Original article
UDC 656.2
doi: 10.46684/2024.1.4

Scientific support for the design and construction of high-speed railway lines[1]

Chronicle of the Development of Competencies for High-Speed Railway Transport in Russia

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The construction of the first high-speed railway in Russia is long overdue. Such a project would be an organic continuation and a new turn in the one and a half century history of Russian railway workers' struggle to increase train speeds on the country's railways.

For citation: Valinsky O.S., Kiselev I.P. Scientific support for the design and construction of high-speed railway lines. Chronicle of the Development of Competencies for High-Speed Railway Transport in Russia. *BRICS transport*. 2024;3(1):4. https://doi.org/10.46684/2024.1.4.

Научная статья

Научное обеспечение проектирования и строительства высокоскоростных железнодорожных магистралей[2]

Хроника развития компетенций высокоскоростного железнодорожного транспорта в России

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Строительство в России первой высокоскоростной железнодорожной магистрали давно назрело. Такой проект стал бы органичным продолжением и новым витком в полуторавековой истории борьбы российских железнодорожников за увеличение скоростей движения поездов на железных дорогах страны.

Для цитирования: *Валинский О.С., Киселёв И.П.* Научное обеспечение проектирования и строительства высокоскоростных железнодорожных магистралей. Хроника развития компетенций высокоскоростного железнодорожного транспорта в России // Транспорт БРИКС. 2024. Т. 3. Вып. 1. Ст. 4. https://doi.org/10.46684/2024.1.4.

[1] Translated into English and reprinted with the permission of the authors and Editorial Board of the journal "Transport of the Russian Federation. Journal of Science, Economics, Practice". 2024;1(110):11-28. The article was supplemented by the authors.
[2] Переведено на английский язык и перепечатано с разрешения авторов и редколлегии журнала «Транспорт Российской Федерации. Журнал науки, экономики, практики». 2024. № 1 (110). С. 11–28. Статья дополнена авторами.

PART 1. THE BIRTH OF HIGH-SPEED RAILWAY TRANSPORT IN RUSSIA

The concept of high-speed railway transport

Tracks in the form of metal troughs, cast or forged rails have been known for a long time[3]. In the 16th and 17th centuries they were increasingly used in mines, quarries, and at industrial enterprises.

On 27 September 1825, an epochal historical event took place — the world's first public railway Stockton and Darlington in England was opened. It changed the paradigm of rail transport, which ceased to be exclusively special-purpose industrial and became universal, suitable for the transportation of both freight and passengers. By the middle of the 19th century, railways had become accessible to the general public, vital for trade, industry and agriculture, and the state. As a universal means of transport they developed until the middle of the 20th century.

On 1 October 1964, the opening of the world's first specialised high-speed railway line (HSL) Tokyo – Osaka again changed the paradigm of railways, which had previously been a universal means of transport for mixed freight and passenger traffic at different speeds. An important variety of railway transport has emerged — specialised high-speed transport with speeds of more than 200 km/h in commercial operation[4]. The concept of "high-speed railway traffic" is conventional[5] and historically established. At the beginning of the 20th century, it encompassed speeds of 150 to 180 km/h, and today the covered range exceeds 250 km/h[6] [1].

The division into "regular" and faster trains, in particular "high-speed" trains, occurred on the first public railways. The concepts of "faster", "fast-speed", "fast", "high-speed", even "racing" as applied to a train, locomotive, and carriage emerged in the first half of the 19th century.

New competencies related to the increase in the speed of traffic, new regulatory requirements for railway infrastructure and rolling stock appeared by leaps and bounds as new technical solutions, machines and materials emerged.

At present, only electric rolling stock is used on high-speed railway lines. In the 1930s–1950s, diesel locomotive traction and diesel trains were used for high-speed traffic, and in the 1960s–1970s, attempts were made to create gas turbine high-speed trains. However, only an electric drive can provide the necessary power for trains travelling at speeds of 200 km/h and above.

Trains travelling at speeds of more than 200 km/h require special designs of infrastructure elements and rolling stock, while physical wear and tear of devices and energy consumption increase. At speeds above 300 km/h, aerodynamic drag increases sharply. Today, the maximum speed in commercial operation is 350 km/h, and there are no high-speed railways with higher speeds in the world[7].

The length of high-speed lines in the world[8] (in kilometres) is 59,498; the longest HSLs are in the PRC (40,493 km), Spain (3,917 km), Japan (3,146 km), France (2,745 km), and Germany (1,631 km) [1].

The desire to increase train speeds required to make research, development, engineering and design efforts in various fields of knowledge. At present, there are research, design, production and training centres around the world that engage in research in the field of railway transport, including high-speed traffic; an important role in coordinating this work is played by the International Union of Railways, the Organisation for Cooperation of Railways, and others.

In the Russian Federation, research and development in the field of high-speed rail transport are carried out by divisions and subsidiary organisations of Russian Railways OJSC: VNIIZhT JSC, High-Speed Lines JSC, a number of research institutes and design bu-

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[3] In 1769–1770, the "Thunder Stone" (Grom-Kamen) — a fragment of a granite rock weighing about 2,000 tonnes, a megalith of the pedestal of the Peter the Great monument in Saint Petersburg — was moved using rails in the form of oak troughs upholstered in copper. Since 1788, a railway with cast-iron rails built by Anikita S. Yartsev operated at the Alexander Cannon Factory in Petrozavodsk. In 1809, a two-kilometre long cast-iron railway was built to the design of engineer Pyotr K. Frolov to transport ore between the Zmeinogorsk mine and the Korbalikhinsky Plant in Altai. The first in Russia railway with steam traction was built in 1834 at the Nizhny Tagil Plant by serf craftsmen father and son Efim A. Cherepanov and Miron E. Cherepanov [2].

[4] Initially it was exclusively passenger transport, but in recent years high-speed freight transport operations have also begun, for which the first high-speed goods train has already been built in the People's Republic of China.

[5] From Latin "conventio" — meeting, agreement, contract, bargain; i.e. conventional, accepted, conforming to tradition or treaty. Unlike aviation, in railway transport there is no physical quantity, such as the speed of sound (about 340 m/s or 1230 km/h), to distinguish between subsonic and supersonic speeds.

[6] The record speed of 574.8 km/h on a traditional railway track was set on 3 April 2007 by the French V150 train on the Paris–Strasbourg HSL. The highest speed on magnetic suspension (maglev) is 606 km/h (Japan, 21 April 2015).

[7] Metaphorically speaking, today there is no marketable product called "high-speed rail services with speeds in excess of 350 km/h".

[8] According to the International Union of Railways, data as of 1 October 2023.

reaus, enterprises of a number of ministries and departments, and higher education institutions of the Russian Ministry of Transport and Roszheldor (the Federal Railway Transport Agency).

The article considers the main stages of railway speed increase through the prism of the development of this area in the first higher engineering educational institution of Russia — Emperor Alexander I St. Petersburg State Transport University. These are correlated with the solution of railway transport problems in general and the chronicle of train speed increase (*Table 1*, *Diagram 1*).

Table 1

Important events, journey times and train speeds on the main track of the Oktyabrskaya Railway — Saint Petersburg – Moscow Line

No.	Year	Event, type of train and means of traction, maximum speed	Travelling time, h, min / Average en-route speed, km/h
1	1851, August 18 (30)	**Before the official opening of the railway.** A special imperial train bringing Nikolay I and his august family to the Oldest Capital travelled from Saint Petersburg to Moscow along the 604 verst (644.4 km) long railway, the construction of which had not yet been completed	20.00 / –
2	1851	**Before the official opening of the railway.** 1–12 (13–24) September (tentatively; Pavel P. Melnikov does not specify the exact date [3]). A disaster in the area of Klin station at a distance of two to three versts towards Saint Petersburg. A head-on collision of two trains with tsar couriers that moved towards each other on the same track. Each of the trains consisted of a steam locomotive and one carriage of the 1st class. The collision occurred due to erroneous actions of the railway administration during its temporary operation. The total speed of the collision of the two trains was about 100 km/h. Both locomotive crews were killed, two passengers and two conductors were injured. Pavel P. Melnikov, travelling in the train from Moscow, was happily unhurt. According to his version, the accident was not reported to the Emperor, and no official report was published	
3	1851, November 1 (13)	Opening of the Saint Petersburg–Moscow railway. At 11.15 am, departure of the first train from Saint Petersburg to Moscow with a steam locomotive of type 2-2-0 of the original series (conventionally "A"). The train arrived in Moscow the next day at 9.00 am. The maximum speed set for passenger trains was 32 km/h (30 verst/h); for mail trains[9] it was 37 km/h (35 versts/h)	21.45 / 29.6
4	1851–1855	Passenger trains in regular operation with steam locomotives of type 2-2-0 of the initial series (conventionally "A"). Max. speed: 50 km/h	18.00 / 35.8
5	1852, February 12 (24)	A disaster on the Verebyinsky Uklon. Several freight wagons rolled down the incline and collided with a passenger train. Five people were killed	
6	1853, September 1	An experimental high-speed train	12 / 53.7
7	1957	Beginning of track superstructure rearrangement — removal of longitudinal wooden planks originally laid under the rails. The sleeper density was increased from 1,166 pcs/km up to 1,480 pcs/km	
8	1863	Fast trains	15.00 / 42.9
9	1869	A fire on the Mstinsky bridge. Traffic interruption for four months	
10	1870–1890	Replacement of wooden bridges with steel ones under the direction and according to the designs of Professor Nikolay A. Belelyubsky of the Institute of Railway Engineering and Construction	

[9] "Mail" trains, later called "fast" or "courier" trains, were faster than passenger trains at the time, unlike today's mail trains which have stops at almost all stations. In 1965, the term "courier train" was removed from timetables. Only "express" and "passenger" trains remained, and later the concept of "high-speed" trains was introduced.

