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УДК 621.3(09)+921.3(477)

DOI: 10.20535/2307-5244.55.2022.269592

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**ECOLOGICAL URBAN PLANNING OF UKRAINIAN
CITIES IN THE LATE 19th EARLY 20th CENT.:
TRAM TRAFFIC AND RESEARCH IN THE FIELD
OF ELECTRIC TRACTION**

(To The 130th Anniversary Of The 1st Electric Tram In Ukraine)

*Екологічна урбаністика міст України наприкінці XIX —
на початку XX ст.: трамвайний рух та дослідження
у галузі електричної тяги*

(до 130-річчя першого електричного трамваю України)

The main goal of the study is to reveal the peculiarities of the emergence and formation of the tram system, as well as to outline the impact of using this type of urban transport on the urbanization of Ukrainian cities in the late 19th — early 20th cent. It is claimed that this type of transport was and still remains the most environmentally friendly. The forerunner of the electric tram — horse-drawn — had several significant shortcomings: its introduction was limited by the terrain and the life expectancy of the animal. Further attempts to use the steam engine were also unsuccessful. The creation of the electric tram expanded the use of public transport. Belgian companies played a significant role in the introduction of tram transport in Ukraine. The popularity of electric trams contributed to further research in the field of electric traction and the construction of tram cars, as well as the design of cities in general. A number of Ukrainian scientists played a remarkable role in the development of tramways, such as Fedir Pirotskyi, Hryhorii Dubelir, Pavlo Kopniaiev, Oleksandr Pohorelko, Ivan Nekrasov, Oleksandr Potebnia, and others. Nowadays, the research on public transport and a thorough analysis of the extensive use of trams are particularly important in the face of environmental problems in large cities of Ukraine.

Keywords: tram, electric traction, transport technology, history of science and technology, Ukrainian studies.

У статті аналізується урбанізація українських міст та використання громадського транспорту — трамвайної конки й електричного трамваю. Саме трамвай сьогодні залишається найбільш екологічним транспортом як у великих містах, так і в містечках. Розглянуто передвісник електричного трамваю — конку, коли рух здійснювався за допомогою тягової сили тварин, а потім використання парового двигуна. Стверджується, що попри доволі велику кількість наукової та науково-популярної літератури з історії електричного трамваю, поза увагою дослідників залишилися особливості початкового етапу формування системи трамвайного руху в Україні. Не були належно віддзеркалені в науковій літературі розрахунок електричної тяги та доробок науковців, які працювали в цьому напрямку.

Обґрунтовано недоліки використання конки через ландшафтні особливості окремих міст України, зокрема Києва. Наведено інформацію щодо фінансової сторони запровадження цього типу міського транспорту. Аналізується успішність чи неуспішність використання трамваїв у різних містах. Наведено перелік фірм і акціонерних товариств, заінтересованих у використанні нового типу транспорту. Узагальнено відомості про перші трамвайні маршрути й з'ясовано вплив використання трамваїв на урбанізацію міст. На основі аналізу матеріалів Державного архіву Харківської області, Державного архіву міста Києва, Інституту рукопису Національної бібліотеки України ім. В. І. Вернадського та вивчення газетної періо-

дики початку ХХ ст. встановлено роль професорів Київського політехнічного інституту Г. Д. Дубеліра та Харківського технологічного інституту О. К. Погорелка, П. П. Копняєва та О. О. Потєбні в розгортанні трамвайного руху на теренах України.

Стверджується, що на початку запровадження трамваїв в Україні для реалізації проектів запрошували бельгійських фахівців, однак деякі міста як Харків, Миколаїв, Маріуполь відмовилися від послуг закордонних учених. Подальші дослідження з електричної тяги, будівництва нових вагонів та проектування всієї міської мережі виконали виключно місцеві науковці.

Ключові слова: трамвай, електрична тяга, транспортні технології, історія науки і техніки, українознавство.

Introduction. Today, the tram is one of the most common types of public transport. According to the authors' calculations trams are used in 363 cities around the world, including 18 cities in Ukraine. Despite the obsolescence of the tram fleet and the limited use of tram tracks for most citizens of Ukrainian towns, the tram remains the only accessible public transport. Electric trams had their harbinger — a horse-drawn tram. The horse-drawn tram was a city railway, the carriages of which moved on wooden rails that protruded 15 cm above the level of the road surface and were driven by draft animals (usually horses). This characterizes the previous stage of the formation of public transport on the territory of Ukraine — the use of horse traction at the end of the 18th century and in the first half of the 19th century. This type of public transport was sufficient for small towns.

