized according to the same concept as ChME3II. Compared to the TEM TMX diesel locomotive with a 970 kW diesel engine, which was created using the crew part of the TEM18DM diesel locomotive and the equipment of modernized ChME3 diesel locomotives, the fuel consumption during shunting was 37.5%. In both cases, it is noted that fuel economy depends on the type of maneuvering. The greatest savings of 40...45% are observed when modernized diesel locomotives are used in export work. The smallest one is at hill work. It is worth noting that during the modernization, the traction characteristics of the diesel locomotive at the positions of the driver's controller and the applied electric drive of the motor cooling fans were changed. This also had an effect on reducing fuel consumption, but this is difficult to assess.

An alternative way to update shunting diesel locomotives is to create a hybrid locomotive. The paper [6] substantiates the feasibility of creating a hybrid locomotive based on the ChME3 diesel locomotive and the technical parameters of such a diesel locomotive for Ukrainian railways. In [7], a study was conducted on the use of combined storage units as part of the power plant of a shunting diesel locomotive. In [8], the application of a traction electric drive based on valve-inductor electric motors in

the traction system of a hybrid shunting locomotive was investigated. [9] shows the expediency of using traction asynchronous electric motors in the modernization of diesel locomotives of ChME3 type.

Hybrid shunting locomotives are becoming increasingly common in commercial operation [10, 11]. New locomotives Prima H3 (Fig. 2a) [12], Prima H4 (Fig. 2b) [13] and modernized locomotives of the BR203H series (Fig. 2c) [14] manufactured by Alstom, HD300 locomotives (Fig. 2d) [14] are in operation. 15] and HDB800 (fig.2f) [16] from Toshiba, locomotive FXN3D (fig.2g) [17] and 1004 (fig.2g) [18] from CRRC, locomotive GG20B (fig.2h) [19], created Railpower Technologies, locomotive CBD80 (fig.2i) [20] from Clayton Equipment, locomotive HLS-700 (fig.2j) [21] from TÜLOMSAŞ. Information about the development or experimental operation of hybrid locomotives can be found at almost every manufacturer of rolling stock.

Diesel locomotives with several diesel power plants are also used. For example, the diesel locomotive MDD5 (Fig. 3a) [22] manufactured by Express Service uses two diesel generator sets, the diesel locomotives 3GS21B (Fig. 3b) [23] from National Railway Equipment and RP20BD (Fig. 3c) [24] from Railpower Technologies – three diesel generators. At the same time, the RP20BD diesel locomotive has a modification where one diesel generator is replaced by an energy accumulator. In TEM2-UGMK diesel locomotive (Fig. 3d) [25] an auxiliary diesel engine is used, which is included in operation during long-term downtimes of the diesel locomotive. The main diesel generator set is not working at this moment.



Fig.2. Hybrid shunting diesel locomotives

At present, extensive research has gained application on locomotives of alternative primary sources of energy - fuel cells, gas engines or exclusively battery cells [26].

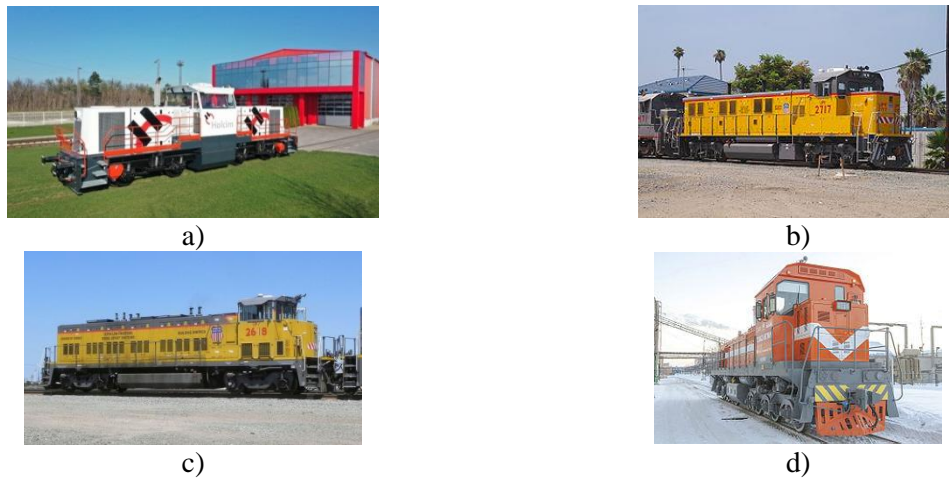


Fig. 3. Multi-diesel shunting diesel locomotives

The experimental sample of the SM42-6Dn locomotive (Fig. 4a) [27] on fuel cells created by the PESA company; the locomotive from CRRC (Fig. 4b) [28]; the MK1200G locomotive with a gas piston engine (Fig. 4c) [29]; the battery locomotive of the company Zarmen (Fig. 4d) [30]; CRRC battery locomotive (Fig. 4e) [31]; EMD Joule battery locomotive (Fig. 4f) [32] produced by Progress Rail; ES1000 series battery locomotive (Fig. 4g) and ES3000 (Fig. 4h) [33] produced by Express Service.