Continued of Table 1

11	1878	The first semi-automatic interlocking with semaphore signalling was installed on the Saint Petersburg–Bologoye section	
12	1881	Arrangement of the Verebyinsky bypass. The length of the line increased to 649.7 km	
13	1882	Steel rails of the same weight were laid along the main tracks along the entire length of the line instead of iron rails with a linear weight of 22 pounds per 1 linear pound (32.7 kg/m)	
14	1892, end of the year	Courier train with new steam locomotive type 1-3-0 of N series. Max. speed: 90 km/h	12.45 ———
15	1913, December 6	Experiments organised by Professor Nikolay L. Shchukin, Comrade (Deputy) Minister of Railways, Chairman of the Rolling Stock and Traction Commission at the Engineering Council of the Ministry of Railways, on the Saint Petersburg – Moscow line with trains nicknamed by journalists “Lightning Trains” that had new steam locomotives type 1-3-1 series S and a train of nine Pullman carriages. Max. speed: 125 km/h	7.59 ——— 81.4
16 16a	1913	Courier trains – the so-called “Black Sea trains” with steam locomotives type 1-3-1 of S series on the section between Saint Petersburg and Moscow: No. 1-Ch Saint Petersburg–Novorossiysk; No. 1-S Saint Petersburg–Sevastopol Max. speed: 100 km/h	9.59 9.40 ——— 65.0 67.2
17	1931	An express train “Krasnaya Strela” Leningrad–Moscow with a steam locomotive type 1-3-1 of Su series and 12 four-axle carriages. It was introduced on 10 June with the departure from Leningrad at 1.30 am and arrival in Moscow at 11.30 am (according to another source, the arrival was at 10.15 am). Max. speed: 80 km/h	10.00 ——— 64.9
18	1938, July 29	An experimental steam locomotive type 2-3-2 of the Kolomna Plant on the Leningrad – Moscow line with a train of 14 axles picked up a speed of 170 km/h[10]	
19	1954	Express train “Krasnaya Strela” Leningrad – Moscow with a steam locomotive type 1-3-1 of Su series and 12 four-axle carriages. Max. speed: 80 km/h	11.015 ——— 57.7
20	1956	Express “Krasnaya Strela” Leningrad–Moscow with a steam locomotive of type 2-4-2 of P36 series and a train of 12 four-axle carriages. Max. speed: 100 km/h on a number of sections; 80 km/h on a number of stations	9.30 ——— 68.4
21	1957, February 7	Experimental passenger train with a TE7-001 diesel locomotive and 790 tonne train. Max. speed: 140 km/h on a number of sections; 120 km/h on a number of stations. Travelling time included a 2 minute stop at Bologoye station	5.54 ——— 110.1
22	1957, May 29	Start of the reconstruction of the main line of the Oktyabrskaya Railway. Order of the Ministry of Railways “On Preparing the Moscow–Leningrad Line for Passenger Trains with Increased Speed”	
23	1958	Night express train Leningrad–Moscow: locomotives: – TE7 diesel locomotives on the head sections of the terminal stations – P36 steam locomotive on the Malaya Vishera–Kalinin section. Travelling time included three 10-minute stops for locomotive change. Max. speed: 140 km/h on a number of sections; 120 km/h on a number of stations	8.15 ——— 78.7
24	1960	Throughout the Leningrad–Moscow line, R50 rails were laid on crushed stone ballast with the extension of the closure rails and straight inserts between the curves; on the main tracks, PR50 turnouts of grade 1/11 with a block fish plate in the heel filler were installed	
25	1960	Daytime express train: a TE7 diesel locomotive with a train of 10 interregional carriages with soft seats of aircraft type. Max. speed: 140 km/h on a number of sections; 120 km/h on a number of stations	6.20 ——— 102.6

[10] A number of publications provide information about a higher speed achieved by pilot steam locomotives. We adhere to the information given in works by Vitaly A. Rakov, one of the most authoritative historians of railway rolling stock [4].

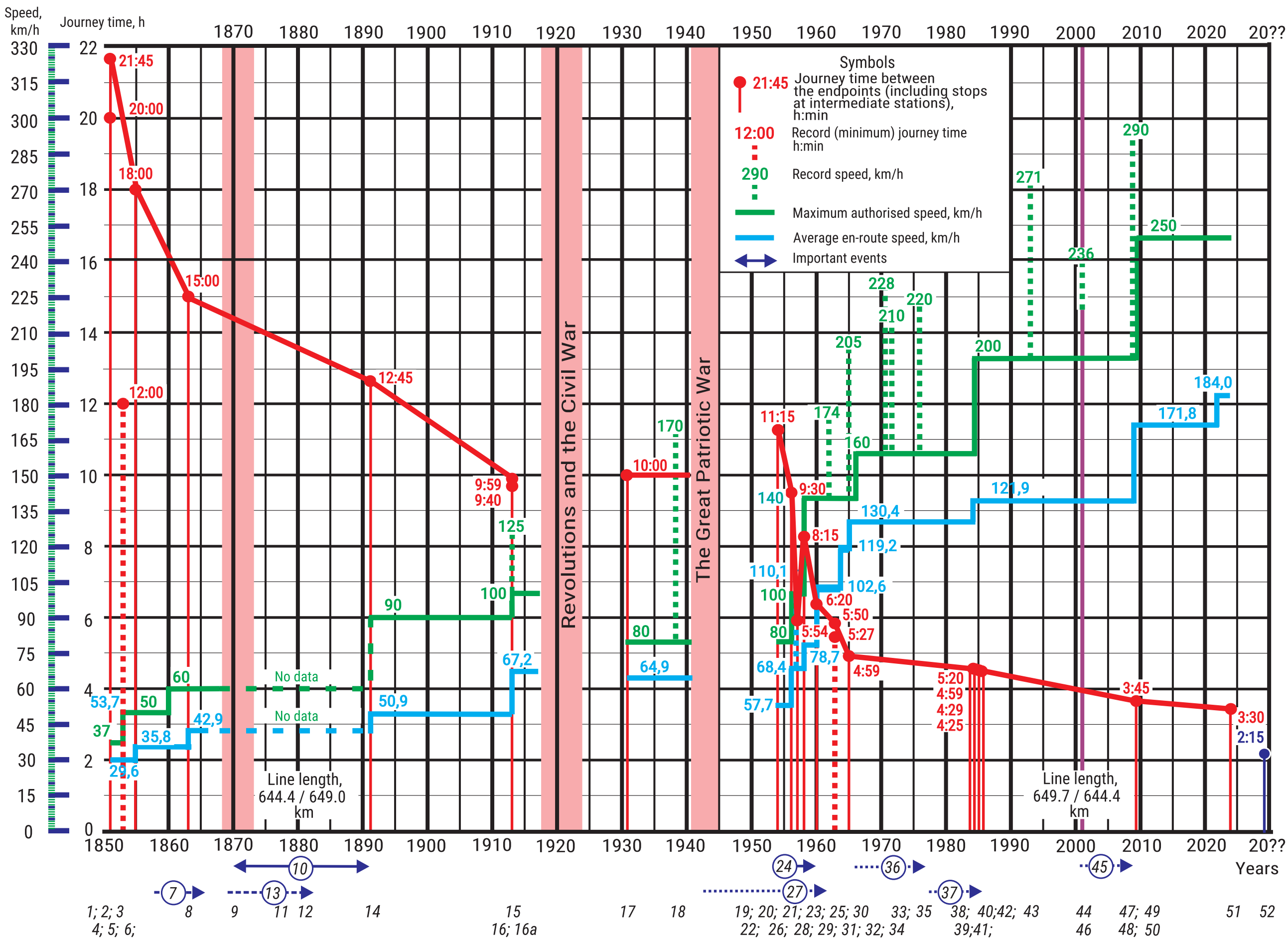
Continued of Table 1

26	1962, May 16	Experimental train weighing 335 tonnes with a diesel locomotive TEP 60-011. Max. speed: 162 km on one of the sections; 174 km/h on the main tracks of Dubtsy station	
27	1962, December	Electrification of the entire Leningrad–Moscow line was completed	
28	1963, June 12	Experimental ride of the so-called “superfast” express train: a ChS2 electric locomotive and a train of 12 carriages. Max. speed: 160 km/h on a number of sections; 140 km/h on a number of stations	5.27 ——— 119.2
29	1963, June 25	Regular daily journeys of Aurora train No. 5/6 with a ChS2 electric locomotive started. Max. speed: 160 km/h on a number of sections; 140 km/h on a number of stations	Train No. 5 – 5.27 Train No. 6 – 5.50 ——— 119.2 111.4
30	1965	Aurora train No. 5/6 with a ChS2 electric locomotive. Max. speed: 160 km/h on a number of sections; 140 km/h on a number of stations	4.59 ——— 130.4
31	1966, March	On some experimental sections of the Leningrad–Moscow line: Dubtsy–Bolshaya Vishera and Torbino–Okulovka, trains with one and two ChS2M locomotives and trains of 15 carriages with KVZ-CNII bogies repeatedly passed along the main tracks at speeds of up to 205 km/h	
32	1971, February 26	Experimental journeys of a train with a ChS2M electric locomotive and three carriages with KVZ-TsNII bogies on LIIZhT type turnouts. 52 journeys along the straight direction with speeds of 200–220 km/h. The above train travelled along the straight side of turnouts at a speed of 228 km/h	
33	1973, June-July	On the Tosno–Chudovo section of the Leningrad–Moscow line, RT200 (known as “The Russian Trio”) carriages were successfully tested at speeds of up to 210 km/h	
34	1976, June 8	The ER200 electric train reached a speed of 220 km/h in a test trip	
35	1976, June 26	A train with a CS200 electric locomotive consisting of nine RT200 carriages reached a speed of 220 km/h on the Luban – Chudovo section	
36	1977	The reconstruction of the Tosno–Malaya Vishera section was completed. The track was laid with R65 long-length rails on reinforced concrete sleepers with KB fasteners. At the stations, 22 turnouts with movable frog cores were installed. Traffic at speeds of up to 200 km/h was permitted on the section	
37	1984–1985	Modernisation of the power supply system was carried out at a number of sections, and the estimated running time of the ER200 train was reduced to 4 hours 25 minutes	
38	1984, March 1	The ER200 electric train was put into operation to make one trip per week: on Thursdays from Leningrad to Moscow; on Fridays from Moscow to Leningrad	5.20 ——— 121.9
39	1984, September 1		4.59 ——— 130.3
40	1985		4.29 ——— 144.9
41	1986		4.25 ——— 147.1
42	1988, August 16	An Aurora train crash killing 31 people	
43	1993, October 5	An experimental eight-axle passenger diesel locomotive with AC-DC electric transmission TEP80-002 set a world record speed for diesel locomotives reaching a speed of 271 km/h in a single train operation on the Shlyuz–Doroshikha section during a test trip on the Saint Petersburg–Moscow line	
44	2001, June 29	An experimental electric train Sokol picked up a speed of 236 km/h	
45	2001–2009	Reconstruction of the line for traffic with a speed of up to 250 km/h	