The next stage is associated with the growth of agglomerations, and therefore the creation of a tram system was of great importance for the development of Ukrainian cities at the end of the 19th century — the beginning of the 20th century. At this time, the largest cities reached significant sizes and there was an urgent need for mass transportation. The concentration of means of production and large-scale industry had a certain influence on the local development of cities and established a special spatial order of urban planning. That is, the development of the city is organically connected with the technical capabilities of movement means. Improvements of the transport network made it possible to expand urban areas. Today, many projects for the development of the transport system also take into account the fact that the use of trams is environmentally friendly. The tram is the most ecological transport. Ecological problems were discussed by authors from the State University of Infrastructure and Technologies (Пилипчук, О. 2020; Бердніченко, У. & Стрелко, О. & Слободянюк, Г. 2021). In European countries and in the United States, there are programs to revive the network of tram connections in cities. This makes it possible to improve the transport system of large cities as a whole (Childers, D. & Bois, P. & Hartnett, H. & McPhearson, T. & Metson, G. & Sanchez, Ch. 2019). The works of S. Mashkevych (Машкевич,

С. 2012; Машкевич, С. 2014) became important for understanding the development of tram networks, where the author justified the close relationship between the development of tram connections and the city's infrastructure. Based on involving a mass of archival materials, Mashkevych systematized and clarified a lot of information about the Kyiv tramway. And today, to create effective urban planning projects, it is necessary to take into account various aspects, such as socio-demographic forecasts, economic growth rates of the city, its structure, etc. Among them, an important issue is the convenient structure of public transport and the environmental condition, which actualizes the topic of the research and contributes to the study of the experience of creating a public transport system on the territory of Ukraine.

So, at the late 19th century — the early 20th century, as a result of industry development, the urbanization of large cities in the south of the Russian empire took place. The concentration of industrial enterprises required a structural change in the infrastructure of cities using the gains of technical progress. Horse-drawn carriages and steam locomotives were replaced by a new form of transport — an electric tram. The tram appeared in Ukraine at the end of the 19th century despite all the obstacles. The first tram connection in Eastern Europe was opened in Kyiv in 1892. A monument to the first Ukrainian electric tram was installed in Kyiv on Poshtova Square (Fig. 14).

The electric tram quickly spread to other cities in Ukraine. At the beginning of the XX century tram traffic operated in 20 cities of Ukraine and was a very popular and needed form of urban transport. The research of Ukrainian scientists made a significant contribution to the development of theoretical and practical issues of electric traction. This is the scientific work of Kyiv Polytechnic Institute's professor Hryhorii Dubelir on the improvement of electric transport, experiments in the area of electric traction by Professor of Kharkiv Institute of Technology Pavlo Kopniaiev, research on special issues of electric transport by Oleksandr Potebnia.

Despite the well-known facts about the existence of the tram in the late 19th century in Ukraine (which at the time was a part of the Russian and Austro-Hungarian empires), most European researchers of the history of science and technology make erroneous statements or ignore the development of this type of a transport and its impact on the urbanization. Thus, a researcher from France Yves Bouquet (Bouquet, Y. 2017) claims that a tram was opened in New York for the first time in the world, ignoring such type as a horse-drawn tram. As for France, the author is wrong too, she made a mistake in the year of the tram implementation in Paris. Korean researchers (Park, R. & Kang, D. 2021) claim that the first trams in Korea appeared in Seoul in 1899, and in 1915 in Busan. The authors state that the first electric tram in the world was invented in 1875 by Fedor Pirotskiy in St. Petersburg (Russian Empire) and full tests were conducted in 1879 at the World Industrial Fair in Berlin. Then, in 1881, the test of the invention took

place on a special track (2.5 km) in Lichterfeld near Berlin. Publications on the tram by researchers from Ukraine largely describe the creation and use of the first trams, limited to only one city — Kyiv (Машкевич, С. 2012; Щербань, Т. 1995) or Lviv (Крижанівський, А. 2006). Kharkiv is also left out of consideration. In the history of science, the achievements of Ukrainian scientists in the field of electric traction have not yet been adequately highlighted; in particular, the theoretical works by Professor Pavlo Korniaiev (Изьюров, В. 1952) have gone unnoticed. In generalized works on the history of tram creation in Ukraine, there is no information about the figure of Hryhorii Dubelir, a specialist in urban planning, Professor of Kyiv Polytechnic Institute, and author of scientific papers on electric traction (Скляр, В. & Тверитникова, О. 2011). In addition, the scientific achievements of the Ukrainian electrician, Professor Oleksandr Potebnia have not yet been fully represented in the historical literature (Машкевич, С. 2014; Тархов, С. & Козлов, К. & Оландер, А. 2010). Meanwhile, he was one of the founders of the Department of Electric Traction at the Kharkiv Institute of Technology, based on which the Ukrainian State University of Railway Transport was later established.

The study is based on a fairly representative source base. Having analyzed the materials of the State Archives of Kharkiv Region, the State Archives of the City of Kyiv, the archives of the Institute of Manuscripts of the National Library of Ukraine named after V.V. Vernadskyi, and having studied newspaper periodicals of the beginning of the 20th century, the authors concluded that there is no historical study of the creation of the electric tram in Ukraine, and the development of modern Ukraine tram network based on it.

The purpose of the study is to reveal the peculiarities of the emergence and formation of the tram system, as well as to outline the impact of using this type of urban transport on the urbanization of Ukrainian cities in the late 19th — early 20th century.

The funds of the State Archives became the source base of this study. The involvement of newspaper periodicals of the end of the 19th century — early 20th century made it possible to analyze the historical conditions of the formation and organization of tram traffic in many cities of Ukraine. The methodology of research is a system of principles and basic approaches to cognition and dialectics, which together allow for a comprehensive analysis. Methods such as content analysis, historiographic analysis, historical-chronological, historical-comparative, biographical methods, and the method of critical analysis based on the principles of objectivity and historicism have been used.