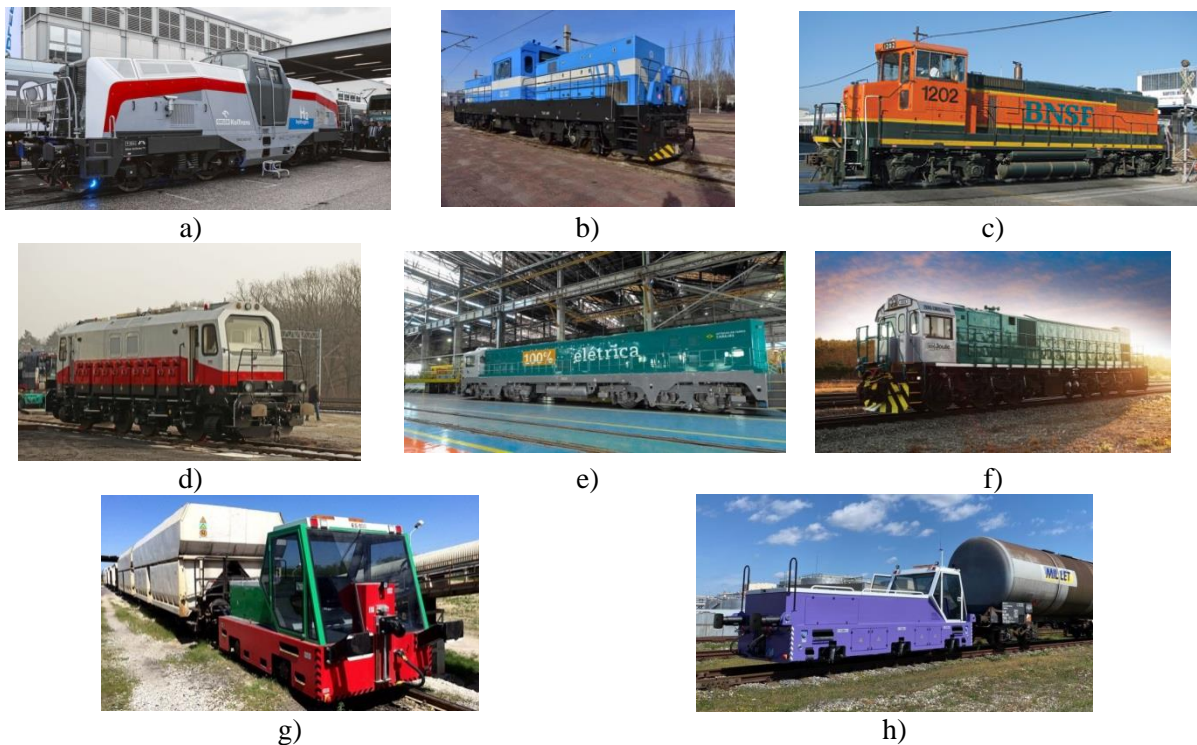


Fig.4. Locomotives with alternative energy sources

Also implemented are projects for retrofitting diesel locomotives to run on natural gas (LNG, LPG, compressed gas) or biogas (TEM2 diesel locomotives in the Baltic countries and Kazakhstan, the

OptiFuel project), use of biodiesel (WDM7 locomotive of the Indian Railways on biodiesel), a mixture of gas and hydrogen in the piston engine (Freightliner Class 66).

It is worth noting that in the CIS countries, samples of hybrid diesel locomotives, two-diesel, with gas engines and biofuels have been created.

It is also worth emphasizing that the locomotives of foreign companies can be equipped with a power plant of any configuration in order to adapt to real operating conditions. In particular, locomotives can be powered by a contact network [34].

Thus, various technologies can be used in the modernization and creation of new shunting locomotives. Classic deep modernization with the use of a modern diesel engine is proven and it ensures a reduction in operating costs. An alternative to it is a hybrid shunting locomotive or electric shunting locomotive, as well as multi-diesel diesel locomotives. The use of fuel cells is considered to be extremely promising for rolling stock, but this technology is actually at a research stage. In addition, today the spread of hydrogen technologies is "impeded" by the high cost of hydrogen. The situation is similar with biofuel, the use of which for locomotives is at the experimental stage. Pure battery locomotives are used for a certain class of shunting operations, which is primarily related to the characteristics of battery cells. Therefore, according to the authors, the acceptable ways to modernize ChME3, in addition to the "classical" modernization with the use of a modern diesel engine, are the creation of hybrid shunting diesel locomotives and contact-battery shunting electric locomotives.