Ending of Table 1

46	2001, October 26	Traffic was opened on the newly constructed Verebyinsky bridge; the Verebyinsky bypass was eliminated, and the original route of the 644.4 km long Saint Petersburg–Moscow line was restored. With the construction of the new bridge and the elimination of the Verebyinsky bypass, the length of the main route – the Saint Petersburg – Moscow Line – was reduced to the original length of 644.34 kilometres. However, it was decided not to change the kilometre markings of the line, the length of which is counted from Saint Petersburg. After the kilometre marker "205", the kilometre marker "211" was installed	
47	2009, May 7	The Sapsan electric train (Velaro RUS, EVS1/EVS2 Sapsan: Siemens high-speed train) reached a record speed of 290 km/h for Russia during pre-operation tests on the Moscow – Saint Petersburg line	
48	2009, July 30	The Sapsan electric train made the first full demonstration trip from Moscow to Saint Petersburg	
49	2009, November 27	The crash of Nevsky Express train on the Saint Petersburg – Moscow line in the Bologovsky district of Tver Region as a result of a terrorist attack. 28 people were killed	
50	2009, December 18	The Sapsan electric trains started running on schedule. Three pairs of trains per day departed synchronously from the two end stations at 6.45 am, 1,00 pm and 7.00 pm. The maximum speed on the most part of the line was 200 km/h, and on some sections it was up to 250 km/h. The day before, on 17 December, the first commercial trip on the Moscow – Saint Petersburg route took place. 17 December is declared by Russian Railways as a corporate holiday, the High Speed Day	3.45 No stops 171.8
51	2024	There are up to 17 pairs of trains in circulation on different days; some trains run the entire route without stops; some make stops at different stations	3.30 No stops 184.0
52	In the measurable future	A prospective high-speed train along the projected Moscow – Saint Petersburg HSL with a length of 679 km	2.15

Diagram 1



The Emperor Alexander I Institute of Railway Engineers is the first research and engineering centre of high-speed railway competencies in Russia

Founded in 1809 by Emperor Alexander I, the Institute of the Corps of Railway Engineers (IKIPS) was the only scientific centre in the country for the collection, analysis and generalisation of materials on rail transport until the end of the 19th century. In 1826, IKIPS launched the first transport publication, *The Journal of Railway Transport*[11], which for the first time raised the railway subject.

In the 1830s, the competencies for training the first railway engineers in the country were formed at the Institute of Railway Engineers. The scientific and academic activities of the Institute were based on the information about railway tracks collected since 1809 in its library and in the Museum of the Institute opened in 1813 [2][12]. The Museum built a collection of foreign and domestic literature, as well as materials provided by university professors who visited foreign railways. The course of construction art (the construction course) included materials of lectures and practical classes on rail tracks. In 1830, the library received books, drawings and sketches brought from England by IKIPS professor Gabriel Lamé, who on 15 September 1830 attended the opening of the world's first double-track steam-powered Liverpool and Manchester railway. On his return, he gave a series of lectures entitled "Building Railways in England" [2].

In 1832–1833, Railway Engineer Professor Pavel P. Melnikov was the first in Russia to introduce a unit on track roads into the course of applied mechanics [5]. In 1835–1836, Railway Engineer Matvey S. Volkov for the first time singled out a unit containing information about different types and designs of railways in the course on construction [2]. In 1835, Pavel P. Melnikov's monograph *About Railways* was published, which was the first academic work in Russian on the new type of transport [6]. Thus, in the 1830s, for the first time in Russia, the systematic teaching of railway business began in IKIPS.

In 1837, Pavel P. Melnikov and Stanislav V. Kerbedz were sent to study railways in France, England, Belgium, Germany, and Austria. In 1839–1840, Nikolay O. Kraft and Pavel P. Melnikov went to the USA for a year on the order of Emperor Nikolay I to study railways in conditions close to those in Russia. Their illustrated reports in several volumes became the first encyclopaedic materials on railways in Russian [7, 8]. By the 1840s, the library and museum of IKIPS had formed a unique information base on the world's railways.

On 11 November (30 October) 1837, the first in Russia and the sixth in the world public railway Tsarskoselskaya was opened. Russia was among the first to put into operation an advanced high-speed mode of transport.

However, the Tsarskoselskaya railway used the latest foreign technologies: all locomotives, carriages, other technical devices were purchased abroad, drivers and other specialists of the railway were foreigners — these were about 30 engineers and technicians from Germany and Austria-Hungary.

We pay tribute to the memory of the Austrian engineer, Czech Franz Anton von Gerstner. Despite all the contradictions of his personality, as the author of the Tsarskoye Selo railway project and a businessman, he was interested in the idea of Nikolay I, who was well versed in military engineering and construction. In 1816, the future sovereign travelled to Europe and became one of the first Russians to see steam locomotives in operation, trying his hand at being a fireman and a train driver [9].

Nikolay I supported the creation of the joint-stock company of the Tsarskoselskaya railway, and the organiser was the sugar producer Count Aleksey Bobrinsky, who invested his considerable capital in it and was not mistaken. A few years later, Count Aleksey Bobrinsky assisted Pavel P. Melnikov in the implementation of the Saint Petersburg–Moscow railway project.

After Gerstner's departure from Russia in 1838, Russian railway engineers, who were graduates of IKIPS, took over the management of the railway.

The Tsarskoselskaya railway, which introduced the country to the latest technologies, gave the students of IKIPS the opportunity to receive practical railway training. *"The Tsarskoselskaya railway, with regard to its general importance for the network of Russian railways and for the purpose that was in mind when deciding to build it, will rightly be considered like the dignified toy regiments and small boats of Emperor Peter the Great which gave Russia glorious victorious guards, army and navy"*, noted the meeting of the Imperial Russian Technical Society dedicated to the 50th anniversary of the railway [2].

Only five years passed after the opening of the most advanced transport system in Russia — a period negligible by historical standards — and on 1 (13) February 1842, Nikolay I, contrary to the position of all ministers [10], signed a historic decree on the construction of the Saint Petersburg–Moscow railway, relying on the opinion of young Russian engineers, graduates of the Institute of the Corps of Railway Engineers Pavel P. Melnikov, Nikolay O. Kraft, Stanislav V. Kerbedz, Dmitry I. Zhuravsky, Nikolay I. Miklukha, and others.

[11] The Railway Transport is the country's oldest transport engineering journal.
[12] The Central Museum of Railway Transport of the Russian Federation.

After the "foreign" Tsarskoselskaya railway, in 1842 on the route of the future Saint Petersburg – Moscow railway, Russian engineers independently conducted surveys, selected the route, carried out design works, and erected unprecedented bridges and other structures. Russia moved from the contemplation of foreign technical miracle — railways — to its own engineering creativity.

Russian engineers, having learnt and adapted foreign experience for Russian conditions, acted on the basis of the norms of design and construction of the main line developed under the leadership of Pavel P. Melnikov, Nikolay O. Kraft and Andrey D. Gotman. Before the beginning of the surveys, the engineer Nikolay I. Lipin was the first in Russia to develop "Some conditions of such surveys for the Saint Petersburg – Moscow railway". At the suggestion of Pavel P. Melnikov, Nikolay I invited as a consultant an American specialist Major George Whistler, who Melnikov met during a trip to the United States. *"Whistler's advice was highly professional and very useful for builders"* [2].

The possibility of a technological breakthrough in just five years was predetermined by the engineering education system created in Russia. It was laid in 1809–1824 by the great engineer, scientist, teacher and statesman Agustin de Betancourt, who trained those engineers who became the first Russian railwaymen.

By 1844, Pavel P. Melnikov, with the participation of American engineers and entrepreneurs Joseph Harrison and Thomas Winans, organised the production of the most complex machines of that time — steam locomotives and carriages — at the Aleksandrovsky Plant in Saint Petersburg by localising (Russifying) production. By 1849, 42 passenger and 120 freight locomotives, 70 passenger and more than 2,000 freight carriages had been built [2]. Only Russian-made rolling stock was operated on the Saint Petersburg – Moscow[13] railway, opened on 1 (13) November 1851 (*Fig. 1*).