The initial stage of the tram traffic network development

The first world city horse-drawn tram was opened in Baltimore in 1828, and later in New York, and New Orleans (1832–1834). Traders and inventors brought the idea of using horse-drawn to Europe. For example, one of the participants in

the organization of horse-drawn in New York, Alphonse Loubat, brought the idea to France, in addition, he perfected the shape of the rails that could be sunk into the road surface. In 1852 he filed a patent for a U-shaped rail. The following year, he was allowed to build the first 2 km test line in Paris on the Cours de la Reine.

After the success in 1854, a thirty-year concession was signed for the construction of a line between Vincennes and Pont-de-Sevres via Concord (Landru, P. 2011). Horse-drawn trams existed for more than a century and the last of them closed in 1954 in the Mexican city of Celaya¹.

It is clear that the use of horse-drawn trams had limitations on the strength of the animals: steep movement uphill was impossible, and the horses after a while got tired of even flat terrain, and they had to be replaced within a few years. Soon the initiators of the creation of trams turned to mechanical traction. Different technologies were tried. They tried to use steam, gas, and gasoline engines, there were also cable trams. Meanwhile, horse-drawn railways and the use of urban steam transport no longer met the needs of society. Already in the 1870's and 1880's, research began on the use of electricity in transport. The impetus for this was the invention of the Gramme generator. In 1879, W. Siemens demonstrated the first small railway at the exhibition. He later built Germany's first tram².

The first practical steps, to transmit electricity over a distance on railway tracks with its subsequent conversion into mechanical, were made by Fedor Pirotskyi in 1874. A year later, i.e. in 1875, under his leadership, a test run of an electric tram was made. In subsequent experiments the scientist aimed at finding economic indicators of electricity transmission and finding ways to improve its efficiency. He researched non-autonomous electric traction and used a conventional railroad to transmit electricity. In August 1880, in St. Petersburg, Fedor Pirotskyi began to study the movement of trams by rail tracks that supplied current to its wheels, modernized double-decker horse-drawn trams, and on August, 22 (September, 3) an experimental tram line appeared in St. Petersburg (Rzhonsnitsky, B. 1951, p. 21).

The transition from horse-drawn to the use of electricity in trams, and the development of the tram system was the impetus for the development of research on traction electrical equipment. A significant contribution to the field of electric traction belongs to Dmytro Lachinov. The scientist studied electromagnetic processes in electric machines and conducted research on power transmission at a distance. His publication «Electromechanical work» is one of the first theoretical works on the theory of electric machines of direct current, which laid the scientific foundations of the theory of electric drive and for the first time formulated the provisions of the theory of power transmission.

As a result of theoretical analysis of processes in the electrical circuit, which included a generator, transmission line, and receiver (electric motor), the scien-

¹ Morrison A. The Indomitable Tramways of Celaya. URL: <http://www.tramz.com/mx/ce/ce.html>

² Из истории трамвая // Газета Зоря. № 12. 1 грудня 1928. С. 20.

tist discovered the basic law of power transmission, which established a quantitative relationship between voltage and resistance of the transmission line. In 1900, Dmytro Lachinov proposed a new scheme for powering car engines, according to which it was carried out through an air (trolley) contact wire; the rails also retained their purpose as inverted wires (Тверитникова О. Е. 2021, с. 102).

Several studies during this period were performed by Hryhorii Dubelir. After graduating from the Kyiv Polytechnic Institute (KPI), he held the position of Head of the Tram department of the Russian Electric Society «Union» and participated in the design of the railway system Lodz-Zgierz, Lodz-Pabianice (Дубелир, Г. 1903). In 1899, in the publication «Determination of the Average Traction in the Design of Electric Trams» Hryhorii Dubelir proposed a new method for average traction determination. This method was simpler and easier to use than existing at the time. His research on the calculation of tram rails, full of practical examples and calculation methods, was interesting. In the work «Rails of Electric Railways», Hryhorii Dubelir summarized all of the existing types of tram rails at that time and for the first time offered to make the calculations of the rails. This problem has not been previously considered by scientists from Europe and America (Дубелир, Г. 1902, 1903).

Extremely relevant at that time were his works «Connection of Electric Carriages-Engines in a Train», and «Electric Railway Faye-Chamonix and its Significance on the Use of Electric Traction on Main lines» published in 1903, where scientist analyzed in detail the entire railway industry of Russian Empire and provided some recommendations for its modernization¹.

Hryhorii Dubelir was a supporter of the use of electric traction on the railway. He presented his point of view, as well as his accumulated experience in the publication «Basic Principles of the Plan and Profile of Electric Traction Railways Designing». The systematization of all his developments and the created plan for further development of the railway supply system made this work unique. There was very little scientific literature on these issues, both foreign and domestic, and this increased the timeliness and importance of the work by Hryhorii Dubelir (Образцов, В. & Кудрявцев, А. [ред.]. 1949, с. 32).

Thus, by the beginning of the 20th century, there were quite successful projects of a new form of public transport. However, the new type of transport that was supposed to replace the horse-drawn has required significant investment.

