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Development and construction of shunting electric locomotives at Dnipropetrovsk electric locomotives plant (1960's – 1970's)

Abstract. *In the article on the basis of the complex analysis of sources and scientific literature the attempt to investigate historical circumstances of development and construction of shunting electric locomotives at the Dnipropetrovsk electric locomotive plant has been made. It was found that during the 1960s and 1970s, the team of designers of the Dnipropetrovsk plant, having strong research and production potential, at the request of the Ministry of Railways of the USSR developed and built unique samples of shunting electric locomotives of the VL41 and VL26 series to meet the needs of Soviet main-line railways with modern high-tech electric vehicles. It is proved that in the absence of thorough experience and, accordingly, the possibility of a rapid technological breakthrough in the development of main-line locomotives, during the experimental operation of shunting electric locomotives VL41 and VL26, several design shortcomings were identified, which led to their further use exclusively on the house tracks of enterprises, and designers of Dnipropetrovsk plant later focused on the development and construction of traction units for industrial application commissioned by the Ministry of Ferrous Metallurgy of the USSR. At the same time, the construction of the main-line railway equipment to the order of the Ministry of Railways allowed the staff of the enterprise to gain valuable experience, which was later used in the implementation of the renewal program of rolling stock of Ukrzaliznytsia. Although today the Dnipropetrovsk plant is in decline, the analysis of historical circumstances of formation and design and technological heritage of electric locomotive construction in Ukraine is of fundamental importance both in the general* *perspective of the development of domestic transport engineering, and the railway industry in particular. Further study of the history of Dnipropetrovsk electric locomotive plant requires clarification of the historical circumstances of institutionalization of the Special Design and Technology Bureau of the enterprise from the creation of industrial electric locomotives and traction units to the development and re-equipment of main traction rolling stock and specialized repair equipment within the state enterprise "Ukrainian Research Design Institute of Electric Locomotive Engineering".*

Keywords: *Dnipropetrovsk electric locomotives plant; railway engineering; Switcher; main-line electric locomotives engineering; Soviet railways*

Introduction.

The search for technical solutions aimed at minimizing operating costs and environmental pollution during shunting work is an urgent task of the domestic locomotive industry. Despite numerous theoretical researches of ways of modernization of the locomotives of the ChME3 series most involved in shunting work on the railways of Ukraine and attempts of involvement of the main electric locomotives for shunting work (Ryabov, 2015, p. 69), indicators of their operational efficiency remain unsatisfactory, in addition, the economic disadvantage of using shunting locomotives on electrified sections of railways is the need to maintain for equipment and repair of additional locomotive facilities along with the existing electric locomotive one, which creates additional costs (Krasnobaev & Vanag, 1970, p. 53). During the 1960's and 1980's, the Dnipropetrovsk Electric Locomotive Plant specialized in the production of rail electric vehicles for industrial purposes and had a powerful special design and technology bureau (hereinafter – SDTB), whose team designed semi-autonomous locomotives with combined types of traction and had specific experience in the development of industrial production of VL41 and VL26 shunting electric locomotives of own development, created by order of the Ministry of Railways of the USSR. Since, today in Ukraine the issue of import of hybrid semi-autonomous locomotives manufactured by the Japanese corporation Toshiba (Vasyl, 2019) is relevant, and given the prospect of unification of production activities of the locomotive industry of JSC "Ukrzaliznytsia" by introducing electric shunting traction, reducing the cost of current maintenance of rolling stock and the possibility of using electricity recovery during locomotives braking at train operation, there is a need for a comprehensive analysis of the historical experience of the domestic design school of electrical engineering in dealing with this issue.

Unfortunately, for a long time, the circumstances of the production activity of the Dnipropetrovsk electric locomotives plant did not find their proper coverage in the domestic historiography, the only exception is the book by O. Shatovsky and H. Volneansky (Shatovsky & Volneansky, 1998), as well as articles by the authors (Ruban & Baka, 2020; Ruban, 2020; Ruban & Ponomarenko, 2020). Some issues of the history of electric locomotive construction at the Dnipropetrovsk plant are presented in engineering surveys of designers of the enterprise (Kuzmenko & Matusevich, 1964; Bichuch & Kuzmenko, 1969; Savysko, 2009), monographs of V. Rakov (Rakov, 1990; 1999), of academician V. Bratash (Bratash et al., 1977). At the same time, most popular scientific and technical publications do not even mention the Dnipropetrovsk electric locomotives plant (Shternov, 1967; Haruk, 2019). Instead, we believe that the analysis of production activities of domestic enterprises of railway engineering is updated because of the need to identify conceptual ways to reconcile their historical design and technological potential with modern needs in the renewal and development of the fleet of traction rolling stock of transport operators of Ukraine.

Thus, the subject of the proposed study is the production activity of the Dnipropetrovsk electric locomotives plant. The chronological boundaries of the study cover the period from the beginning of the development of projects of wide-track shunting electric locomotives with combined types of traction to the actual curtailment of this activity after the modernization of the last shunting electric locomotive VL26 in 1972.

The aim of the article is that on the basis of a comprehensive analysis of sources and scientific literature to reproduce a holistic picture of the preconditions for the development and circumstances of construction of shunting electric locomotives in Ukraine in 1963–1972, which involves solving the following research tasks: first, to clarify the historical circumstances of the Dnipropetrovsk electric locomotives plant development; secondly, to consider preconditions of construction and technical features of domestic shunting electric locomotives; thirdly, to find out the impact of the experience of development and construction of shunting locomotives of the Dnipropetrovsk plant on the design and technology school of main electric locomotive construction in Ukraine.