The railway was 604 versts (644.4 km) long and was characterised by straightness — it was only 6.4 km longer than the air straight. The railway had relatively small maximum gradients[14]. The combination of a straight track with the minimum curve radii (1,600 m on sections between stations and 1,065 m at operation points) ensured high speeds. For more than a century and a half, the Saint Petersburg–Moscow main line remained the only high-speed test track in Russia.

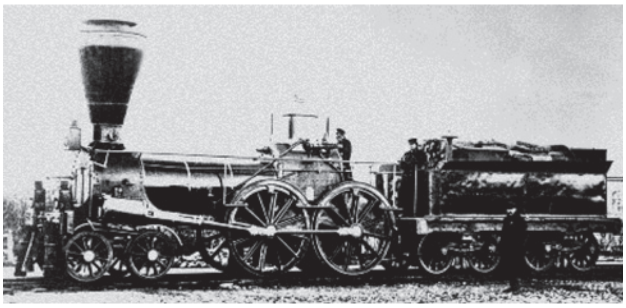


Fig. 1. One of the first passenger steam locomotives of type 2-2-0 of the Saint Petersburg–Moscow railway, 1860s [11]

In the second half of the 19th century, apart from the Institute of Railway Engineers (IIPS)[15], the Ministry of Railways of the Russian Empire had no other unified scientific centre, and there was no plan for research work [2]. In the last third of the century, the work of IIPS graduates in technical departments of the Ministry of Railways and at conferences of railway service managers became more active. Professors, specialists and graduates of the only transport university were responsible for scientific and engineering works, collection, analysis and generalisation of information on the normative base for railways, planning of their development, and possibilities of speed increase. With the growth of the length of railways and the number of railway companies, the issues of unification of requirements to the railway system became critical.

Under Emperor Alexander II, the number of private railway companies increased, especially after Pavel P. Melnikov resigned as the Minister of Railways in 1869. The problems of control over railway construction and operation worsened. In the mid-1870s, out of 53 railways existing in the country there were many private railways that did not meet the requirements of the increased volume of transport [2]. There was a need to create a unified legislative framework for railway transport, to develop unified rules of technical operation of railways, and to unify construction standards.

In 1877, Professor of IKIPS Arseny M. Shishkov published the first fundamental work, *The Operation of Railways*, which gave answers to many urgent problems of train traffic organisation, rules of train formation and safety [2]. The scientists and graduates of the

[13] Since 1855 — Nikolaevskaya Railway, since 1923 — the main course of the Oktyabrskaya Railway.
[14] The steepest gradient of 7.8‰ had to be built on the Verebyinsky ascent, which caused problems both with the upward movement of goods trains and the braking of descending ones. On 12 (24) February 1852, this led to a catastrophe: several freight carriages went down the incline and collided with an oncoming train, killing five people. In 1881, the Verebyinsky bypass was built, which allowed to reduce the gradient on the ascent to 6‰, but lengthened the road route to 649.68 km.
[15] In 1864, the status of the Institute was changed: military training was reduced and a new name, the Institute of Railway Engineers, was given. In 1877, the Institute was named after Emperor Alexander I.

Institute of Railway Engineers, in particular Ivan I. Richter, Alexander N. Frolov, Nikolay A. Demchinsky and others, made a significant contribution to the formation of the first set of general rules of railways, The Rules of Technical Operation of Railways Open for General Use, published in 1898.

An important role in the elaboration of scientific community position, development and adoption of a regulatory framework for design and construction of the Trans-Siberian Railway or Transsib — a major railway system of all times and peoples — was played by scientists and graduates of the Institute of Railway Engineers both by their independent works and within the framework of collective activity in the Engineering Council of the Ministry of Railways (transformed from the Technical Department of the Ministry of Railways in 1892) in the Imperial Russian Technical Society (IRTS)[16]. The first chairman of the Society was Andrey I. Delvig, a famous railway engineer, a graduate of the Institute of Railway Engineers.

The outstanding role in the creation of Transsib was played by graduates of the Institute of Railway Engineers — surveyors, designers and builders of the railway Orest P. Vyazemsky, Nikolay F. Dormidontov, Alexander F. Kiparisov, Nikolay S. Kruglikov, Alexander V. Liverovsky, Nikolay P. Mezheninov, Leon M. Rosengard, Alexander I. Ursati, Vladimir S. Shmakov, the founder of Novosibirsk Nikolay G. Garin-Mikhailovskiy, the founder of Harbin Nikolay S. Sviyagin, and many others. More than 200 graduates took part in the Transsib construction. Operation points of the Transsib and the Chinese Eastern Railway are named after many of them: Vyazemskaya, Gedike, Dormidontovka, Drozdov, Ilovayskaya, Knorring, Kraevsky, Krasitsky, Kruglikovo, Kurdyumovka, Prokhasko, Rosengartovka, Sviyagino, Siarskiy, Shmakovka, Ebergardt, and others [12].

Throughout the 19th century and the first decade of the 20th century, the Institute of Railway Engineers of Emperor Alexander I remained the only scientific and training centre in the country for the formation of competencies in the field of railway design and construction, including the issues of increasing the speed of traffic[17].

On 1 September 1913, the Imperial Moscow Engineering School of the Railway Department was transformed into the Imperial Moscow Institute of Railway Engineering and became a higher educational institution with a four-year term of study and a fifth diploma year. The organiser and the first rector of the Imperial Moscow Engineering School (IMIU) was a major hydraulic scientist, a graduate of the Institute of Railway Engineers and its Vice-Rector Filipp E. Maksimenko. Since the establishment of IMIU (the Moscow Institute of Transport Engineers, MIIT), about 30 graduates of the Emperor Alexander I Institute of Railway Engineers (LIIZhT) — prominent scientists and specialists — have joined the new higher education institution, became its professors, heads of departments, and deans of faculties. Professors Evgeny A. Gibshman, Fyodor P. Kochnev, Nikolay T. Mityushin, Dionisiy F. Parfenov, and Alexander A. Einkhenwald were rectors of the Imperial Moscow Engineering School — the Moscow Institute of Transport Engineers — the Russian University of Transport in different years [14].

PART 2. FROM STEAM TO ELECTRIC TRACTION: PROGRESS OF THE TECHNOLOGICAL PLATFORM FOR HIGH-SPEED RAILWAY TRAFFIC

Projects to increase the speed of traffic on the railways of Russia and the USSR in the first half of the 20th century

At the beginning of the 20th century, high-speed steam-driven trains with speeds of up to 100–120 km/h were developing in the world. By that time in Russia, domestic schools of steam locomotive building were formed, based on deep research in the field of rolling stock mechanics, rail track, steam engines, heat engineering, and transport economics.

In 1904, Alexander P. Borodin, a graduate and professor of the Institute of Railway Engineers, and Mikhail V. Gololobov, a lecturer, established a steam locomotive laboratory with a rolling station at the Putilov Plant in Saint Petersburg[18] [15], which for the first

[16] The Society was established by the efforts of the corps of engineers, industrialists, transport workers, including professors of the Institute of Railway Engineers, in particular, Director of the Institute of Railway Engineers named after Emperor Alexander I, Mikhail N. Gersevanov. The Charter of the Society was approved by Emperor Alexander II on 22 April 1866.

[17] In 1896, the Imperial Moscow Engineering School (IMIU) of the Railway Department was opened — today it is known as the Russian University of Transport (RUT) (MIIT). Initially, it offered a three-year training programme for students. Those who graduated from the IMIU course were awarded the title of civil engineer [2]. *"A civil engineer who successfully passed additional tests at the Institute of Railway Engineers named after Emperor Alexander I under a special programme approved by the Minister of Railways is given the title of a railway engineer with all the rights assigned to it."* [13]

[18] On a steel platform there were rotating rollers, imitating rails, on which the steam locomotive was mounted in a working condition. When the steam engine was started, the locomotive remained in place due to the rotation of the rollers. By creating resistance to their movement with special brakes, the operation of the locomotive with different load was modelled, and the speed of the wheels (speed of the locomotive), fuel and water consumption were measured.

Fig. 2. Steam locomotive type 1-3-1 of S series of the first series at Nikolaevskaya Railway, 1915 [11]

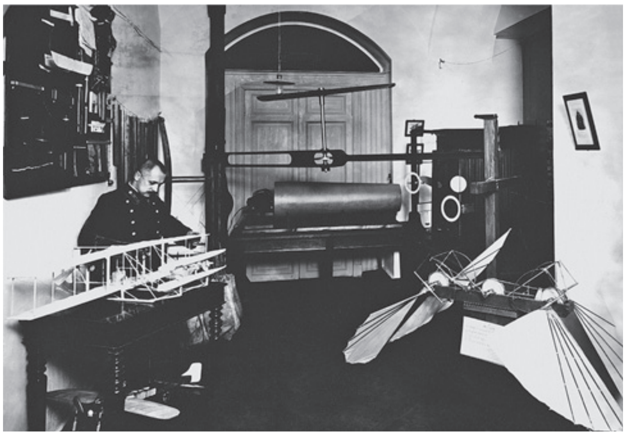


Fig. 3. Aerodynamic laboratory of Nikolay A. Rynin Emperor Alexander I Transport University, St. Petersburg, the turn of the 19th and 20th centuries [11]

time allowed for conducting locomotive research at a new scientific level.

In 1912, Professor Yury V. Lomonosov, a graduate from the Institute of Railway Engineers, organised a research institution under the Engineering Council of the Ministry of Railways with a somewhat strange-sounding name — the Office of Experiments on Types of Steam Locomotives[19] [16].

In December 1910, at the Sormovsky Plant under the guidance of Bronislav S. Malakhovsky and Director Sergey I. Mikhin, elaborating on the ideas of Professor Nikolay L. Shchukin, developed the project and built five new high-speed steam locomotives, which received the serial designation S (Sormovsky) (*Fig. 2*). On 6 December 1913, a train with an S steam locomotive and 9 Pullman carriages passed the whole way from Saint Petersburg to Moscow in 7 hours 59 minutes with the maximum speed of 125 km/h[20] [4]. Professor Shchukin nurtured the idea of introducing daytime fast trains between Saint Petersburg and Moscow, but the outbreak of war stopped the project [17].