In Ukraine, which in the early 20th century was a part of two empires, the first electric tram was introduced in Kyiv. Topographic conditions of the city, with steep ascents, and descents became an obstacle to the introduction of a horse-drawn tram. In the 1870s and 1880s, several projects for the construction of a horse-drawn city railway in Kyiv were considered, but none were implemented. Later, a detailed analysis showed that neither traction on horseback nor

¹ Personal file of H. D. Dubelir // State Archives of Kyiv. F. 18. Desc. 2. Case 81.



Fig. 1. Tsar's Square, 1892
(<http://surl.li/euidl>)



Fig. 2. Oleksandr's Descent, 1892

traction with steam will allow overcoming the steep ascent from Podil Street to Khreshchatyk.

In 1886, among others, the project was proposed by Engineer-Major General Amand Yehorovych Struve. For three years, in June 1889, he signed a contract with the Kyiv City Duma, and six months later in December 1890, a statute of the joint-stock company «Kyiv City Railway» was approved, which was engaged in the construction of the tram line¹.

The construction of the tram line began in June 1891, and on July 20, 1891, the first horse-drawn carriages roamed the streets of Kyiv. The horse-drawn was opened on two lines 13 miles long — from Zhandarmaska Street (Saksagansko-ho) to Demiivka, and a little later — to Tsar's (European) Square. However, after several months of operation, it became clear that the use of horse-drawn carriages was unprofitable due to the difficult urban terrain.

The first test of the steam tram took place on February 7, 1892 (Fig. 1). Soon, in addition to horse-drawn, at Khreshchatyk and Velyka Vasylkivska began to run loco-mobiles. Kyivans accepted the innovation with great enthusiasm. However, the terrain of Kyiv was difficult not only for horses but also for loco-mobiles. Therefore, guided by the developments of engineer Fyodor Pirotskyi, relating to the transmission of electricity by rails, the joint-stock company «Kyiv City Railway Company» decided to build a tram line with electric traction. The test trip took place on May 8, 1892, on one of the steepest slopes of Kyiv — Oleksandr's Descent (Fig. 2). On June 13, 1892, in the presence of hundreds of citizens, the first electric tram in the Russian Empire passed from Tsar's Square (at Khreshchatyk) to Oleksandrivska Square.

The road was single-track (with a siding on Oleksandrivsky Descent), 1.5 km long. In 1893 there were already two tram lines in Kyiv with a total length of 150 versts (160.02 km). The tram service connected the suburbs (Sviatoshyn, Demiivka, Pushcha-Vodytsia) with the center. Kyivans were proud of their tram. It was given a prominent role in many celebrations. It should be mentioned that at the

¹ Kyiv province. Projects of the Kyiv city railway: 1890–1910 // Russian State Historical Archives. F. 1293. Desc. 166. Case 118. 60 p.

opening of the All-Russian Agricultural and Industrial Exhibition in 1897, Kyiv Metropolitan Ionykii (Rudnev) arrived by tram (Олейник, В. 2005).

The development of tram traffic in Kyiv was quite rapid. At the initiative of the teaching staff of KPI, the city railway industry underwent significant restructuring; in particular, Hryhorii Dubelir created a project to improve the source network of the tram (Дубелір, Г. 1910).

However, during this period, all tram transport was subordinated to the Belgian corporation, which hampered the further development of the transport system. In 1912, the City Council decided to buy the tram from Belgian owners. Nevertheless, this issue was resolved very slowly and the final decision was made in 1918, and tram traffic was resumed only in 1922. Despite the emergence in subsequent years of the Kyiv subway, trolleybus, bus, and tram remained a popular vehicles in Kyiv¹.

At the same time, in the west of Ukraine, the construction of a tram service has also started in Lviv. In 1878, the Lviv City Council announced a competition, which was won by the Belgian society «Societa Triestina Tramway». This company undertook the construction and operation of public transport, which in 25 years was to be transferred to city ownership. On November 25, 1879, a test drive took place of three carriages through Customs Square, and on May 3, 1880, the tram was put on the city route. It should be noted that it was in Lviv that the horse-drawn was first operated in modern Ukraine. By 1889, the Lviv tram fleet consisted of 105 horses and 37 passenger and 3 freight carriages, which carried an average of 1,867,000 passengers a year².

Meanwhile, in 1893, the Lviv magistrate announced a tender for the construction of electric tram lines and a power plant, which was won by the Austrian firm «Siemens & Halske». The company's representative office invited its specialist Yosyf (Yuzef) Tomytskyi to Lviv. This event was facilitated by the work of a Polish electrical engineer, professor of Lviv Polytechnic R. Dzeslevskiy, who together with his compatriot, the famous architect J. Gokhberger on behalf of the Lviv magistrate during 1891–1892 conducted research related to the possibility of building electrical tram in the city (Гутник, М. & Тверитникова, О. & Хржан, К. 2021).

The results of research on existing tram traffic systems in Europe and America were summarized by scientists in the 1892 edition of the «Report on the electric track in the city of Lviv» (Kshinyanovskiy, A.). The authors substantiate the advantage of using the actual electric tram “Siemens & Halske” company pledged to sell the tram to the city after two years of operation at the request of the city council, if so. The construction of the electric tram line began in September 1893, and on the night of May 15, 1894, a two-carriage test drive took

¹ Київський трамвай відзначає своє 50-річчя (1832–1942) // Нове українське слово. № 112. 17.05.1942. С. 4.