Research Methods.

The proposed research used general scientific methods and principles of historical research, in particular, historicism, objectivity, continuity, multifactoriality, complexity, and comprehensive knowledge (Fullerton, 2011), which provided a detailed analysis of the historical circumstances of the construction of shunting locomotives at Dnipropetrovsk electric locomotives plant in a clear chronological sequence.

Results and discussion.

The construction of the Dnipropetrovsk locomotive repair plant “Promparovoz”, which was to serve as a repair base for locomotives of domestic transport of metallurgical plants of Ukraine, began in 1933, and in the spring of 1937 the company, designed for annual repairs of 300 locomotives and spare parts, was officially introduced. into operation (Shatovsky & Volneansky, 1998, p. 26). Resolution of the Council of Ministers of the Ukrainian SSR No. 1040 of August 7, 1958, approved the organization of production of industrial electric locomotives at the Dnipropetrovsk locomotive repair plant, and on November 13, 1958, by order of the Dnipropetrovsk Council of National Economy No. 862-R the enterprise was reorganized into "Dnipropetrovsk electric locomotives plant". According to the order, starting from 1959 it was planned to organize the production of electric locomotives and spare parts for them with the subsequent bringing of the enterprise's capacities to 200 locomotives per year till 1965. The production range consisted of contact four-axle electric locomotives with an adhesive weight of 100 tons and six-axle electric locomotives with an adhesive weight of 150 tons (The State Archive of Dnipropetrovsk Oblast, f. 4593, op. 1, spr. 2, ark. 153–154). In addition to the main activity of development and construction of locomotives, the Dnipropetrovsk plant had orders for the manufacture of electric arc steel furnaces, vibrating screens, as well as traction engines for walking excavators (Shatovsky & Volneansky, 1998, p. 79–81, 96).

Dnipropetrovsk electric locomotive plant (DELP) specialized in the production of electric locomotives for access tracks of mining enterprises and had a powerful special design and technology bureau (hereinafter – SDTB). In 1959, the company began designing and organizing the production of the first in the USSR industrial single-phase electric locomotives with a frequency of 50 Hz high voltage industrial frequency of 10 kW. Along with the repair of the last locomotives, the company built the bodies of the first electric locomotives, and at the end of 1961, the first two four-axle research locomotives of the company's own design were manufactured, which were designated the D100 series. (Rakov, 1999, p. 401–402). At present, the procedure for assigning the types of the first electric locomotives of the Dnipropetrovsk plant has not been precisely documented, however, apparently the digital designation was carried out taking into account the adhesive weight of the locomotive. The electric locomotive had an adhesive weight of 100 tons, a traction force of 16,3 tf, and a speed of 29,9 km/h in hourly mode, and in long-term mode – 10,9 tf and 35 km/h, respectively. The double-pitch body of the locomotive, which became the basis for the future electric locomotives of the plant, provided a good overview during the loading of cars at the location of the side current collectors, and access for maintenance of the power and auxiliary equipment.

After testing the first two electric locomotives of the D100 series on the experimental branch of the Dnipropetrovsk Institute of Railway Engineers, under the leadership of the chief designer of DELP V. Bezruchenko the locomotive design was significantly redesigned, in particular, the shape of the body was simplified (the size of the side bevels was reduced to improve the visibility of the track from the driver's cab), the bogie frame was strengthened and the location of the traction motors was changed to increase the utilization of the adhesive weight. Traction electric motors and drive of auxiliary mechanisms were also replaced on the experimental electric locomotive D100M (Bezruchenko, Grigor'yev, & Matusevich, 1961, p. 7, 10). In total, during 1962–1963, 51 locomotives were built under the renewed project, which received the serial designation D100M (modernized), although the numbering continued from the first two experimental electric locomotives D100. D100M electric locomotives

(Figure 1) were delivered to work on the access tracks of coal mining enterprises, in particular, "Vakhrushevvuhilya" and "Korkinovuhilya" (Rakov, 1999, p. 403–404).

Figure 1. Electric locomotive D100M-006, Dnipropetrovsk Electric Locomotive Plant (1962) (D100M-006, 1962).

AC electric locomotive VL41

Since the reorganization, the Dnipropetrovsk plant has been constantly considering the possibility of building main electric locomotives. In particular, back in July 1959, a group of Dnipropetrovsk designers headed by the first head of SDB B. Kolyushnyk (The State Archive of Dnipropetrovsk Oblast, f. 4593, op. 1, spr. 28, ark. 28) was sent to the Novocherkassk electric locomotive plant to " *study the design of the ignitron installation and control panel of the H-60 electric locomotive* ", also at the enterprise it was planned to organize "*production of freight eight-axle double-powered electric locomotives with a capacity of 4800–5200 kW of VL82 type*" (The State Archive of Dnipropetrovsk Oblast, f. 4593, op. 1, spr. 227, ark. 23–24), the construction of which was later deployed at the Novocherkassk plant (Rakov, 1999, p. 130). In the early 1960s, Dnipropetrovsk designers developed projects for four-axle and six-axle shunting electric locomotives equipped with small diesel generator sets to work at stations with non-electrified low-efficiency tracks. The plan to produce new equipment in 1961 provided for the construction of a four-axle electric locomotive weighing 100 – 120 tons with ignitron rectifiers and an autonomous power plant (Shatovsky & Volneansky, 1998, p. 106). A project of a six-axle shunting electric locomotive with a capacity of 2500 kW with a design speed of 80 km/h, equipped with a diesel generator set with a capacity of 440–588 kW, was also developed (Rakov, 1999, p. 404).