The increase in the speed of trains acutely raised the issue of studying the aerodynamics of rolling stock. In 1909, Professor Nikolay A. Rynin organised an aerodynamic laboratory at the Institute, where he began to study the effect of air flow on rolling stock (*Fig. 3*).

In 1909–1914, a project was developed with the participation of professors and specialists of the Institute of Railway Engineers, and the construction of the Oranienbaum Electrified Line (Oranel), Russia's first high-speed electrified railway line between Petrograd and Oranienbaum settlement was started. The rail track was laid to the village of Strelna, but the outbreak of war interrupted the implementation of the project. In 1918, the unfinished line was included in the city tram system.

By the mid-1930s, the USSR railways had been generally restored after the destruction in the years of the revolution and the civil war. The country paid great attention to the development of railway transport. Emphasis was placed on increasing mass passenger traffic associated with labour migration, as well as freight traffic necessary for the implementation of grandiose plans of socialist industrialisation.

Scientific support of railway development was provided by several sectoral research institutes. In 1918, the Experimental Institute of Railway Transport under the People's Commissariat of Railway Transport (NKPS) was formed on the basis of the Office of Experiments on Types of Steam Locomotives organised by Yury V. Lomonosov, which after several transformations became the All-Union Scientific Research Institute of Railway Transport (TSNII NKPS). Today it is known as the Scientific Research Institute of Railway Transport (VNIIZhT JSC), the country's largest research centre of railway technologies.

In the 1930s, the People's Commissariat of Railway Transport (NKPS) set a task to increase the training of railway engineers. The two existing higher education institutions — in Leningrad (LIIZhT) and Moscow (MIIT) — could not train the required number of specialists. With the active participation of professors and teachers from LIIZhT and MIIT, new railway institutes were established in Rostov-on-Don, Kharkov, Dnepropetrovsk, Tiflis (Tbilisi), Tashkent, Tomsk (later Omsk), Novosibirsk, and Khabarovsk [15].

Despite the fact that in the 1930s the party and government directive aimed the railways at the development of freight traffic, enthusiasts of the People's Com-

[19] Traction and heat tests were carried out on various steam locomotives in motion on the railways. Train load, plan and line profile were compared with dynamometer car readings — speed, tractive forces, as well as fuel and water consumption. Before 1917, studies of Russian steam locomotives of O, N, Ku, Y, B, U and S series were carried out.

[20] The S series steam locomotive was one of the best high-speed locomotives in Europe. Today, S series steam locomotive No. 68 is a valuable exhibit of the Museum of Russian Railways in St. Petersburg.

missariat of Railway Transport and the People's Commissariat of Heavy Engineering carried out research and development work in the field of high-speed passenger traffic.

On 29 June 1938, a 14 axles train driven by a high-speed steam locomotive of 2-3-2 type built by the Kolomna Machine-building Plant named after Valerian V. Kuibyshev established a speed record in the USSR reaching 170 km/h on the section Likhoslavl – Kalinin[21] (*Fig. 4*) [4].

By the end of the 1930s, the problem of providing freight and mass passenger traffic on the USSR railways became even more acute. Attempts to organise high-speed passenger traffic were an obvious hindrance to solving the main task of the industry. All projects of high-speed traffic on the USSR railways, including the construction of high-speed steam locomotives[22] (*Fig. 4*), electric locomotives[23], electric multiple units[24] and diesel multiple unit trains[25], as well as original designs for high-speed monorail systems[26] (*Fig. 5*), were closed, unfinished rolling stock structures were scrapped, aerodynamic fairings were removed from high-speed locomotives, and they served ordinary trains.

Nevertheless, the research and development work carried out significantly advanced specialists in the field of high-speed vehicles, the study of interaction between rolling stock and track, aerodynamics of high-speed traffic, electrification of railways, and the creation of signalling systems for high speeds. Much of this was in demand in the 1950s.

The two post-war five-year plans required great efforts from railway workers and builders to restore the railway network destroyed by the war. Many railways in the European part of the country had to be virtually built anew.

In 1948, Boris P. Beshchev, a graduate of LIIZhT, was appointed the Minister of Railways of the USSR. He was

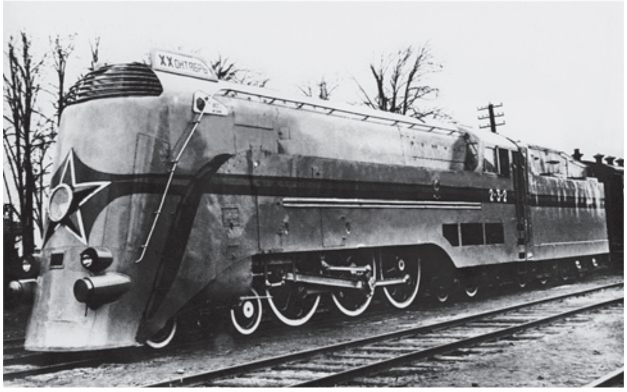


Fig. 4. The first of high-speed steam locomotives of 2-3-2 type by the Kolomna Plant, 1937 [11]

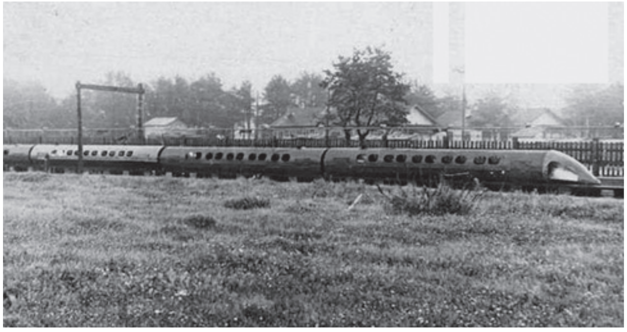


Fig. 5. Experimental ball-bearing electric trough train by Nikolay G. Yarmolchuk on the experimental sharodrom — this was the name of the field testing ground for the new train. Moscow, 1933 [11]

associated with the development and implementation of a plan for technical re-equipment of the industry — electrification of the USSR railways, which was the most ambitious plan in the history of world's railway transport.

[21] Information about it was published a year later, in 1939, in an article by engineer P.A. Gursky in the journal *Transport Engineering* [18]. If we remember what national holidays accompanied the achievements of Soviet pilots, polar explorers, and metro builders, it becomes clear that the cool attitude to speed records on the USSR railways was determined by the country's leadership.

[22] In addition to two experimental high-speed steam locomotives of 2-3-2 type with fairings by the Kolomna Plant, a high-speed steam locomotive of 2-3-2 type was built at the Voroshilovgrad Plant. High-speed passenger carriages for the Silver Swallow (Serebryannaya Lastochka) train were designed for the ordered high-speed steam locomotives in Leningrad with the participation of LIIZhT scientists. No high-speed carriages were manufactured [4].

[23] In 1934, the Kolomna Plant built a high-speed passenger electric locomotive with a capacity of 2,040 kW and axle arrangement 2-3o-2, designed for a maximum speed of 140 km/h, which was known as "PB21-01" (named after Politburo (political bureau); 21 tonnes per axle). The locomotive was successfully tested, but it was not used in high-speed traffic and served ordinary passenger and freight trains [4].

[24] In 1940, the successful project for the creation of high-speed (so-called "resort") electric multiple units: high-speed streamlined with narrow body and high-speed streamlined ones with wide body (both for standard 1524 mm gauge) was shut down [19].

[25] Projects to build high-speed railmotors and high-speed diesel trains were discontinued [20].

[26] We are talking about the large-scale operating models of original high-speed monorail vehicles built in 1933–1938: Nikolay G. Yarmolchuk's ball-bearing electric trough system and Sevastian S. Waldner's aero-train. The models were successfully tested at experimental testing grounds in Moscow, where they developed speeds of up to 150 km/h [21, 22].

Fig. 6. The first high-speed diesel locomotive TEP60-001, 1961 [11]

Fig. 7. Departure of the experimental high-speed express train No. 5/6 Leningrad–Moscow, 12 June 1963 [11]

In the post-war period, high-speed traffic in the USSR, as well as in other countries, was connected with the use of diesel locomotive traction. The first operable mainline diesel locomotives were built in Soviet Russia in 1924 according to the designs of Professor of the Leningrad Institute of Railway Engineers (LIIPS) Yakov M. Gakkel and a graduate of the Institute of Railway Engineers Professor Yury V. Lomonosov. By the 1950s, the Soviet diesel locomotive industry had achieved significant results: several series of freight and passenger diesel locomotives were produced. On 6 August 1960, a 335-tonne experimental train with a TEP60 high-speed diesel locomotive (*Fig. 6*) picked up a speed of 140 km/h. On 16 May 1962, during a test run, a 335-tonne train with a TEP60-011 diesel locomotive picked up a speed of 162 km/h on one of the sections, and 174 km/h on the main tracks of Dubtsy station [11]. By that time, specialists of the Oktyabrskaya Railway and scientists of the LIIZhT headed by Professor Stepan V. Amelin had created new R65 grade 1/11 turnouts designed for straight-line speeds of up to 160 km/h.

By the end of 1962, the Leningrad – Moscow railway was electrified along its entire length, and the track and signalling equipment were reconstructed. In 1965, the daytime express train Aurora (*Fig. 7*) with a route speed of 130.4 km/h and a total running time of 4 hours 59 minutes was put into operation [11].