² 50-річчя Львівського міського трамвая // Рідний край. № 12. 06.06.1944. С. 2.



Fig. 3 Lviv 1894, tram line «Station — Exhibition» (left),



modern I. Franko Street (right) (<http://surl.li/euidp>)

place. These first carriages were made in Austria (Graz). In 1893, Yosyf Tomytskyi moved to Lviv, where he supervised the construction of the first DC power plant and tram infrastructure (Fig. 3).

On May 31, 1894, the second electric tram in Ukraine was opened to the Galician Regional Exhibition in Lviv, which operated on three routes from the modern Svobody Avenue to Stryj Park, Lychakiv, and the railway station. In 1896 the city bought an electric tram network and a power plant for 1 million 680 thousand crowns (koronas).

In the early 20th century, the modernization of both the energy sector and the transport network was carried out under the leadership of Yosyf Tomytskyi. He developed routes for new tram connections. The system of tram traffic in Lviv in 1914 was quite extensive. At that time, Lviv trams carried more than 31 million passengers.

The third (after Kyiv and Lviv) Ukrainian city where the electric tram appeared was Katerynoslav (now Dnipro) (June 26, 1897), Chernivtsi (July 18, 1897), Kirovohrad, Zhytomyr, and Kremenchuk (Table 1).

Table 1

The development of tram service in Ukraine in the late XIX — early XX century (Rudakevich, I. & Sochuvka, A. 2019; Dubelir, G. 1902 Nalivayko, V. S. & Hohorenko, O. A. 2021; Tverytnykova O. E. & Posvyatenko N. I. & Melnyk T. V. 2015).

Year	City	Year	City
1892	Kyiv	1914	Mykolayiv
1894	Lviv	1928	Donetsk
1897	Dnipro (June 26), Chernivtsi (July 18), Kirovohrad (July 26)	1931	Kostiantynivska
1899	Zhytomyr (September 3), Kremenchuk (December 11)	1932	Yenakiievo (May 24), Zaporizhzhia (July 17), Horlivka (November 7)
1906	Kharkiv	1933	Mariupol
1910	Odesa	1934	Luhansk
1913	Vinnitsa	1935	Kryvyi Rih (August 2), Kryvyi Rih (August 2), Kamianske (November 27)



Fig. 4 Belgian tram on Yekaterininsky Avenue, Katerinoslav (<http://surl.li/euidq>)

Rolling stock for the first tram lines came from Germany, Belgium, and Austria (Rudakevich, I. & Sochuvka, A. 2019).

The construction of a narrow-gauge electric tram in Katerynoslav, led by the Franco-Belgian Joint Stock Company, was completed in 1897. However, the Belgians bought the project from the French in full, so Katerynoslav's tram was named the «Belgian Tram» (Fig. 4).

On June 26 this year, traffic began from the railway station to Soborna Square and along the routes «Prystan-Yuazarna», and «Vokzal-Yordanska». The «Belgian tram» was designed by Oleksander Kohan, a talented engineer, and energy specialist. Then the management of the tramway of Katerinoslav passed to Gaston Cambier.

The new type of public transport gradually gained popularity in Katerinoslav and in 1901 the City Duma decided to build a city tram. Already under the patronage of the City Duma, two more routes were launched in 1906. Two types of tram: Belgian and city ones operated until 1917. The resumption of tram traffic, after the revolutionary events, took place only in 1920. Both tram fleets were repaired and merged into a single trust. This made it possible to significantly increase the number of tram routes. In 1932 a wide-gauge line was built (Naumenko, I. 1997).

In Chernivtsi, at the time of the start of the tram traffic, the entire tram system, as well as the power plant, was owned by «Schuckert & Co». Instead, the creation of a joint-stock company, where the city would act as one of the shareholders, was postponed. It should be noted that the Chernivtsi treasury did not have enough funds to buy trams and power plants, so the citizens insisted on the creation of a joint stock company. The Statute of this ociety was approved by the magistrate in August 1897, but approval in Vienna (the capital of Austria-Hungary, part of which at that time was the city) was obtained only in June 1898. At the first meeting of shareholders (July 30, 1898) it was decided to transfer the trams and power plant in favor of the city, which took place already the next day.

It should be emphasized that the Chernivtsi tram did not become a financially successful investment. Although the first financial reports were quite encouraging and even planned to build another tramway, the following years became more expensive. Due to the landscape of the city, most of which is complex (has steep climbs), divided by ravines with landslides, the available power of electric motors allowed to bring into the tram network no more than 6 units. In 1899, attempts were made to solve this problem, so 4 more tram cars with more powerful

electric motors were ordered at the plant in Prague (Fig. 5) (Tarkhov, S. 1997; Selezinka, V. 2006).

New technical solutions in the expansion of tram traffic

The history of the appearance of the tram service in Kharkiv deserves special attention. Just like in Kyiv, there was a horse-drawn tram at that time, which had the support of the Belgian Society of Urban Equestrian Railways (Societe Anonyme des Tramways de Kharkoff (Russie).