It was shown in [35] that the modes of operation of the ChME3 diesel locomotive depend significantly on the place of its operation, that is, on the types of shunting work performed by the diesel locomotive. Therefore, **the purpose of the researcher** is to analyze the modes of operation of a shunting locomotive during shunting operations, which will allow to specify the requirements for a modernized locomotive

Materials and methods of research. Data analysis from on-board systems installed on diesel locomotives is widely used to determine operating conditions [5, 6, 35]. The authors processed data on the operation of diesel locomotive ChME3 No. 1190 during three shifts in the period 23-25.03.2021 at Kozyatyn-I station. The diesel locomotive performed shunting operations to form and break up freight trains, including the release of wagons on the sorting chute. Data from the БIC-P system and entries in route sheets were analyzed. The indicators of the average power of the traction generator of the diesel locomotive are given in tables 1, 3 and 5. Tables 2, 4 and 6 show the characteristics of the maneuvering operation, the number of axles, the approximate mass of the train and the time of the start and end of the operation. The color of the cell in the table.1 and 2, 3 and 4 and 5 and 6 coincide and indicate one maneuver operation. The "Dismantling" operation includes the approach of the locomotive to the group of wagons, coupling with the group of wagons, release of automatic brakes in the group of wagons by "bleeding" air from the air distributors, moving the group of wagons to the sorting chute and disbanding the group of wagons through the sorting chute. The "Disbanding" operation is carried out by feeding a group of wagons to the sorting chute and then, depending on the need, new trains of wagons are formed by moving a group of turnouts. At the same time, the locomotive pushes the wagons up the hill at a speed of 2-3 km/h. The "Replenishment" operation is performed to complete the freight train according to weight standards or train length standards. For this, the diesel locomotive adds one or a group of carriages to the already formed composition of the train. The "Rearrangement" operation is the movement of one or a group of wagons from one track to another, or the coupling of wagons on one track into one warehouse, or any other movement of wagons in the fleet of formation and disassembly of trains.

Table 1. Indicators of the average generator power of ChME3 diesel locomotive №1190 during operation for the shift of March 23-24, 2021 from 8:00 p.m. to 8:00 a.m. in kW according to the BIC-P system diagram

Minutes	Hours											
	20-21	21-22	22-23	23-00	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08
00-02	0	0	125	38	20	40	35	180	110	200	0	80
02-04	0	0	150	15	2	0	0	60	140	280	60	35
04-06	0	50	0	0	0	40	6	55	175	140	90	0
06-08	0	100	15	42	0	125	20	6	30	170	160	0
08-10	0	0	30	12	0	0	20	2	160	70	100	0
10-12	0	140	4	2	0	15	2	25	175	25	50	0
12-14	0	150	30	0	40	0	70	0	140	30	35	0
14-16	0	60	20	6	30	0	75	0	50	35	30	50
16-18	0	5	22	15	28	0	100	0	15	40	10	70
18-20	0	0	12	25	0	0	140	35	30	-1	150	40
20-22	0	12	20	15	25	115	80	35	175	25	60	0
22-24	0	25	0	16	25	235	75	6	175	0	65	15
24-26	15	0	15	30	20	0	80	0	185	0	40	50
26-28	48	0	20	2	0	0	90	0	220	10	6	15
28-30	50	0	36	0	12	0	0	0	420	120	0	30
30-32	48	12	80	2	40	0	0	40	120	0	8	10
32-34	0	4	36	162	0	0	40	170	0	50	6	20
34-36	0	0	34	170	0	0	-1	90	15	140	0	120
36-38	6	0	25	45	0	0	12	0	0	110	0	200
38-40	75	12	6	100	0	0	10	0	100	280	0	100
40-42	125	6	29	12	0	0	25	150	60	100	25	90
42-44	25	-1	4	0	0	65	28	180	100	260	35	70
44-46	0	4	75	60	50	115	0	165	200	160	0	2
46-48	0	12	25	62	10	90	0	180	140	0	0	40
48-50	65	15	40	40	0	80	115	175	30	6	0	0
50-52	12	70	2	50	45	25	230	180	0	40	3	2
52-54	0	15	110	0	60	60	90	175	0	35	12	170
54-56	50	65	125	0	0	25	220	65	0	60	25	110
56-58	8	12	200	6	0	40	200	15	40	110	60	20
58-60	4	48	150	12	0	30	190	90	165	0	30	0

Table 2. Characteristics of maneuvering operations for the shift of 03/23-24/2021

Dismantling, 500 tons, 32 axles, 20.24-20.32	Dismantling, 1500 tons, 156 axles, 01.20-02.32
Dismantling, 400 tons, 24 axles, 20.38-20.42	Replenishment, 900 tons, 48 axles, 02.48-03.12
Dismantling, 350 tons, 16 axles, 20.48-20.52	Rearrangement, 700 tons, 44 axles, 03.30-04.32
Replenishment, 1100 tons, 76 axles, 21.04-21.20	Rearrangement, 500 tons, 36 axles, 04.38 - 05.18
Rearrangement, 300 tons, 24 axles, 21.20-21.34	Dismantling, 600 tons, 32 axles, 05.26-06.28
Replenishment, 400 tons, 32 axles, 21.44-22.04	Dismantling, 300 tons, 16 axles, 07.14-07.56
Dismantling, 1000 tons, 156 axles, 22.12-23.04	Traffic reserve/hot standby
Dismantling, 500 tons, 52 axles, 23.14-23.26	Cold standby
Dismantling, 800 tons, 68 axles, 23.32-00.52	