In 1964, the joint creative work of the Ministry of Railways, Oktyabrskaya Railway, Central Research Institute of the Ministry of Railways (VNIIZhT) and the Leningrad Institute of Railway Engineers (LIIZhT) was organised into the Public Research Institute of Oktyabrskaya Railway (ONII) [23], the main focus of which was to ensure high-speed traffic (*Fig. 8*).

Two projects of high-speed rolling stock were implemented with the active participation of VNIIZhT, ONII, and LIIZhT:

- At the Kalinin Carriage Works (KVZ) — RT200 high-speed carriages (The Russian Troyka) (*Fig. 9*) of locomotive traction (up to 200 km/h) for operation with a ChS200 electric locomotive made in Czechoslovakia;
- At the Riga Carriage Works — ER200 high-speed electric train (200 km/h) (*Fig. 10*).

For the purpose of research of wheel-rail interaction at speeds of 200 km/h and higher, which was nec-

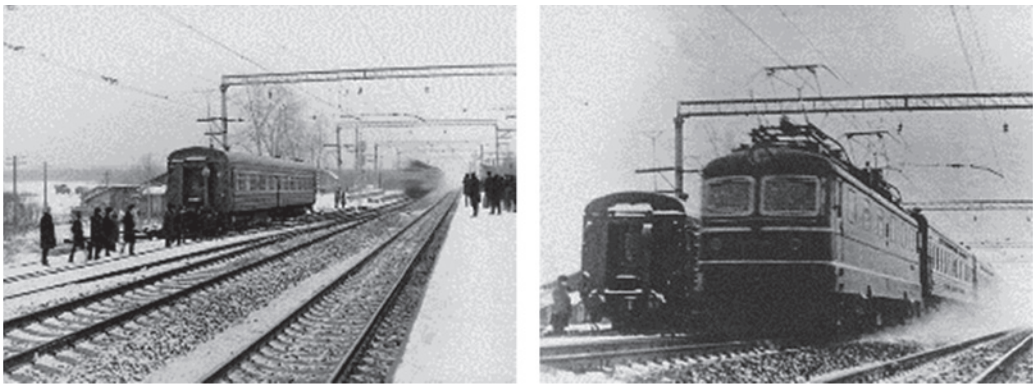


Fig. 8. Testing of a turnout designed by the Design Bureau of the Main Railway Department of the Ministry of Railways and Leningrad Institute of Railway Engineers (LIIZhT) with a movable frog core at Pomeranye station of Oktyabrskaya Railway. A train running at a speed of 228 km/h, 26 February 1971 [11]

Fig. 9. The RT200 carriage "Russian Troika". Troika (rus. — Troika) — a vehicle (sleigh or wheeled carriage) drawn by three horses. 1974 [11]

Fig. 10. The first three-car section of the ER200 train, 1974 [11]

essary for the creation of the crew part of the new rolling stock, a high-speed laboratory carriage was built at the Kalinin Carriage Works in 1970[27] with a design speed of 250 km/h [4]. In February 1972 on the Pridneprovskaya Railway, the high-speed laboratory carriage reached a record speed of 249 km/h for the 1,520 mm track gauge.

In 1974, the Kalinin Carriage Works with the participation of specialists from VNIIZhT and LIIZhT developed a design and manufactured a train of eight new high-speed locomotive traction carriages RT200 [11] with light alloy bodies. The RT200 carriages were tested with locomotives $ChS2^M$, $ChS2^T$, as well as with electric locomotives ChS200.

By the end of 1974, the Riga Wagon Building Plant (RVZ) with the participation of VNIIZhT and LIIZhT developed a design and manufactured 13 carriages of the ER200 electric train, including two head carriages, at the facilities of the Riga branch of the Institute.

On 8 June 1976, the ER200 train picked up a speed of 220 km/h in a test trip [24]. On 26 June 1976, a train weighing 210 tonnes with a ChS200 electric locomotive with RT200 carriages also picked up a speed of 220 km/h [11].

A report on successful tests noted, *"With regard to technical characteristics the created rolling stock <ER200, ChS200 and RT200> corresponds to the modern level achieved by domestic and foreign locomotive and coach-building"* [25].

In 1976–1978, tests with a train of nine experimental RT200 carriages were continued, after which they were removed from experimental operation for scheduled repair, which, however, was not performed. The management of the USSR Ministry of Railways decided to terminate the project and not to start serial production of PT200 carriages. By that time, economic problems were multiplying in the railway network as well as in the country as a whole. The Ministry of Railways had no time for high-speed traffic. The RT200 carriages, the quintessence of the latest technologies, were soon handed over to different divisions of the railway for their needs and later scrapped[28].

The issue of regular operation of the high-speed electric train ER200, which has been standing "under the fence" since 1978[29], was raised by Nikolay S. Konarev, who was appointed Minister of Railways of the USSR in 1982.

On 28 February 1984, the *Leningradskaya Pravda* newspaper published an announcement, *"For the information of railway passengers. From 1st March this year, the high-speed express train No. 17/18 with one stop at Bologoye Station is put into circulation on the Leningrad–Moscow line..."* [26]. Regular operation of the ER200 train began.

High-Speed Environmentally Friendly Transport State Scientific and Technical Programme

In 1988, on the initiative of Minister of Railways Nikolay S. Konarev, dozens of academic and design institutes, with the active participation of VNIIZhT and LIIZhT, developed the State Scientific and Technical Programme "High-Speed Environmentally Friendly Transport" which was approved by the USSR Council of Ministers on 30 December 1988. The task was to build the "Centre-South" High-Speed Railway (Leningrad – Moscow–the Crimea and Caucasus) and create rolling stock for it [27].

[27] It was a head (trailing) carriage of an ER22 electric train with an additional fairing on the frontal part in front of the driver's cabin and two turbojet engines of the YAK-40 aircraft installed on the roof. They accelerated the laboratory carriage to high speeds, while the carriage bogies, which had no traction motors and gearboxes, made it possible to conduct effective research.
[28] In the late 1980s, a video salon was located in one of the RT200 carriages at the Varshavsky Railway Station in Leningrad.
[29] An electric train, which had many traction drive elements, parts and devices in its carriages, was apparently of less interest for use as a carriage in railway divisions, and so it has survived.

In 1991, Russian Joint Stock Company "High-Speed Lines" (RAO VSM) was formed. In cooperation with the Lengiprotrans, VNIIZhT and LIIZhT – PGUPS institutes, it developed a feasibility study for the main line. In 1991–1995, LIIZhT – PGUPS had an expert council of leading scientists, which provided scientific support of the project, held technical conferences, scientific hearings and seminars on a regular basis held for expert discussion of the most important elements of the feasibility study, and conducted two successful international conferences.

In 1992–1995, the feasibility study for the Saint Petersburg–Moscow HSL received a positive conclusion of the government expert review panel, which allowed the start of working design on the basis of the Norms and Specifications for the Design of the Saint Petersburg–Moscow HSL developed with the participation of VNIIZhT and PGUPS and approved by the State Construction Committee of Russia on 28 April 1997 [28, 29].

In accordance with the High-Speed Environmentally Friendly Transport Programme, work to create a high-speed train Sokol was in progress since 1992 (*Fig. 11*, *12*). RAO VSM in cooperation with VNIIZhT, PGUPS and other research organisations of the industry engaged the Rubin Central Design Bureau of Marine Engineering, based in Saint Petersburg, which had an extensive experience in creating complex transport systems, as the lead contractor.

More than 80 research institutes and enterprises of various industries, specialists and scientists from VNIIZhT, PGUPS, Transmash Plant JSC, VNII Transmash JSC, Almaz Shipbuilding Company, and NPO Aurora took part in the implementation of the Sokol train project. In 1992–1999, a pilot six-carriage Sokol train was manufactured.

In difficult economic conditions RAO VSM in collaboration with other organisations created a new Russian electric train, which was not inferior to the world models in its parameters and had an acceptable price for the Russian railways. The Sokol train as a whole, as well as its individual units and assemblies, represented the basis for a new generation of electric passenger trains.

On 28 July 1999, the company handed over a Sokol-350 train to the Ministry of Railways of the Russian Federation for running tests in the presence of the Minister of Railways Vladimir N. Starostenko at the Transmash Plant in Tikhvin, the Leningrad Region.

After inspecting the train, the Minister expressed his gratitude to the participants of the project, Russian enterprises and organisations that took part in its implementation. *"The most important achievement is that the train is 90 % made of Russian-made components"*, Vladimir I. Starostenko emphasised [24].

Fig. 11. High-speed electric train Sokol, Russia, during tests on the experimental ring of VNIIZhT, January 2001 [11]

Fig. 12. Test driver Dmitry V. Pegov in the cabin of Sokol train, 2001 [11]

In 2000–2001, Sokol was tested on the experimental ring of VNIIZhT at Shcherbinka station and on the Saint Petersburg–Moscow line, where on 29 June 2001 it picked up a speed of 236 km/h[30]. Further increases were not possible due to speed restrictions on the railway line [30].

In 2002, Sokol was returned to the plant in Tikhvin with a total test mileage of more than 50,000 kilometres. Until 2005, RAO VSM and other organisations, including the Russian Academy of Sciences, tried to complete the project and start the production of trains, but the management of Russian Railways JSC shut down the project[31].

[30] It happened at km 407 between Spirovo and Kalashnikovo stations, when the train travelled on the odd-numbered track towards Moscow.

[31] A few years later the Sokol train was dismembered into two sections of three carriages each, one of which is in the Museum of Russian Railways in Saint Petersburg, and the second one was exhibited at the exhibition of railway equipment at Rizhsky railway station in Moscow.