Businessmen Petr Cleman Bonnet and Eduard Otley had a 42-year contract to build more than 19 km of equestrian railway. This contract had a negative impact on the distribution of electric trams in Kharkiv city. In addition, foreign corporations were not interested in the promotion of domestic specialists, although the professors of both Kyiv Polytechnic Institute and Kharkiv Institute of Technology were certified specialists who had theoretical skills and practical experience. Considering the growing industry and trade in the city, the problem of the creation of the first tram line got paramount importance for the city government. The peculiarity of the creation of the Kharkiv tram was the involvement of domestic specialists and the rejection of foreign offers (Radoguz, S. & Gutnyk, M. & Zaitsev, R. & Tverynykova, O. 2019).

Oleksandr Pohorelko is known to the scientific community as a theoretical physicist, who put an important place for the use of applied achievements in electrical engineering, especially for the development of the city's economy. Having attracted attention as an experienced specialist in a new field — electrical engineering, Oleksandr Pohorelko was appointed as a Head of the commission for the construction of a tram line in Kharkiv¹. An important transport project for the city, which was developed intensively in the early XX century, was the appearance of the first tram line, which started from the Center to the factory districts (Gutnyk, M. & Tverynykova, E. & Sklyar, V. 2019). So, the City Duma, on the initiative of Professor Oleksandr Pohorelko, considered the issue of buying a horse-drawn tram, and at the suggestion of the scientist the construction of a tram in Kharkiv was given to domestic specialists².

On July 16, 1906, tram traffic from Pavlovska Square to Petinska Street near Balashovsky Station was opened in Kharkiv (Fig. 6). Oleksandr Pohorelko defended the need for further development of the tram network in the city.



Fig. 5. The two-track tram line near the new Chernivtsi railway station, 1910 (<http://surl.li/euidt>)

¹ Personal file O.K. Pohorelko // State Archives of Kharkiv Region. F. 770. Desc. 3. Case 1533. 22 p.

² Personal file O.K. Pohorelko // State Archives of Kharkiv Region. F. 1682. Desc. 2. Case 242. 173 p.



Fig. 6 Oleksandr Pohorelko (left) on the construction of a tram line, 1906 (funds of the historical museum of NTU «KhPI»)

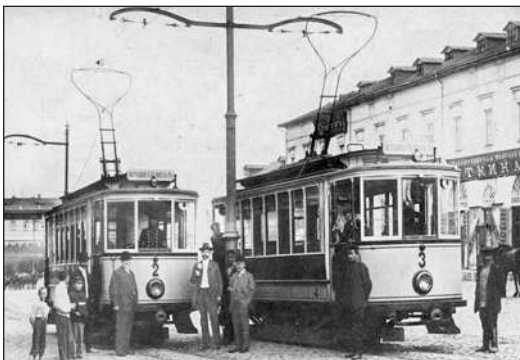


Fig. 7 Kharkiv tram, 1910 (<http://surl.li/euidu>)

In a short time, during 1909–1912, six tram routes were opened in Kharkiv: June 3, 1906 — Petinska line; December 17, 1909 — Klochkivska line; December 23, 1909 — Panasivska line; December 20, 1910 — Pushkinska line; July 17, 1911 — Grekovsko-Zaikovskaya line; February 2, 1912 — Cemetery line (Fig. 7)¹.

To the implementation of this project, Oleksandr Pohorelko invited Professor Pavlo Kopniaiev, who started research in this area at the Kharkiv Institute of Technology².

It should be added that Professor Pavlo Kopniaiev made a significant contribution to the development of electric traction in Ukraine. He is an author of works on tram traction (Fig. 8). He also implemented his theoretical developments in his area directly in practice. He participated in the design of switching schemes for tram substations in St. Petersburg and the Lubyankaya substation in Moscow, in the reconstruction of the Kharkiv tram network (Fig. 9). He worked in the joint-stock company «Westinghouse», which was engaged in the design of electric trams, where he became one of the developers of the project of the St. Petersburg tram.

He worked in the joint-stock company «Westinghouse», which was engaged in the design of electric trams, where he became one of the developers of the project of the St. Petersburg tram. The scientist also created the technical design of the city electric tram in Mariupol³.

¹ Южный край. 17 июля 1906. С. 2.

² About the Reconstruction of the Kharkiv tram. Bulletin of the All-Ukrainian Central Executive Committee No. 254 Dated November 6, 1925. P. 3.

³ Scientific report on the topic «The value of the work and activities of Professor P.P. Kopniaiev for the development of domestic electrical engineering» for 1953 // Archives of the Institute of Archival Studies of the National Library of Ukraine named after V. I. Vernadsky. F. 263. Desc. 2. Case 171. 94 p.



Fig. 8 Professor Pavlo Kopniaiev
(funds of the historical museum of NTU «KhPI»)



Fig. 9 Kharkiv tram, 1910
(<http://surl.li/euidu>)

The theoretical developments of Professor Pavlo Kopniaiev on electric traction deserve special attention. These works were published in 1914–1915 in the periodical «Electricity»: «Analytical calculation of tram traction» and «Graphic calculation of tram traction». Based on the works on traction mechanics by A. I. Lipets and D. M. Lebedev, the Kharkiv scientist proposed a graphical method for determining of energy consumption depending on the track profile and the analytical equation of tram car motion.