Table 3. Indicators of the average power of the generator of the diesel locomotive ChME3 No. 1190 during work for the shift of 03/24/2021, from 08.00 to 20.00 in kW according to the diagram of the BIC-P system

Minutes	Hours											
	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20
00-02	0	0	0	0	25	50	10	0	0	10	200	0
02-04	0	25	130	120	15	80	35	0	12	20	270	0
04-06	0	30	200	120	20	275	0	18	20	0	20	0
06-08	0	0	160	220	35	150	60	20	18	0	5	0
08-10	0	0	230	70	30	180	12	22	18	0	45	15
10-12	0	15	40	100	0	375	20	25	8	20	50	0
12-14	0	20	8	135	70	0	35	22	10	50	-1	0
14-16	0	15	30	35	20	0	30	22	20	230	10	20
16-18	0	25	20	65	80	0	2	25	35	150	8	50
18-20	0	50	20	30	150	0	75	0	5	75	30	25
20-22	0	0	0	110	40	0	70	12	20	90	35	0
22-24	2	0	20	200	40	15	120	35	0	240	35	10
24-26	35	25	0	150	60	2	180	65	0	80	30	20
26-28	2	30	300	85	65	0	75	25	0	85	0	25
28-30	45	10	150	110	150	165	2	22	10	50	20	0
30-32	45	0	160	75	80	250	12	22	0	2	25	0
32-34	90	15	290	0	25	190	5	60	0	20	20	10
34-36	90	140	260	40	50	40	2	25	0	8	5	35
36-38	85	130	20	35	60	5	35	2	165	40	0	2
38-40	10	220	45	25	8	0	40	225	260	15	45	2
40-42	0	150	250	8	25	80	25	200	270	12	10	0
42-44	2	120	250	25	30	240	8	110	220	15	30	0
44-46	100	8	240	20	0	120	60	5	170	80	25	5
46-48	150	0	170	25	0	230	20	0	120	200	25	0
48-50	165	0	180	100	25	120	35	125	200	120	0	0
50-52	200	160	70	70	0	12	65	240	350	50	15	15
52-54	100	0	0	20	5	28	70	10	225	120	0	0
54-56	165	0	0	20	250	0	70	25	300	20	0	0
56-58	25	0	0	18	350	30	70	15	35	150	8	10
58-60	50	0	0	30	45	50	0	0	110	110	10	30

Table 4. Characteristics of shunting operations for the shift of 03/24/2021

Dismantling, 1500 tons, 68 axles, 8.28-9.02	Dismantling, 900 tons, 40 axles, 13.58 - 14.16
Dismantling, 700 tons, 32 axles, 9.06-9.24	Dismantling, 2000 tons, 84 axles, 14.18 - 15.04
Dismantling, 1900 tons, 224 axles, 9.30-10.22	Dismantling, 1500 tons, 60 axles, 15.18 - 15.56
Dismantling, 3600 tons, 208 axles, 10.24- 11.34	Dismantling, 1000 tons, 56 axles, 15.58 - 16.28
Dismantling, 1600 tons, 80 axles, 11.42- 12.08	Dismantling, 4100 tons, 208 axles, 4:30 - 6:50
Dismantling, 1000 tons, 48 axles, 12.10-12.48	Traffic reserve/hot standby
Dismantling, 2200 tons, 96 axles, 12.50 - 13.22	Cold standby
Dismantling, 3500 tons, 232 axles - 13.26 - 13.56	

Table 5. Indicators of the average power of the generator of the ChME3 diesel locomotive No. 1190 during the shift work on March 24-25, 2021, from 8 p.m. to 8 a.m. in kW according to the diagram of the BIC-P system