In general, the social and economic crisis of the 1990s, the 1998 default, and the worsening social and economic situation prevented the construction of a high-speed railway and mass production of Sokol electric trains. Nevertheless, a set of research and development activities in the field of high-speed railway lines and the creation of the Sokol train significantly advanced Russia in the field of high-speed traffic. Developed under the guidance and with the participation of scientists and specialists of VNIIZhT and LIIZhT – PGUPS, the regulatory framework of the High-Speed Railway formed the basis for further development of the high-speed railway.

Scientists from PGUPS under the direct supervision of its Rector Varely I. Kovalev presented the results of the High-Speed Environmentally Friendly Transport Programme in Russia's first scientific monograph in two volumes, *The High-Speed and Very High-Speed Railway Transport* (2001–2023) [31]. Most of the authors were scientists of PGUPS, major experts in their field: V.L. Belozerov, L.S. Blazhko, G.I. Bogdanov, Yu.P. Boronenko, A.T. Burkov, D.V. Gavzov, D.M. Golitsinsky, K.N. Dyakov, Yu.I. Efimenko, G.K. Zaltsman, I.P. Kiselev, V.I. Kovalev, Yu.G. Kozmin, E.A. Kraskovsky, A.P. Ledyaev, S.I. Loginov, O.A. Nasedkin, A.B. Nikitin, A.M. Orlova, V.E. Pavlov, A.V. Plaks, I.V. Prokudin, Val.V. Sapozhnikov, V.V. Sapozhnikov, B.F. Tarasov, A.V. Tretyakov, M.M. Uzdin, A.I. Khozhainov, N.A. Churkov, E.D. Shapilov, V.V. Yakovlev, V.F. Yakovlev, as well as scientists and specialists of other enterprises and scientific organisations, including institutes of the Russian Academy of Sciences: A.F. Alimov, A.S. Arsentiev, S.V. Zubarev, G.I. Ivakhnyuk, V.M. Korovkin, V.M. Malyutin, V.A. Odintsov, F.S. Pekhterev, L.V. Rymsha, V.M. Savvov, E.A. Sotnikov, V.I. Tulayev, E.K. Potemkin, and A.I. Chistobayev. The monograph comprehensively and thoroughly covers both theoretical and practical issues of creating high-speed railway transport, and presents a set of problems to be solved.

PART. 3 CREATING HIGH-SPEED RAILWAY TRANSPORT IN RUSSIA

The current stage of harnessing high speeds in Russian railway transport and the role of PGUPS

With the improvement of the economic, social and political situation in the country in the early 2000s, it was considered expedient to gradually introduce high-speed traffic and purchase foreign rolling stock for operation on the reconstructed lines.

In the 2010s, the Saint Petersburg – Moscow mainline was reconstructed for speeds of up to 250 km/h. Specialists and scientists of PGUPS took an active part in the development of design documentation and scientific support of the project. On a significant part of the line the track was reconstructed with the expansion of the roadbed area, which allowed it to be straightened, the track superstructure was reinforced, and turnouts were replaced for the straight-line traffic with the speed of more than 200 km/h.

Barrier places were island stations with station sections that required speed reduction. One of such island stations at Okulovka station had to be sacrificed, as this is the location of the testing ground on the Mstinsky Most–Okulovka section, where the train reaches a speed of 250 km/h — the maximum speed for the Russian railways. The Verebyinsky bypass, which had existed since 1881, was also eliminated, new turnouts with a continuous rolling surface were laid on the main tracks, and auto-blocking tonal rail circuits were introduced. The power supply system of the line was considerably strengthened and partially reconstructed using a new catenary system KS-250 [24].

Russian specialists chose the ICE 3 electric train[32] built by Siemens, Germany as the rolling stock. By the early 2000s, the train was well established not only in Germany, but also in Spain and the PRC[33].

On 18–20 May 2006, Russian Railways and Siemens Corporation signed an agreement for the manufacture of high-speed trains in Germany and their delivery to Russia [24].

Initially, Russian Railways executives intended to set up their own production (localise the production) of trains using the German technology, but this was not implemented. Nevertheless, the participation of Russian specialists — mostly graduates and specialists from PGUPS — in the modification of German trains for Russia, which were labelled Velaro Rus and Sapsan[34] (*Fig. 13*), has yielded fruit and has brought the country to the technology of manufacturing modern high-speed rolling stock. In the course of creating a 1,520 mm gauge train for Russia, Russian specialists received more than 150 protection certificates, many of which were authored by PGUPS employees.

[32] The third generation of German Intercity Express (ICE) trains, series 403, or Siemens Velaro, has been in operation since 2000. The train with a design speed of 330 km/h is built according to the distributed traction concept (4 motor coaches + 4 trailing coaches) for sections electrified on alternating current voltage of 15 kV with a frequency of 16⅔ Hz.
[33] AVE Class 103 (Velaro E) in Spain, CRH 3 (Velaro CH) in the PRC.
[34] Sapsan trains with a design speed of 250 km/h are formed of 10 carriages and designed for 600 passengers with the possibility of operating twin trains with a multi-unit control system.

Fig. 13. Sapsan train, 2009. Photo by I. Kurtov

Fig. 14. Unified Dispatch Control Centre of Oktyabrskaya Railway, 2009. Photo by I. Kurtov

In 2009, the first Sapsan trains arrived in Russia. The tests took place on the VNIIZhT experimental ring in Shcherbinka near Moscow, on the Belorechenskaya – Maikop high-speed range of the North Caucasus Railway, as well as on the Moscow – Saint Petersburg Line. On 7 May 2009, Sapsan picked up a speed of 290 km/h, setting a record for the Russian railways [32].

Commercial operation of Sapsan trains on the Moscow – Saint Petersburg line began on 17 December 2009. Three pairs of trains per day were put into circulation. The route soon became extremely popular with passengers[35].

The start of the Sapsan operation was preceded by a lot of preparatory work to create maintenance facilities — the Metallostroy TCh-10 electric depot in the suburbs of Saint Petersburg, one of the best depots in the world in terms of technical equipment.

The personnel was trained to operate and maintain the new electric trains. An important role in this work was played by the departments of PGUPS, such as the Electric Traction, the Carriages and Carriage Facilities, and a number of others, as well as by the entire scientific and teaching staff of the university. Almost all drivers, engineers and managers involved in the operation and maintenance of Sapsan trains are graduates of PGUPS.

A special division, the High-Speed Railway Directorate, was created within the structure of Russian Railways JSC, which is responsible for the entire range of issues defined by its name. Its first head was a graduate of PGUPS, one of the Sokol test drivers Dmitry V. Pegov, now Deputy Director General of Russian Railways and Head of the Traction Directorate.

In 2003, the Unified Dispatch Control Centre (UDCC) of the Oktyabrskaya Railway was put into operation, which made it possible to achieve a state-of-the-art level in management of complex train operations on the Saint Petersburg – Moscow line, which combines control of high-speed, regular passenger, suburban and goods trains (*Fig. 14*).

The successful implementation of the project to organise Sapsan train traffic on the Saint Petersburg – Moscow line at speeds of up to 250 km/h has brought into sharp focus the need for Russian Railways and the country's leadership to fully engage Russia in high-speed railway traffic technologies.

It is well known that a regulatory framework for design, construction and operation is the basis for the creation of complex infrastructure engineering projects, especially megaprojects, which include high-speed railway lines and rolling stock for them. It is in PGUPS that a unique team of professionals has been formed and maintained over two centuries by the living connection of generations of scientists, engineers, teachers and their students who have confirmed their competence and ability to fulfil the most important national tasks in the field of construction technologies, transport and especially railway transport.

On the example of leading scientists of PGUPS of our time who solve the problems of high-speed traffic, we can trace the dialectical relationship of the development of scientific solutions from a teacher to a student. It dates back to the early days of railway transport development in Russia in the 1830s. No doubt, to understand the role and place of PGUPS in the development of modern railway transport it is important to know about its unique library, research and laboratory facilities, but it is much more important is to understand the connection between generations of scientists and their students, which was not interrupted neither during the years of wars and the revolution, including the Great

[35] To meet the passenger demand, Russian Railways put into operation twin Sapsan trains on the Moscow – Saint Petersburg – Moscow route from 1 August 2014. Each of the trains consists of 20 carriages instead of 10. The start of their operation was preceded by the reinforcement of the electric supply of the Saint Petersburg–Moscow line [32].

Patriotic War, nor during the collapse of the USSR and the social and economic collapse of the country in the 1990s – early 2000s.

For three decades, the team of scientists and engineers of PGUPS has been working on the creation of unique documents, which, figuratively speaking, fuse together the results of their own scientific developments and the world's best practices on the regulatory framework for the design and construction of high-speed railways.

In the 2010s, scientists of PGUPS, at the request of Russian Railways JSC, focused on the creation of the Special Technical Specifications for the Design and Construction of High-Speed Railways (STS), which cover all the components of high-speed railway systems. This scientific and engineering work was prepared under the leadership and with the determining role of PGUPS in cooperation with Russian Railways JSC and a number of specialised scientific and design and survey institutions.

The work was completed in 2014 with the development of the Special Technical Specifications (STS) for the design of the Moscow – Kazan section of the Moscow – Kazan – Yekaterinburg HSL with a speed of up to 400 km/h. The prepared STS have passed all necessary state approvals.

After the position of the government leadership regarding the strategic priority of the construction of the HSL in the country changed in 2021 and Moscow – Saint Petersburg was identified as the first line, the PGUPS team developed a modified scientific and engineering complex, the Special Technical Specifications (STS) for the Design, Construction and Operation of the Moscow – Saint Petersburg High-Speed Railway Line (HSL-1). On 9 September 2021, the document was agreed upon with the Russian Ministry of Construction.

Thus, today Russia has a scientific, methodological and regulatory framework for the design and construction of high-speed railway lines created under the guidance and with the active participation of PGUPS scientists.