In contradistinction to his predecessors, Pavlo Kopniaiev's graphical method, based on mathematical calculations, determined the characteristics of speed, current, time, and energy consumption (i.e., the necessary diagrams were built). Thus, there was a complete set of characteristics of the movement of the tram, which determined the speed, travel time, the amount of current, and the amount of electrical energy consumed by the tram depending on the profile of the road¹.

In 1880, in Odessa, with the support of the city government, in particular Hryhorii Maralizi, the Belgian Society of Equestrian Railways opened the first route of the horse-drawn tram on Richelieu Street. Later, among the new routes, two more were built using steam trams². And already on September 24, 1910, the project of a tram with electric traction was realized. The first electric tram was named «Vystavkovyï» («Exhibition»)³ (Fig. 10). The appearance of tram routes significantly expanded the transport system of the city, made it easier to get to the beaches, and to the Center of the city, and contributed to the development of Lustdorf township (Fig. 11) (Терентьева, Н. 2006).

¹ Report of the Kharkiv Institute of Technology for 1916 // State Archives of Kharkiv Region. F. R-1682. Desc. 1. Case 1. 106 p.

² Электричний трамвай в Одесі // Рада. № 101. 05.05.1911. С. 3.

³ From the History of the Odessa Tram. URL: <http://surl.li/euidu>



Fig. 10 Odesa tram
(<http://surl.li/euidz>)



Fig. 11 Tram, Odesa — Lustdorf, 1910
(<http://surl.li/euiea>)

The need to create a tram service in the city of Vinnytsia was considered in 1898, but the implementation took place only in 1913. In October, with the support of the Kyiv branch of the Russian company «General Electricity Company» was built a city railway, 8.6 km long and 1 m wide¹.

In October, with the support of the Kyiv branch of the Russian company «General Electricity Company» was built a city railway, 8.6 km long and 1 m wide².

The first attempt to open tram traffic in Poltava also took place in the early 20th century. The complete absence of public transport in the city contributed to the creation of a project involving Belgian engineers. However, this proposal was not implemented³.

The opening of tram traffic in Mykolayiv took place on December 21, 1914. The city commission was headed by a graduate of the Kharkiv Institute of Technology, a member of the Mykolayiv branch of the Russian Technical Society, Professor Ivan Nekrasov (Наливайко, В. & Гоноренко, О. 2021). The electric tram replaced the equestrian transport of the Belgian Equestrian Railway Corporation. The economic inexpediency of further development of the horse-drawn tram required the introduction of a new type of transport. In 1912, it was decided to build an electric tram, relying on city specialists and funds, without the involvement of Belgian corporations. A «tram» commission was organized and taking into account engineering experience and organizational skills Ivan Nekrasov was offered to head it. He prepared a project for an open electric tram car, which included 46 seats for passengers⁴.

In Zaporizhzhia, as well as in Vinnytsia, the need to build a tram in the city was announced in 1898. Then, in 1913, Belgian experts studied the possibility of building an electric tram in the city. But the realization took place only on June 17,

¹ Centuries on Rails: From the City Railway to the Modern «VinWay» — the History of the Vinnytsia Tram. URL: <http://surl.li/euieg>

² Centuries on Rails: From the City Railway to the Modern «VinWay» — the History of the Vinnytsia Tram. URL: <http://surl.li/euieg>

³ Електричний трамвай у Полтаві // Рада». № 59. 13 березня 1911. С. 3.

⁴ History of the First Electric Tram in Mykolayiv. URL: <http://surl.li/euieh>

1932. The impetus for this was the industrial development of the region, the construction of «Dnipro Hydroelectric Power Station», and industrial enterprises. The tram became a convenient public transport that carried a large number of people¹.

The first issue of building a tram in Mariupol became relevant in 1904. The City Duma negotiated with a Belgian company. However, these plans were never implemented.

Only in 1923, Mariupol returned to the issue of building a tram line to connect the residential quarters with the factory ones. The city administration addressed a request to develop a technical project for the Mariupol tram to the professor of Kharkiv Institute of Technology Pavlo Kopniaiev. And he designed such a project. The cost of construction, according to the «Preliminary design of the electric tram for Mariupol», which was developed in 1923, was calculated in a relatively significant amount at that time — 1 million 372 thousand rubles. The main construction work began in the spring of 1932, and on May 1, 1933, the first tram passed along the line of Schmidt Harbor — Franko Street (Fig. 12)².



*Fig. 12. Opening of the first tram line in Mariupol, 1933
(<http://surl.li/euiej>)*

Further work was aimed at improving the methodology for the calculations of tram traction without graphical constructions. The result was the development of an analytical method that did not depend on the graphic. This method, proposed by Pavlo Kopniaiev, had to be used with combination of two methods to obtain accurate calculation results. The technical advantage of methods of tram traction calculations proposed by the scientist received full confirmation when carrying out tests on operating trams.

The publication of these works has attracted the attention of scientists and students. Pavlo Kopniaiev's calculations became the basis of diploma projects for students of KhIT, such as «Tram installation of alternating current with substations», which contributed to the creation of a new specialization, which was supported and continued by a student of the scientist — Oleksandr Potebnia³.