Since DELP during 1962 – 1963 produced a sufficient number of electric locomotives D100M series electrified by a single-phase current system with a voltage of 10 kW, at the suggestion of the head of the Main Department of Locomotive

Industry of the Ministry of Railways of the USSR A. Tyshchenko a decision was made to begin construction at the Dnipropetrovsk plant of shunting electric locomotives of single-phase current of 25 kW for the main railways of the Soviet Union. In order not to stop the construction of electric locomotives at the plant and to make its initial reconstruction minimal, a modified version of a four-axle shunting locomotive, based on an industrial electric locomotive D100M with an ignitron rectifier was proposed as a temporary intermediate type. The first electric locomotive of the new series, designated D92 (later – VL41), was built in 1963. Compared to the prototype of the new locomotive, the traction force was increased (at an hourly mode by 1,1 tf and 2,2 tf – at a long time mode) and the speed was increased by 3,7 km/h and 3,8 km/h, respectively. The power of traction motors increased: at an hourly mode from 355 to 425 kW and from 290 to 380 kW – at a long-time mode, design speed was increased by 30 km/h as well (Rakov, 1999, p. 403, 406). The weight of the electric locomotive D92 (VL41 (Figure 2)) was 92 tons. In the hour mode, it developed a traction force of 17,5 tf and a speed of 34,7 km/h, in the long-time mode – 14,9 tf and 36,5 km/h, respectively. The initial design speed was 100 km/h, and the traction force at this speed was 2,5 tf (Kuzmenko & Matusevich, 1964, p. 22).

Figure 2. Electric locomotive VL41-001, Dnipropetrovsk Electric Locomotive Plant (1963) (VL41-001, 1963).

The mechanical part of the electric locomotive consisted of a body and two two-axle carts. The all-metal body of a welded design from rolled and bent profiles and steel sheets consisted of a frame, a driver's cab, and also two bevels. On each of the carts the body leaned with a flat central and two side supports. Traction and braking forces were transmitted to the body through the central supports. Four lateral elastic sliding supports transmitted vertical impulse to the trolleys and gave the body transverse stability. The control cabin, as on D100 electric locomotives, was located in the center of the locomotive. The frame of the trolley consisted of boxlike section side frames (340×200 mm), welded from sheet steel 12 mm thick, as well as cast parts made of special steel with a carbon capacity of not more than 0,25%. All parts and components were connected together by welding and subjected to burning. Wheelsets (wheel diameter 1200 mm), driving gear (gear ratio 3,905), and traction motors (NB-406B) were similar to electric locomotives of the VL8 series. Traction gear was helical, double-sided, rigid. The normal diametral pitch is 10 mm, the angle of its inclination is 24^0 37’ 12’’. The gears were made of solid rolled steel and subjected to three-dimensional hardening. The gears were made of 40CrNi steel forgings. The teeth of the gearwheel were subjected to surface hardening. Truck axle boxes are non-pedestal, two-linking with bearings, as at VL60 electric locomotives, bearings are with cylindrical rollers (Kuzmenko & Matusevich, 1964, p. 22). The spring suspension of both carts was the same balanced in the longitudinal direction and consisted of cellar leaf springs connected by longitudinal balancers and end cylindrical springs. The locomotives were equipped with standard devices for controlling the brake system and air distributors No. 270.002. The lever brake system was made with one-sided pressure of the hobs on each wheel. The suspension of the traction engine was of the axial type. To make better use of the electric locomotive's adhesive weight, its engines were mounted on carts so that their spouts were directed towards the middle of the body (Bezruchenko, Grigor'yev & Matusevich, 1961, p. 7).

Electrical and pneumatic equipment was located in two bevels, the driver's cab, on removable bevel hatches, cab roof and under the body. The high-voltage chamber, which housed the rectifier and the engine room, was located in the bevel No. 1. The power transformer, smoothing reactor, and control equipment were located in the bevel No. 2. Two control panels were installed in the driver's cab, the main switch was placed on the detachable hatches and the roof of the driver's cab, two current collectors with disconnector were located. The electric locomotive was equipped with two Ts-13-50 No. 5 fans, one in each bevel, and one axial SVM-5M fan for cooling silicon rectifiers, transient resistors, and a smoothing reactor. Heat removal from ignetrons was carried out by a cooling system with a capacity of 200 liters. The main temperature control equipment and several units were used from serial AC electric locomotives (temperature regulator TSR-48, temperature relay TR-4P, current relay RSE, induction heater IN-1, radiators and main pump). Asymmetric pantograph PN-2 was a single-bow collector weighing 200 kg, designed for a long current of 1000 A and a maximum speed of 110 km/h (Kuzmenko & Matusevich, 1964, p. 23).

The main switch EKG-41 (designed for low-voltage step voltage control on traction motors), which had 29 fixed positions and was similar in design to the main switch ECG-60/20 electric locomotives series VL60, housed 12 contactors with arc suppression and 12 contactors without arc suppression, (Rakov, 1999, p. 405). The nominal insulation voltage of the cam elements was 3350 V. The single-phase oil transformer OCR-2800/25 had a nominal power of the primary winding of 2260 kW, the no-load voltage of the traction windings was 2 × 1515 V, the voltage of the windings for own needs – 404 and 227 V. The traction winding consisted of two half-phases, each of which was divided into three parts: adjustable, unregulated and boosting, as in the transformer OCR-2200/10. The adjustable part had four pins (three sections). Six rectifiers IVS-300/5, connected in two groups of three connected in parallel in each were used to rectify the current, which was carried out according to the zero-output circuit. (Kuzmenko & Matusevich, 1964, p. 23–24).