Minutes	Hours											
	20-21	21-22	22-23	23-00	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08
00-02	0	0	120	0	125	0	15	30	5	150	15	35
02-04	0	2	200	0	150	120	0	25	0	120	0	2
04-06	0	0	260	0	0	60	0	0	100	60	165	0
06-08	0	12	0	0	0	130	0	0	200	0	140	0
08-10	0	15	15	8	0	250	0	20	180	0	55	60
10-12	0	0	35	20	10	110	0	75	0	0	65	140
12-14	0	0	120	190	60	0	0	65	0	0	65	20
14-16	0	0	2	180	0	20	6	35	0	0	140	12
16-18	0	75	18	215	0	40	0	30	2	0	10	10
18-20	0	150	6	210	0	15	0	35	0	0	20	20
20-22	0	0	2	65	0	10	0	12	0	0	18	0
22-24	0	10	0	30	0	5	0	35	20	0	165	20
24-26	0	10	0	50	0	60	0	60	25	0	65	35
26-28	0	2	0	60	0	40	0	30	8	0	0	0
28-30	0	0	0	0	0	0	0	30	0	150	100	0
30-32	0	0	25	0	15	0	0	60	0	75	60	8
32-34	0	80	120	0	90	0	0	20	0	0	120	50
34-36	0	30	10	40	120	5	0	10	15	0	60	0
36-38	0	0	20	80	100	25	0	10	30	25	0	20
38-40	0	0	10	85	60	150	0	60	40	90	0	22
40-42	8	30	8	170	0	40	0	20	380	120	0	0
42-44	15	0	70	70	30	40	0	8	400	55	0	0
44-46	0	2	20	120	35	180	0	8	460	0	0	0
46-48	50	25	18	80	0	8	0	25	110	35	10	0
48-50	275	6	0	0	40	2	0	190	2	0	0	0
50-52	120	0	15	0	2	100	0	20	100	0	0	0
52-54	30	0	140	0	5	320	75	2	0	75	0	0
54-56	45	0	10	0	12	70	240	25	0	2	0	0
56-58	0	0	20	0	90	12	360	5	55	12	0	0
58-60	35	0	0	0	5	6	150	2	100	115	0	0

Table 6. Characteristics of maneuvering operations for the shift of 03/24-25/2021

Dismantling, 104 axles, 2100 tons, 20.44 - 21.06	Dismantling, 224 axles, 4000 tons, 01.50 - 03.02
Dismantling, 80 axles, 1700 tons, 21.10 - 21.44	Rearrangement, 40 axles, 700 tons, 03.04 - 03.32
Dismantling, 228 axles, 3000 tons, 21.50 - 22.46	Rearrangement, 56 axles, 1000 tons, 03.34 - 04.22
Dismantling, 112 axles, 2300 tons, 22.48 - 23.26	Dismantling, 184 axles, 2450 tons, 04.28 - 05.46
Rearrangement, 48 axles, 800 tons, 23.28 - 00.10	Dismantling, 136 axles, 2300 tons, 05.48 - 06.46
Dismantling, 84 axles, 1000 tons, 00.14 - 00.42	Rearrangement, 76 axles, 1200 tons, 07.04 - 07.36
Dismantling, 232 axles, 1600 tons, 00.46 - 01.14	Traffic reserve/hot standby
Dismantling, 96 axles, 1800 tons, 01.16 - 01.46	Cold standby

Fig. 5 shows the power dependence of the generator of diesel locomotive ChME3 No. 1190 during shift operation on March 23-24, 2021, from 8:00 p.m. to 8:00 a.m. (Fig. 5a), on 03/24/2021 from 8:00 a.m. to 8:00 p.m. (Fig. 5b), on 03/24-25/2021 from 8:00 p.m. to 8:00 a.m. (Fig. 5c).