Oleksandr Potebnia (Fig. 13), a graduate of the Faculty of Physics and Mathematics of Kharkiv University, gained practical experience as an assistant to the head of the Moscow section of the traction service of the Moscow — Kursk Railway. In 1900 he graduated from the mechanical department of Kharkiv Institute

¹ Tram № 1 Zaporizhzhia. URL: <http://surl.li/euiei>

² Report of the Kharkiv Institute of Technology for 1922 // State Archives of Kharkiv Region. F. R-1682. Desc. 1. Case 120. 118 p.

³ Personal file of O. O. Potebnia // State Archives of Kharkiv Region. F. 1682. Desc. 2. Case 260. 13 p.



Fig. 13 Professor Oleksandr Potebnia (funds of the historical museum of NTU «KhPI»)

of Technology, under the guidance of P. Kopniaiev completed a diploma project on theoretical issues of electric traction, and was one of the first graduates of the institute to receive the title of engineer-technologist specializing in electrical engineering (electric transport)¹.

During the next two years, he underwent an internship abroad, gaining practical experience in electrical laboratories in Europe. In February 1907, after defending his dissertation: «On the theory of parallel operation of alternators», he first worked as an ordinary professor at the Tomsk Institute of Technology. In 1923 he was appointed as the Head of the Department of Electric Traction at the Faculty of Electrical Engineering of KhIT. In 1930, the Department of Electric Traction KhIT became the

basis for the mechanical faculty of the newly created Kharkiv Operational and Traction Institute of Railway Transport².

Professor Oleksandr Potebnia is the author of a number of valuable scientific papers on electric traction. In particular, the following: «Nomogram of the Regime of Urban and Suburban Railways» (1926), «Electric Traction on the Track» (1920), «Electric Formulas for the Characteristics of Traction Motors» (1932), «Nomogram for Calculating the Heating of Traction Motors» (1934), «About Rationalization Design of Electric Railways» (1934), as well as textbooks for students: «Energy Recovery», «Task Book on Electric Traction», «Features of the Traction Motors Calculation».

Conclusion. So, at the late 19th century — the early 20th century as a result of industry development, the urban agglomeration in the south of Russian empire took place. Cities acquired a new functional purpose. The concentration of industrial enterprises required a structural change in the infrastructure of cities using the gains of technical progress. Horse-drawn carriages and steam locomotives were replaced by a new form of transport — the electric tram, which in turn created the conditions for the growth of cities, population growth, building density and contributed to the creation of new ways and forms of using urban space, and urbanization.

Despite all obstacles the tram appeared in Ukraine at the end of the 19th century. The first tram service in Eastern Europe was opened in Kyiv in 1892. A monument to the first Ukrainian electric tram was placed in Kyiv on Post Square (Fig. 14).

¹ Personal File O. O. Potebnia // State Archives of Kharkiv Region. F. 770, Desc. 3. Case 2423. 21 p.

² Protocols of the Meetings of the Commission of the Electrical Engineering Faculty, 1924 // State Archives of Kharkiv Region. F. 1682. Desc. 1. Case 151. 17 p.

Very quickly, the electric tram spread to other cities in Ukraine. At the beginning of the 20th century tram traffic operated in 20 cities of Ukraine and was a very popular and demanded type of public transport.

The construction of tram connections was a significant and important event for the cities because the first tram routes were directed to railway stations. Despite



Fig. 14 The monument to the first Ukrainian electric tram (photo by authors, 2021)

the fact that at first the tram was a rather expensive means of transport, a network of new routes was built very quickly. In particular, in Kharkiv there were six routes directed to the working suburbs, connecting them with the industrial zones of the city. Considering the growing industry and trade in Kharkiv at the beginning of the 20th century, the problem of transport was of primary importance.

Although attempts to introduce public transport in Ukrainian cities date back to the middle of the 19th century and related to the use of horse, cable traction or the creation of steam tram routes, but this type of transport became widespread with the creation of the electric tram project. This is due to the complex topography of many cities. In particular, for Kyiv («the city on seven hills»), Chernivtsi, Lviv, and etc. A characteristic of the formation of the tram system was the involvement of domestic specialists in the projects. It should be noted that research by Ukrainian scientists has made a significant contribution to the world experience of the theoretical and practical issues of electric traction development. This is the scientific work of KPI Professor Hryhorii Dubelir on the improvement of electric transport, work in the field of electric traction of KhTI Professor Pavlo Kopniaiev, and research on special aspects of electric transport by Oleksandr Potebnia.

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УДК 94:355.23(477)

DOI: 10.20535/2307-5244.55.2022.269755

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СОЦІАЛЬНО-ПРАВОВИЙ СТАТУС УЧИТЕЛІВ НАДДНІПРЯНСЬКОЇ УКРАЇНИ (XIX — ПОЧАТОК XX ст.)

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*Social and Legal Status of Teaching in the Dnipro Ukraine
(19th — Early 20th Centuries)*

У статті висвітлюється історія становлення соціально-правового статусу педагогів початкових та середніх закладів загальної освіти як соціально-професійної групи у Російській імперії XIX — початку XX ст. у межах Наддніпрянської України. Аналізуються аспекти матеріального забезпе-