In the circuit of traction engines in the absence of transient reactors was included smoothing reactor REDR-2500. Traction motors NB-406B operated at pulsating current, as a result of which their nominal voltage on the terminals, as well as on electric locomotives D100M, was reduced from 1500 to 1200 V, a constant excitation attenuation (92% of maximum) was introduced to pass the alternating current component. The NB-406B electric motor had in an hour mode: power 425 kW, current strength 380 A, armature speed 600 rpm; in long-time mode: power 380 kW, current 340 A, armature rotation 630 rpm. The main switch VOV-25U, phase splitter NB-453, compressors E-500, their electric motors AC-81-6 and electric motors AP-81-4 fan drives were similar to the electric locomotives of VL60 series, the release of 1962 (Rakov, 1999, p. 406). The connection scheme of the traction motors allowed to obtain 29 stages, in addition, the supply winding made it possible to do this with a small number of terminals in the adjustable part of the traction winding. All 29 stages were running, except for full arousal, it was possible to get two stages of attenuation – 75 and 55%. Schemes of control circuits of traction motors, protection of power circuits from excessive loads, short circuits, reverse ignitions in ignitrons and atmospheric overvoltages, and also the scheme of control cabinets of ignitrons were similar to the VL60 electric locomotive (Kuzmenko & Matusevich, 1964, p. 24). The driver's controller had a reversible handle with five positions (“Back”, “0”, “Forward 1st full field”, “Forward 2nd weakened field”) and the main one with seven positions (“0”, “Automatic shutdown”, “Manual shutdown”,”Lock-off”, “Lock start”, “Manual start” and “Automatic start”). The power supply of control and lighting circuits, charging of the accumulator battery was carried out by a constant voltage of 50 V from the statically charging unit consisting of the single-phase transformer and silicon rectifiers. To ensure the charge of the battery, which consisted of 38 elements of KN-100, during the period of the highest load in the control circuits, a scheme developed by engineer Yu. Marchenko was adopted (Kuzmenko & Matusevich, 1964, p. 25).

In January – February 1964 the electric locomotive VL41-001 together with the electric locomotive VL80-007 was tested by the All-Union Research Institute of Railway Transport of the USSR Ministry of Railways (Vsesoyuznyy naukovo-doslidnyy proektno-konstruktors′kyy instytut zaliznychnoho transport; hereinafter – VNIIZhT). The test results showed that at a speed of 70 km/h the electric locomotive VL41 had a worse effect on the track than the electric locomotives of the VL80 series, and the course of the electric locomotive was uneasy. Given the results of tests, VNIIZhT recommended setting the maximum speed of the electric locomotive VL41 70 km/h. In order to improve the dynamic characteristics of the electric locomotive VL41-065, DELP designers decided to install friction spring shock-absorbers between cross bars of carts and a buffer bar of a body – two and two shock-absorbers with their arrangement on a longitudinal axis of the locomotive. When testing the electric locomotive VL41-066 it was noted that when driving on straight sections, its course was restless due to "friction failure" in the shock absorbers, and when driving curves due to the damping moment the impact of the locomotive on the track increased. In the end, it was decided to abandon the shock absorbers and limit the maximum speed of the locomotive to 70 km/h. In 1963, the Dnipropetrovsk plant produced 28 electric locomotives of the VL41 series (No. 001–028), and in 1964 – 50 (No. 029–078), in total, the company built 78 electric locomotives of the VL41 series (Rakov, 1999, p. 406).

In 1966, one electric locomotive of the VL41 series was converted into a contact-battery locomotive. A two-axle tender with a 648-TNZh-400 battery was attached to the electric locomotive. In the same tender, a part of the electric equipment of the electric locomotive was mounted, which allowed to reduce the load of the wheel pairs of the electric locomotive on the tracks from 23 to 21,5 tons, as well as to facilitate the pass conditions of the locomotive by station tracks with a weak upper structure. The battery was placed in a tender in 12 compartments of 54 cells in the compartment and closed with a metal roof that had hatches for adding water. After re-equipment, the electric locomotive could receive train and shunting modes when receiving energy from the catenary. In train mode, traction motors were powered by a transformer winding with a nominal voltage of 1524 V, and in shunting mode – by a winding with a nominal voltage of 514 V. The battery could be charged from the catenary both in the lay-out and while driving. When powered by traction motors from the battery, the electric locomotive could only operate in shunting mode. Start-up was carried out using rheostats and switching of electric motors from serial-parallel to parallel connection. During 1975–1977 according to the project of the Design Bureau of the Main Department of Locomotive Economy of the USSR Ministry of Railways, 13 electric locomotives of the VL41 series were re-equipped with the replacement of ignetronic rectifiers to silicon ones and received the designation VL41K. (Rakov, 1999, p. 406).

Electric locomotives of the VL41 series (Figure 3) were delivered for shunting work on the East Siberian, Gorky, West Siberian, Moscow, Odessa-Chisinau, North Caucasus, and South-Eastern railways. However, the locomotives were poorly adapted for shunting work: they had insufficient traction weight, high track load, low traction, and speed, as well as in the absence of a contact wire over the individual spare tracks of stations, were limited to use in shunting and export work. VL41 electric locomotives began to be transferred to industrial enterprises of the coal mining industry and the tracks of power plants (with the replacement of transformer windings with voltages from 25 to 10 kV). Most of these locomotives were transferred to the access tracks of mining and power plants between 1970 and 1975. As of January 1, 1976, there were 24 electric locomotives of the VL41 and VL41K series left on the railways of the USSR Ministry of Railways, of which 18 in the North Caucasus, 4 in the West Siberian, and 2 in the East Siberian. (Rakov, 1999, p. 407).