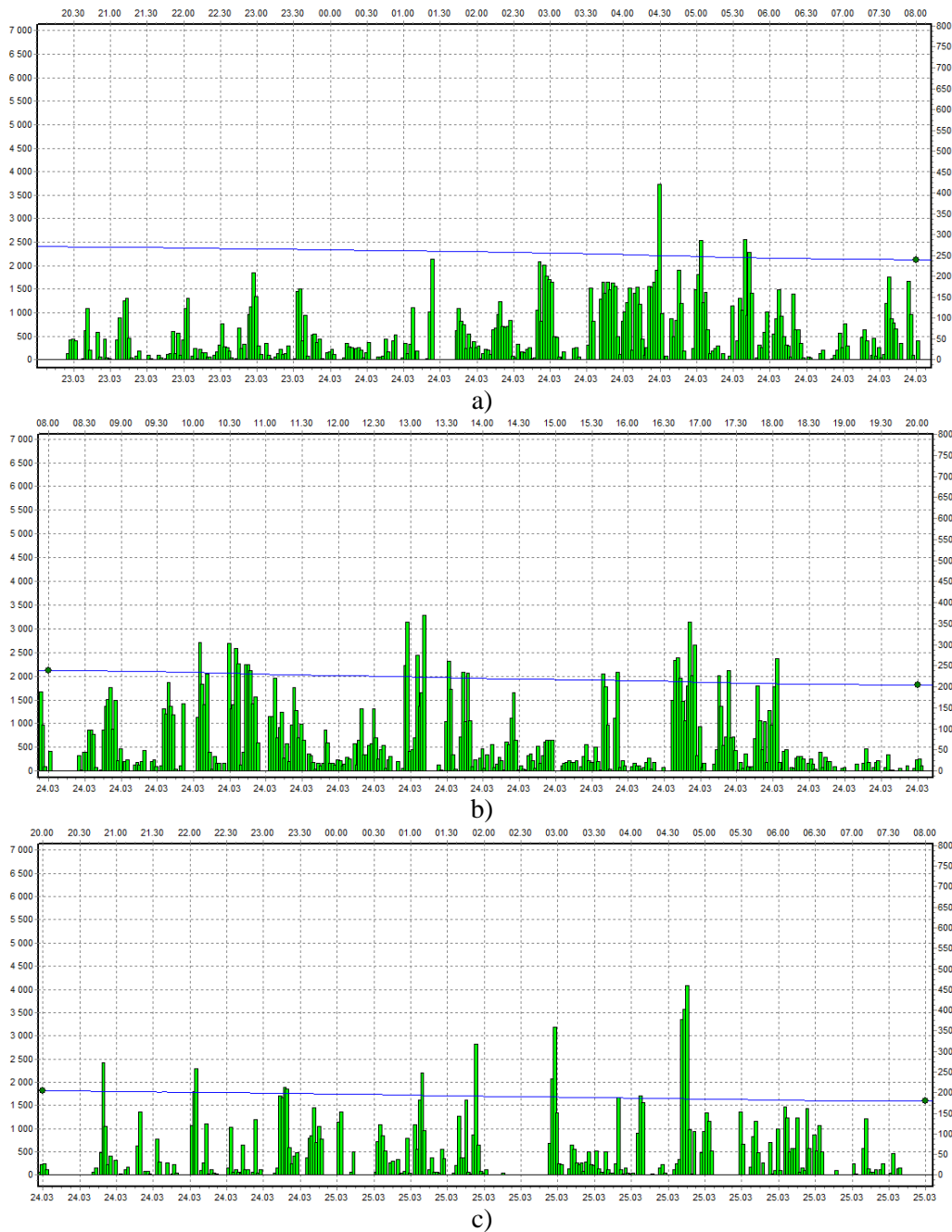


Fig.5. Traction generator power diagrams according to BIC-P system data

In fig. 6 shows the distribution of working time in a certain range of power depending on the total working time in traction mode. It should be noted that the BIC-P registers the average power for 2 minutes of operation, and therefore the actual power cannot be determined from them.

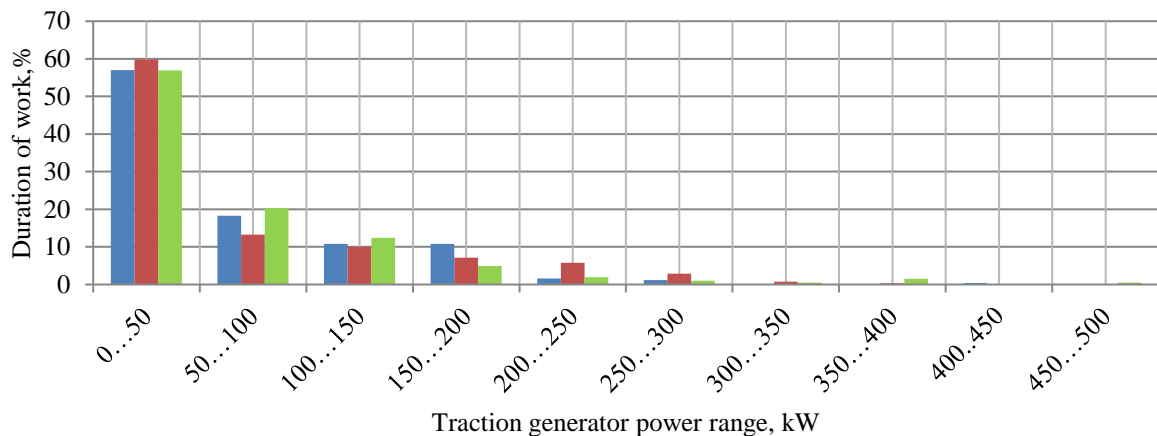


Fig.6. Distribution of the duration of work (in blue is the data for the 23-24.03.2021 shift, in red - for the 24-24.03.2021 shift, in green - for the 24-25.03 shift)

From fig. 6, it can be seen that for more than half of the working time in the traction mode (both when moving with wagons and when moving in reserve), the average power is within limits that do not exceed 50 kW, with an average power of 50...100 kW, the diesel locomotive works no more than 20% of the time. With larger values - 100...150 kW and 150...200 kW - power duration is 5...10%. With the maximum capacity, the diesel locomotive works at 0.5...1.0%.

The analysis of the mass of trains and groups of wagons shows that they varied from 300 t to 4100 t, and the mass of a significant part belongs to the range of 1000...2000 t. A comparison of the data on power and the type of shunting operation shows that when rearranging wagons, the diesel locomotive works with greater power, than in other types of work. This can be explained by the need to maintain a certain speed of movement, for which it is necessary to spend energy to overcome movement resistance. The operations of formation and de-formation are carried out at speeds close to zero by the method of "shocks", and therefore the energy consumption is related to displacements of the composition from its place and its acceleration. For this case, the position of the driver's controller is selected from the condition of realizing a certain traction force.

Table 7 shows the quantitative indicators characterizing the modes of operation of the diesel locomotive during the investigated shifts, as the following values are used.