Figure 3. Electric locomotive VL41-004, Dnipropetrovsk Electric Locomotive Plant (1963) (VL41-004, 1963).

Due to the complexity of operation of shunting electric locomotives VL41 on the main railways of the USSR, Dnipropetrovsk plant returned to the production of industrial electric locomotives AC with a nominal voltage of 10 kW, creating at the end of 1964 as part of the continuation of the series (D100, D100M, D92/VL41) experimental electric locomotive D94-001, which differed from VL41 by increasing the total length, the location of the equipment in the body, the voltage of the primary winding of the transformer and the presence of side current collectors (Bratash et al., 1977, p. 23). According to V. Rakov, the transition of the Dnipropetrovsk plant to the construction of six-axle electric locomotives equipped with diesel generators with internal combustion engines with a capacity of about 552 – 736 kW, which would allow the shunting locomotive to operate freely on non-electrified tracks, would solve the main number of problems that arose during the experimental operation of electric locomotives VL41, however, the further development of the project was stopped due to the beginning of construction of shunting electric locomotives of a direct current with rechargeable batteries of the VL26 series (Rakov, 1999, p. 407).

DC battery electric locomotive VL26.

In order to replace shunting locomotives with electric locomotives at the stations of electrified sections of railways and at the same time not to incur unreasonable costs for electrification of inactive sections, Baltic Railway engineers initiated the creation of a contact-battery electric locomotive. The great advantage of such locomotives over diesel locomotives was also the absence of noise and smoke, which is especially important when carrying out shunting work within cities. The actual precedent that prompted the beginning of work on the development of contact-battery locomotive was the successful experience of operation of the converted for operation on the battery of an industrial electric locomotive IVKP at the Magnitogorsk Metallurgical Plant (Krasnobaev & Vanag, 1970, p. 54). In 1964, the public design bureau of the Scientific and Technical Society of the Baltic Railway developed a preliminary design of a contact-accumulator shunting electric locomotive with a voltage of 3000 V, which was approved by the commission of the Scientific and Technical Council of the USSR Ministry of Railways. The design and construction of experimental contact-battery electric locomotives were carried out by the Dnipropetrovsk plant. In 1966, the first experimental electric locomotive was built, which received the serial designation VL26 (Figure 4, Figure 5), and during 1966 – 1967 which came into operation on the Dnieper, Sverdlovsk, and Baltic railways, as well as a number of industrial enterprises. (Krasnobaev & Vanag, 1970, p. 54).

Figure 4. Electric locomotive VL26-001, Dnipropetrovsk Electric Locomotive Plant (1966) (Electric locomotive VL26-001,1966).

When designing a new contact-battery electric locomotive, the designers of the Dnipropetrovsk plant developed a fundamentally new scheme of the locomotive, decided on the location of the battery, ventilation system, and equipment layout. Among the main developers of the electric locomotive was the head of the design and installation department of SDTB L. Kuzmenko, group leaders M. Bichuch, V. Frolov, F. Raslin, designers M. Kogai, A. Gurevich, artist-designer V. Zhilko, specialists of the electric machines department V. Zakatov, E. Arshinov, V. Artyukh, I. Matusevych, I. Karlenko, head of the group of electrical appliances department V. Savysko, as well as its designers V. Denisenko, G. Svetlov, V. Chmykhalov, A. Nazarenko, V. Przhepyurko, I. Ryzhenko, group leaders E. Moskvichov, V. Volodarsky, I. Handelman and L. Guzik (Shatovsky & Volneansky, 1998, p. 116). It should be noted that in 1967 one of the electric locomotives VL26-005 was built over time by Komsomol youth brigades to the 50th anniversary of the All-Union Leninist Young Communist League. Enthusiasts of electric machines, wheeled, electric locomotive, blacksmith and foundry shops were especially noted, in particular, only the crews of masters V. Chernega and V. Kurochkin worked in the fund of overtime locomotive for more than 220 standard hours (Shatovsky & Volneansky, 1998, p. 118).

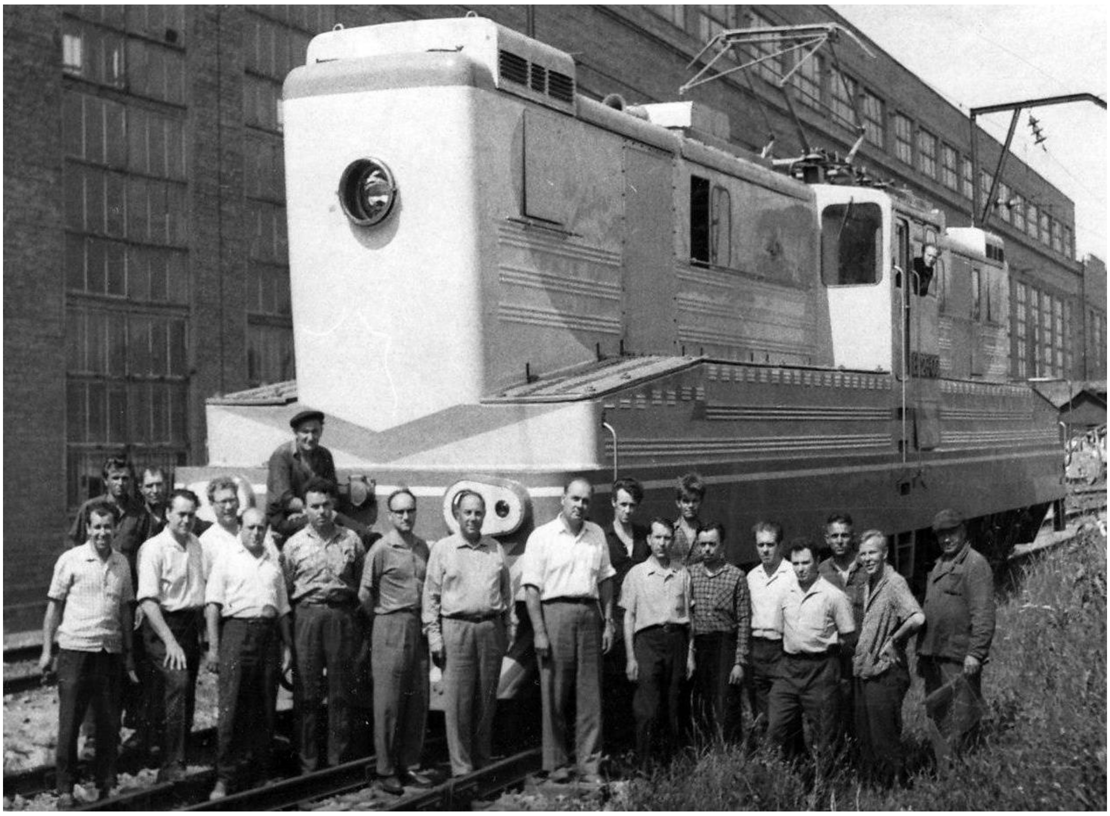

Figure 5. Electric locomotive VL26-001, Dnipropetrovsk Electric Locomotive Plant (1966) (VL26-001, 1966).

The VL26 electric locomotive had an all-metal body, in the middle of which there was the driver's cab (Figure 6). In the side compartments of the lower part of the body there were sections of the battery, which were charged when working from the catenary. The length of the electric locomotive along the axles of the auto-couplings was 19900 mm, the distance between the pins of the carts was 10000 mm, the wheelbase of the cart was 3900 mm, and the total wheelbase was 13900 mm. The three-axle carts of the electric locomotive had sheet cellar springs and cylindrical springs. The diameter of the wheels was 1050 mm. Transmission from traction engines was one-way, rigid, its gear ratio was 79:16=4,9375. Six DT-7A traction electric motors were installed on the electric locomotive, developed with the participation of the head of the sector of the department of chief technologist Yu. Bereznyak, the head of the SDTB group V. Frolov and the head of the electric machine shop A. Mironov on the basis of electric motors RT-113 of electric trains series ER22 (Shatovsky & Volneansky, 1998, p. 115). At a voltage of 750 V, the DT-7A motors had in an hourly mode: power 235 kW, current 350 A, armature speed 525 rpm; in long-time mode: power 180 kW, current 265 A, armature rotation 570 rpm (Rakov, 1999, p. 396). Initially, electric locomotives used TNZh-550 rechargeable batteries, which consisted of 672 series-connected elements placed in 16 boxes. The nominal voltage of the batteries was 840 V, the capacity was 550 A, weight – 25 tons. Traction motors could be connected in series and series-parallel; the battery, which was charged during the operation of the electric locomotive from the contact drive, was connected in series with them. It was not possible to connect the three motors connected in series directly to the contact wire (without the battery), as this would create unacceptable voltages on the machine collectors.

Figure 6. Electric locomotive VL26-005, Dnipropetrovsk Electric Locomotive Plant (1967) (VL26-005, 1967).

The start was carried out using the starting resistors. In the lay-out, the battery was charged through starting resistors, in which about 2/3 of the energy consumed from the catenary was lost. Electric motors of DK-258A fans were connected to the ballast resistor, which also caused energy losses when powering the electric locomotive from the catenary. At a voltage in the catenary of 3000 V and a series-parallel connection of traction electric motors, the electric locomotive developed a traction force of 24 tf and a speed of 17 km/h in an hourly mode. The design speed was 80 km/h, weight – 126 tons (Krasnobaev & Vanag, 1970, p. 53).

Operation of prototypes of electric locomotives of the VL26 series at the Riga junction of the Baltic Railway confirmed the feasibility of using a locomotive with an autonomous electric power supply in shunting and export work on electrified sections and non-electrified tracks of shunting parks and adjacent depots. However, operational experience also showed that the design of the contact-battery electric locomotive VL26 had several significant shortcomings caused by a number of unsuccessful design decisions (Krasnobaev & Vanag, 1970, p. 55). In particular, during the operation of the electric locomotive in contact mode on heavy shunting work on a shunting hill with trains weighing up to 4000 tons, there were large energy losses, as the train was pushed on the slide at rheostatic positions, in addition, when shifting from the place there were significant pushes due to lack of starting positions. The accepted method of charging the battery led to its overheating during operation of the electric locomotive with high currents, and the lack of control over its charge led to cases of the electric locomotive on non-electrified tracks with an uncharged battery or, conversely, to recharging and boiling of the electrolyte.

The system of auxiliary machines and their mode of operation were also unsuccessful. The voltage of the auxiliary machines was inconsistent with the voltage of the traction motors, which led to the complication of the electrical circuits of the auxiliary machines and caused their unstable operation and the need for duplication. The mode of operation of the fans was inconsistent with the mode of operation of the traction motors and the traction battery, as a result of which they overheated. The power supply circuit of the fan motors from ballast resistance caused significant energy losses.