The coefficient that determines the full use of the installed capacity of the diesel engine for powering the traction electric drive [35, 36]

$$K_p = \frac{E_F}{E_N}, \quad (1)$$

where E_F – the actual energy that is transmitted to the traction electric motors,
 E_N – theoretical value of the energy that can be given under the condition of operation of a diesel generator with nominal power.

The actual energy supplied to the traction electric motors is determined by the expression

$$E_F = \Delta t \sum_{i=1}^N P_i, \quad (2)$$

where Δt – the time interval over which the power is averaged,
 P_i – power at the i -th reading,
 N – the number of intervals at which traction electric motors are powered.

Accordingly, the theoretical energy value is calculated by the expression

$$E_N = P_N \cdot \Delta t \cdot N, \quad (3)$$

where P_N – power at the generator terminals at the nominal speed of the diesel engine is 890 kW.

The coefficient that determines the full use of the maximum available traction power (for powering the traction electric drive)

$$K_M = \frac{P_{max}}{P_N}, \quad (4)$$

where P_{max} – the highest average power per shift.

Also, from the input data, we determine the duration of shunting operations with wagons, reserve movement, operation of the diesel generator without load (hot idle and coasting) and cold idle. The results are shown in Table 7.

Table 7. Results of experimental data processing

Parameters	Units	Shift	Shift	Shift
		23-24.03.2021	24.03.2021	24-25.03.2021
The actual energy supplied to the traction motors	kWh	576,7	696,3	452,2
Theoretical energy	kWh	7446,3	8277,0	5992,7
Maximum average power	kW	420	375	460
Coefficient K_P	%	7,74	8,41	7,55
Coefficient K_M	%	47,2	42,1	51,7
The duration of shunting operations with wagons during the shift	min	440	496	356
	%	61,2	68,8	49,5
Duration of movement in reserve	min	70	82	52
	%	9,7	11,4	7,2
Duration of operation of the diesel generator without traction load (hot idling and coasting)	min	196	130	266
	%	27,2	18,1	36,9
Duration of cold standby time	min	14	12	46
	%	1,9	1,7	6,4

Figure 7 shows the duration of work modes during the shift. From Table 7 and Fig. 7 it follows that the duration of traction modes when moving with wagons is 49.5...68.8% of the shift duration, the duration of traction when moving with a reserve is 7.2...11.4%. The duration of operation of the diesel engine without a traction load is 18.1...36.9% of the duration of the shift, and falls on both "preparatory" operations, which are necessary for performing maneuvers, and simple "inside" maneuvering operations. From 1.7 to 6.4% of the shift duration, the diesel does not work on the diesel locomotive.

Table 7 shows that the K_P coefficient does not exceed 10%, and the maximum value of the K_M coefficient does not significantly exceed 50%, which indicates that for the studied operating conditions, the full power of the diesel engine is not used.

In general, for the studied case of operation of the ChME3 diesel locomotive in shunting work, it is established:

- its power is redundant,
- more than 50% of the time, the traction electric drive consumes power up to 50 kW, the most demanded power reaches 200 kW, which corresponds to positions 1...4 of the driver's controller, peak power is 460 kW;

- when the weight of the composition increases, work is carried out with higher power values.

Thus, the above information testifies the possibility and expediency of using a less powerful diesel engine on a locomotive in cases of its use, similar to the one under study.

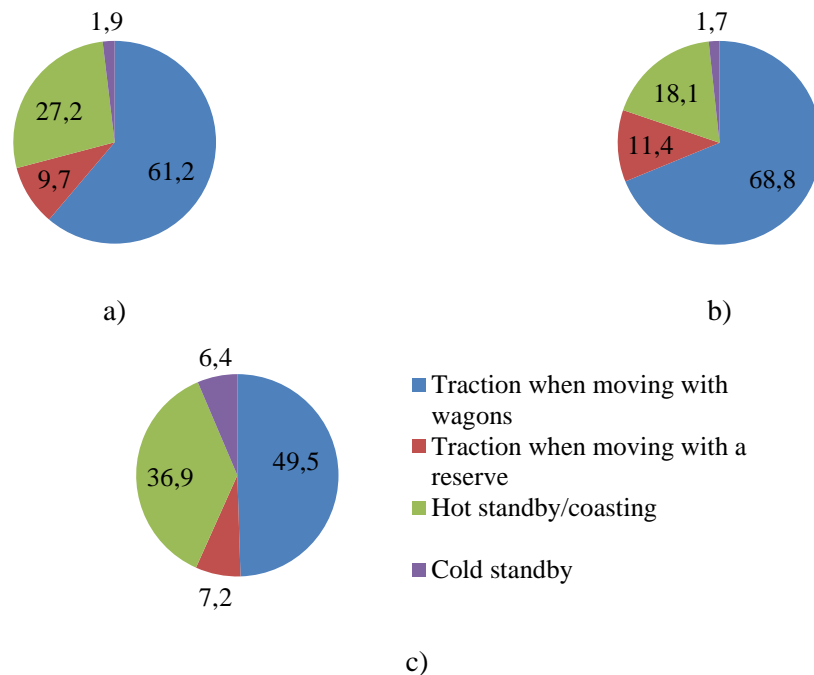


Fig.7. Duration (relative) of locomotive operating modes (a – shift 03.23-24.2021, b – shift 03.24.2021, c – shift 03.24-25.2021)