In 1967, the electric locomotive VL26-005 passed traction and energy tests at the station Sverdlovsk-Sortuvalny (maneuvers, moving the train on the hill) and at the section Sverdlovsk – Pidvoloshna (work with export trains), as a result of which it was found that the existing designs of motor fans, battery boxes and air ducts did not provide effective ventilation of the traction battery (Krasnobaev & Vanag, 1970, p. 55). In general, the following shortcomings of the new locomotive were revealed: a small number of starting positions, which led to large slams during acceleration; when working on batteries and current mode, the speed was only 1,2 km/h, which was much lower than the design speed; due to the large internal resistance of the battery, the voltage at its terminals at an hourly current reduced to 360 – 400 V; when using an electric locomotive to move the train on the hill it was necessary to work on rheostatic positions, which led to additional energy losses; Based on the tests carried out by

VNIIZhT a conclusion was made about the inexpediency of further construction of electric locomotives VL26 with the existing design (Rakov, 1999, p. 397).

In order to eliminate the above shortcomings, the public design bureau of the Scientific and Technical Society of the Baltic Railway has developed a project to modernize electric locomotives VL26. The development of the project was carried out taking into account that modernization should not affect the mechanical part and traction engines of the electric locomotive (Krasnobaev & Vanag, 1970, p. 55). It was envisaged: replacement of starting resistors in the circuits of traction motors with thyristor pulse-width converters with a frequency of 400 Hz in order to eliminate energy losses, application of regenerative-rheostatic braking, increasing the voltage of the battery to 1500 V with the possibility of charging it through the converter (operating frequency 400 Hz) regardless of the current in the circuit of traction motors, as well as replacing the battery TNZh-550 with a more powerful one. It was assumed that the modernized electric locomotive could also be used to service export, transfer, and pickup trains. The locomotive was to provide shunting operation with trains weighing up to 4,000 tons and to drive pickup trains weighing up to 2600 tons on electrified sections (Krasnobaev & Vanag, 1970, p. 55). In 1972, the Dnipropetrovsk plant modernized the electric locomotive VL26-002, which was designated VL26M-002. The locomotive was equipped with an MT-8 rechargeable battery from SAFT (France), which had 1,096 cells. The battery was also modernized on a number of other locomotives of this series, which operated on the Baltic Railway (a TNZh-400 battery with 840 cells was installed). In addition, a series connection of four traction motors was used to increase the speed (Rakov, 1999, p. 397).

The experience of development, construction, and experimental operation of VL26 electric locomotives allowed to outline the prospects for the development of shunting contact-battery locomotives for driving pickup trains with a design speed of 80–90 km/h. In particular, given the then maximum weight of trains of 4000 tons, the leadership of the Baltic Railway, led by Honored Scientist and Engineer of the Latvian SSR Neil Krasnobaev considered as a perspective for the main type was considered a six-axle electric locomotive with an adhesive weight of 126 tons, an hourly power of 1400–1500 kW in contact mode and 300–500 kW – in stand-alone mode. The increased capacity of the contact mode was to provide an opportunity to service export and pickup trains. Two options were considered for heavy rolling work with trains weighing 6000–7000 tons. The first option involved the creation of an eight-axle electric locomotive with an adhesive weight of 176–184 tons, the capacity of 1800–2000 kW in contact mode and 400–550 kW in a stand-alone mode based on a four-axle locomotive and a four-axle booster trailer, which was important not only due to the increase in traction, but also to facilitate the placement of additional equipment. In the long run, the possibility of creating a powerful ten-axle shunting locomotive based on the design of a six-axle locomotive and a four-axle booster trailer was considered. Also promising was the project of a four-axle electric locomotive with an adhesive weight of 72 tons, an hourly capacity of 500–600 kW in contact mode, and 150–250 kW in stand-alone mode for facilitated shunting and economic work (Krasnobaev & Vanag, 1970, p. 57).

However, due to the imperfection of the new locomotives in the absence of technology for the construction of small batteries, further work on the development and improvement of shunting locomotives at the Dnipropetrovsk plant was deemed inexpedient, and the company focused on the production of traction units for access tracks to the Soviet industry. In the mid-1980s, to ensure shunting and export work on electrified sections of railways and non-electrified station tracks, the main department of locomotive economy of the USSR Ministry of Railways updated the development of projects of semi-autonomous eight-axle DC and AC electric locomotives. The power of electric locomotives in contact mode was to be 4000 kW (1200–1500 kW in stand-alone mode), traction force 32.4 tons, speed 47 km/h, and design speed 100 km/h. Rheostatic and pneumatic braking was provided. When the locomotive was under the contact wire, the batteries had to work in charge mode (Rakov, 1990, p. 211). However, with the onset of the economic crisis of the 1990s and the need to prioritize the production of passenger electric locomotives alongside restrictions on imports of equipment in the absence of convertible currency, the project was not implemented.

Conclusions.

Thus, during the 1960s and 1990s, the staff of the Special Design and Technology Bureau of the Dnipropetrovsk Electric Locomotive Plant, having a strong research and production potential, created unique projects of shunting electric locomotives VL41 and VL26 to meet the needs of the USSR railways with innovative high-tech electric vehicles. Despite the possible perception of the exclusively negative nature of operation of electric locomotives produced by Dnipropetrovsk plant on the main railway transport, it should be noted that the experience of designers confirmed the accuracy of initial technical decisions on the feasibility of creating a shunting locomotive with combined traction on the basis of the first industrial electric locomotives D100. The continuation of this direction of design activity was a joint project with engineers of the Baltic Railway to create contact-battery electric locomotives VL26 of direct current. Despite the fact that due to the technological imperfection of the locomotives of the experimental batch and their components, in particular batteries, electric locomotives VL26 were not widespread on other railways of the USSR, instead, their creation laid the foundations for a promising direction of domestic locomotive construction, updated only in the mid-1980s. Finally, the study of the historical experience of formation and achievements of the design and technological heritage of the Dnipropetrovsk plant is of exceptional importance both in the general perspective of Ukrainian transport engineering, finding ways out of the crisis of the historic enterprise and modernization of the locomotive fleet of the domestic railway industry.

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Розробка та будівництво маневрових електровозів на Дніпропетровському електровозобудівному заводі (1960 – 1970-х рр.)

Анотація. *У статті на підставі комплексного аналізу джерел і наукової літератури здійснено спробу дослідити історичні обставини розробки та будівництва маневрових електровозів на Дніпропетровському електровозобудівному заводі. З'ясовано, що протягом 1960 – 1970-х рр. колектив конструкторів Дніпропетровського заводу, маючи потужний науково-виробничий потенціал, на замовлення Міністерства шляхів сполучення СРСР здійснив розробку й побудував унікальні зразки маневрових електровозів серій ВЛ41 та ВЛ26 для забезпечення потреб радянських магістральних залізниць сучасним високотехнологічним електротранспортом. Доведено, що за відсутності ґрунтовного досвіду й відповідно можливості здійснення стрімкого технологічного прориву в розробці магістральних локомотивів, під час дослідної експлуатації маневрових електровозів ВЛ41 та ВЛ26 було виявлено ряд конструктивних недоліків, які обумовили їх подальше використання виключно на під'їзних коліях підприємств, а конструктори Дніпропетровського заводу в подальшому зосередились на розробці та будівництві тягових агрегатів промислового призначення на замовлення Міністерства чорної металургії СРСР. У той же час будівництво магістральної залізничної техніки на замовлення МШС дозволило колективу підприємства отримати цінний досвід, який згодом був використаний при реалізації програми оновлення рухомого складу Укрзалізниці. Попри те, що нині Дніпропетровський завод перебуває в занепаді, аналіз історичних обставин становлення й конструкторсько-технологічної спадщини електровозобудування в Україні має принципове значення як в загальній перспективі розвитку вітчизняного транспортного машинобудування, так і залізничної галузі зокрема. Подальше дослідження історії Дніпропетровського електровозобудівного заводу потребує з'ясування історичних обставин інституалізації Спеціального конструкторсько-технологічного бюро підприємства від створення промислових електровозів і тягових агрегатів до розробки та переобладнання магістрального тягового* *рухомого складу, а також спеціалізованої ремонтної техніки у рамках державного підприємства "Український науково-дослідний проектно-конструкторський інститут електровозобудування".*

Ключові слова: *Дніпропетровський електровозобудівний завод; залізничне машинобудування; маневровий локомотив; магістральне електровозобудування; радянські залізниці*

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Разработка и строительство маневровых электровозов на Днепропетровском электровозостроительном заводе (1960 – 1970-х гг.)

Аннотация. *В статье на основании комплексного анализа источников и научной литературы предпринята попытка исследовать исторические обстоятельства разработки и серийного строительства маневровых электровозов на Днепропетровский электровозостроительном заводе. Установлено, что в течение 1960 – 1970-х гг. коллектив Специального конструкторско-технологического бюро Днепропетровского завода, имея мощный научно-производственный потенциал, по заказу Министерства путей сообщения СССР осуществил разработку и изготовил уникальные маневровые электровозы серий ВЛ41 и ВЛ26 для обеспечения потребностей советских железных дорог современным высокотехнологичным электротранспортом. Доказано, что при отсутствии основательного опыта и соответственно возможности осуществления стремительного технологического прорыва в разработке магистральных локомотивов, при опытной эксплуатации маневровых электровозов ВЛ41 и ВЛ26 был выявлен ряд конструктивных недостатков, которые обусловили их дальнейшее использование исключительно на подъездных путях предприятий, а конструкторы Днепропетровского завода в дальнейшем сосредоточились на разработке и строительстве тяговых агрегатов промышленного назначения по заказу Министерства черной металлургии СССР. В то же время строительство магистральной железнодорожной техники на заказ МПС позволило коллективу Днепропетровского завода получить ценный опыт, который впоследствии был использован при реализации программы обновления подвижного состава Укрзализныци. Несмотря на то, что в настоящее время Днепропетровский завод находится в упадке, анализ исторических обстоятельств становления и конструкторско-технологического наследия электровозостроения в Украине* *имеет принципиальное значение как в общей перспективе развития отечественного транспортного машиностроения, так и железнодорожной отрасли в частности. Дальнейшее исследование истории Днепропетровского электровозостроительного завода требует выяснения исторических обстоятельств институализации Специального конструкторско-технологического бюро предприятия от создания промышленных электровозов и тяговых агрегатов к разработке и переоборудование магистрального тягового подвижного состава, а также специализированной ремонтной техники в рамках государственного предприятия "Украинский научно-исследовательский проектно-конструкторский институт электровозостроения".*

Ключевые слова: *Днепропетровский электровозостроительный завод; железнодорожное машиностроение; маневровый локомотив; магистральное электровозостроение; советские железные дороги*

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