An important direction of improving the traction and energy characteristics of the locomotive for shunting work is the use of energy-efficient traction electric motors and optimization of their control. Traction motors TE006 are used in ЧМЕ3 diesel locomotive, in accordance with the recommendations [37]. The calculation of their efficiency taking into account the parameters of the external characteristics of the generator at the positions of the driver's controller [38] shows that the efficiency of the electric motors varies from 27% to 50% at high current values, that flow through the traction electric motors, when the locomotive moves and moves at low speeds. And it is precisely these modes of operation that prevail during the "disassembly" of trains on the sorting slide or maneuvers with "shocks". Since such modes of operation are the most common, it is advisable to use traction electric motors that have significantly higher energy efficiency indicators in such modes. The paper [9] proposed the use of asynchronous traction electric motors simultaneously with the replacement of axial gearboxes. In [8], the use of valve-inductor motors is proposed. When creating the HD300 diesel locomotive, synchronous electric motors with excitation from permanent magnets were used [39]. In [40], the structure of the traction system of a hybrid shunting diesel locomotive was investigated.

The wide range of changes in the mass of the train also draws attention, and therefore the possibility of optimizing the number of working traction motors depending on the mass of the trains: it is advisable to turn off part of the traction motors when working with trains of small mass, because this reduces losses in the traction electric drive.

An important aspect of energy saving is the optimization of locomotive auxiliary systems, which can account for up to 20% of total energy consumption. Reduction of energy consumption is provided both by the use of energy-efficient equipment and by controlling its operating modes.

Since energy accumulators can be used on locomotives, in order to reduce operating costs, it is advisable to provide for the possibility of charging the on-board energy accumulator from an external source with a low energy cost [41-44].

Thus, the analysis of the parameters of the operational modes of the ЧМЕ3 diesel locomotive when performing shunting work shows the inconsistency of its characteristics for this work. To improve a diesel locomotive, and even more so when creating a new one, it is necessary to take into account the operating conditions and the application of modern energy-saving technologies.

Conclusions. Modern trends in the modernization and creation of shunting locomotives are considered. Currently, the most common for old diesel locomotives is remotorization with the renewal of traction electrical equipment. When creating new locomotives, hybridization of their power plants is used.

The operating parameters of the shunting diesel locomotive at the Kozyatyn-I station were analyzed. Based on the results of the analysis, it was established that for the studied case of shunting operation, the power of the diesel locomotive is excessive, and its traction electric drive operates with low efficiency. The use of the ChME3 diesel locomotive in such conditions leads to increased consumption of fuel and energy resources for shunting operations.

For the investigated case of shunting work, it is advisable to use a locomotive with a power of about 500 kW. The type and structure of the power plant and traction electric drive must be optimized for low-speed operating conditions.

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Аналіз режимів експлуатації маневрових тепловозів при виконанні маневрової роботи

Виконано огляд сучасних напрямів оновлення маневрових локомотивів, які засновані на застудванні бортових накопичувачів енергії, багатодизельних силових енергетичних установок, енергетичних установок на основі водневих джерел енергії. Показано необхідність врахування умов експлуатації маневрового тепловоза при виборі варіанту оновлення. Розглянуто режими експлуатації маневрових тепловозів при виконанні маневрових операцій на вантажній станції Козятин-І протягом трьох змін. Шляхом аналізу даних бортової системи БІС-Р та опрацювання маршрутних листів визначено параметри експлуатаційних режимів. Виконано розрахунки показників використання потужності дизельного двигуна, за якими встановлено, що повноту використання встановленої потужності дизель-генератора складає 7,5...8,4%, а максимальна потужність дизеля, яка зафіксована у досліджуваних умовах експлуатації, складає близько 50%. Тривалість роботи з тягових навантаженням складає 49,5...68,8% часу зміни. Найбільш тривалими – 55...60% загальної тривалості роботи під тягою – є режими з потужністю 0...50 кВт. Тривалість роботи без навантаження складає 18,1...36,9% тривалості зміни. Виконувана маневрова робота пов'язана з формуванням і розформуванням составів, у тому числі з використанням сортувальної гірки, внаслідок чого тягова передача потужності працює з низьким коефіцієнтом корисної дії. Для зниження споживання паливно-

енергетичних ресурсів при виконанні маневрової роботи необхідно оновлення парку локомотивів для маневрової роботи, характеристики яких адаптовані до режимів експлуатації.

Ключові слова: *гібридний тепловоз, модернізація, маневрова робота, енергоефективність, накопичувач енергії*