Development of competencies in the field of high-speed rail transport and participation of PGUPS in international and Russian national scientific and educational programmes

By 1990, LIIZhT – PGUPS had developed a comprehensive system of training in almost all specialist, bachelor's and master's degree courses, including the introduction of students to competencies related to high-speed railway traffic, depending on their future professional activities. It includes materials of lectures and practical classes on special academic disciplines in the field of design, construction and operation of high-speed railway lines and special rolling stock, topics of coursework and final qualification papers (diploma theses).

An important role in the actualisation of educational activities was played by the fact that since the early 1990s a significant part of the teaching staff of all graduate chairs and many general science departments has been involved in research and development work in the field of high-speed rail transport, including the reconstruction of the Saint Petersburg–Moscow main line for high-speed traffic, the creation of the Sokol train, and then the adaptation of the German ICE 3 train, that is, in fact, the creation of a new Sapsan train on its basis. In academic terms, these works resulted in the preparation and publication of educational and methodological literature, materials for lecture courses and practical classes. In particular, in 2013, a group of specialists, mostly graduates of LIIZhT – PGUPS, published a textbook titled *"Sapsan High-Speed Trains B1 and B2"* edited by PGUPS Associate Professor Aleksey V. Shiryaev. It provides a detailed description of the train design, its main assemblies, parts, and components [33].

In 2014, the first and so far the only Russian fundamental textbook in two volumes *"High-Speed Railway Transport. General Course"* was published [32].

The books were highly appreciated in the circles of specialists dealing with problems of high-speed railway transport and were included in the list of recommended literature for academic disciplines related to high-speed railway transport. In 2018 and 2020, the textbook was published twice as a second revised and supplemented edition. The authors are leading scientists of PGUPS whose research covers a range of high-speed railway transport issues. Most of them are members of the scientific group that developed the previously named Special Technical Specifications. These are L.S. Blazhko, Yu.P. Boronenko, M.Ya. Bryn, A.T. Burkov, N.S. Bushuyev, L.K. Dyachenko, A.M. Evstafiev, V.B. Zakharov, I.P. Kiselev, V.I. Kovalev, A.F. Kolos, V.V. Kostenko, A.P. Ledyayev, A.B. Nikitin, A.Yu. Panychev, P.A. Plekhanov, A.V. Romanov, P.K. Rybin, V.M. Savvov, S.S. Sergeyev, V.V. Seronosov, V.N. Smirnov, T.S. Titova, A.M. Uzdin, Yu.S. Frolov, A.V. Shiryayev, and S.V. Shkurnikov. The authors of the guide also include major railway transport specialists who directly supervised the reconstruction of the Saint Petersburg – Moscow line and the creation of Sapsan train Valentin A. Gapanovich and Dmitry V. Pegov, scientists and specialists from other scientific organisations Alexander V. Mizintsev and Yury I. Sokolov.

The system of advanced training of specialists in the field of high-speed railway transport created at PGUPS was highly appreciated by the expert community and in 2016 was honoured with the Saint Petersburg

Government Award for Outstanding Achievements in Higher Education[36].

In 2012–2016, as part of a grant from the European educational project TEMPUS[37] a consortium of universities and transport organisations in Russia (PGUPS, RUT (MIIT), and Russian Railways), as well as Latvia, Poland, Ukraine and France, developed a set of training and methodological materials for additional professional education (professional retraining) covering the issues of infrastructure and operation of high-speed railways, with the scope of about 800 training hours. It was implemented at PGUPS in 2017–2019[38]. This programme was attended by 4th-5th year students of PGUPS and employees of Russian Railways JSC. Internships for trainees were organised on railway lines in the PRC. The programme participants successfully defended their final qualification papers and received diplomas of additional professional education from PGUPS and the National Technical University in Paris[39].

In 2018–2023, PGUPS in the consortium of universities from Russia, Germany, Spain, Kazakhstan and Poland, which won a grant from the European Education Programme ERASMUS+[40], participated in the project "Economy, Ecology and Infrastructure at High-Speed Railway Lines (EEIHSR)". As part of this project, PGUPS, as the lead organisation, developed a Master's degree programme, including a unique set of teaching and learning materials with visualisation elements, assessment tools, and assignments for final qualification papers.

The participation of PGUPS in the Erasmus+ Programme was interrupted in March 2023, but PGUPS independently completed the preparation of this unique educational programme, and in 2023 the fourth intake of Master's students took place, and the three previous groups completed training and defended their Master's theses.

In 2020, the integrated system of high-speed transport training at PGUPS was submitted to the Russian Ministry of Education and Science of Russia to obtain the status of a federal innovation platform, and by its decision[41] PGUPS was recognised as a federal innovation platform for international educational programmes for advanced training of personnel for high-speed railway lines (FIP VSM).

On 27 September 2021, the Russian Ministry of Education and Science included PGUPS, through a competition, in the list of 106 universities in the Priority-2030 strategic academic leadership programme. Within the framework of the programme, the university's scientists are working on two strategic projects directly related to the development of the HSL: The Safe Ecosystems of Intelligent Transport Infrastructure and The New Technologies and Materials in Construction. In November 2023, a commission of the Ministry of Education and Science of the Russian Federation approved the work of PGUPS on these scientific programmes.

Among the most important issues in the development of the High-Speed Line are traffic control and transport safety. These areas of scientific and engineering activities have been among the priorities of IKIPS–PGUPS throughout the history of the university. On 5 December 2023, the Ministry of Education and Science defended the programme of the advanced engineering school ISKRA[42] PGUPS, according to the results of which the competition commission of the Ministry of Education and Science included the university among the 50 strongest universities in the country. PGUPS became a participant of the Federal Project "Advanced Engineering Schools". In 2024, funding in the amount of RUB 230.4 million was approved for the creation and development of the ISKRA school in cooperation with major industrial partners — Russian Railways JSC, Concern VKO Almaz-Antey JSC, Transmashholding JSC, and VNIIAS JSC.

ISKRA engineering school plans to create fundamentally new safety systems for rail transport based on the integration of stationary and on-board intelligent data transmission systems, including radio channels.

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[36] For the creation of this system, PGUPS employees Professors Lyudmila S. Blazhko and Igor P. Kiselev, as well as Associate Professor Pavel A. Plekhanov, won the Saint Petersburg Government Award for Outstanding Achievements in Higher Education in the category "In the Field of Integration of Education, Science and Industry 2016".

[37] From English "Trans-European Mobility Programme for University Studies".

[38] Due to the coronavirus pandemic in 2020, the programme's training and internships have been discontinued. Their resumption is currently under consideration.

[39] Conservatoire National des Arts et Métiers, CNAM. Paris.

[40] Erasmus (currently known as "Erasmus+") is an international programme of the European Union for exchange of students and teachers between universities of EU member states and other countries. The programme offers the opportunity to study and undertake an internship in another country participating in the programme.

[41] Order of the Ministry of Education and Science "On Approval of the List of Organisations Attributed to Federal Innovation Platforms Constituting the Innovation Infrastructure in Higher Education and Related Additional Professional Education" dated 25.12.2020 No. 1580 (registered by the Ministry of Justice of the Russian Federation on 03.02.2021, Reg. No. 62355).

[42] Abbreviation for the Russian name which translates as "Integrated Systems of Complex Distributed Architecture for Train Traffic Control".

Social-political component of high-speed railway projects

The construction of the Moscow – Saint Petersburg High-Speed Line and the creation of specialised passenger rolling stock for it is, of course, an event that goes beyond a specific transport and territorial project. It affects many aspects of life and includes transport, technical, economic, cultural and political aspects.

It is known that major investment projects, such as railway and motorway lines, gas terminals and pipelines, sea and air ports, large bridges and tunnels, nuclear power plants and large hydroelectric power plants, are projects with a long implementation period and complex implementation procedures. Their cost reaches billions of dollars, their implementation affects the interests of thousands and sometimes millions of people and affects large territories. As such, such projects always include a political component.

Many transport projects, including high-speed railways, are characterised by the fact that they cannot be implemented in parts. It is necessary to create a kind of start-up complex that includes almost the entire set of elements[43].

An important conclusion from the experience of the high-speed railways projects implemented so far in the world is that the implementation of these projects must be supported at the highest political level of the country. High-speed railway projects took place when the first persons of the state and the ruling political party took full responsibility for them.

This is confirmed by the history of the creation of the first railways in Russia, which were certainly high-speed for their time. Thus, Emperor Nikolay I took responsibility for the construction of the Saint Petersburg – Moscow railway and introduced the country to advanced transport technologies.

At the end of 2023, the President of Russia Vladimir V. Putin unequivocally expressed the necessity and timeliness of the construction of high-speed railways in the country on two occasions: first, at a direct line with citizens combined with a press conference with media representatives on 14 December and second, in his speech at the IV Railway Congress on 15 December [34–36]: *"We are expanding, as you know, Baikal–Amur Mainline and Transsib, modernising other railway lines and approaches to seaports, including the Azov-Black Sea and Caspian basins, and at the same time we are launching a large-scale project to create networks of high-speed railways. As a first step, such a route should drastically reduce the travelling time between the two largest agglomerations of our country, Moscow and Saint Petersburg. Then such routes should connect the capital with brotherly Belarus, with Minsk, Voronezh, Nizhny Novgorod, Kazan, Yekaterinburg, Rostov-on-Don, and provide accessibility to the resorts of the Black Sea coast — for greater, better accessibility for our citizens. And I would like to emphasise that in the future, we will certainly build them to Lugansk and Donetsk.*

It is planned that the high-speed lines will run through the territories where more than 111 million of our citizens live, which is 80 per cent of the country's population" [36].

Main indicators of the Moscow – Saint Petersburg HSL Project are given in *Table 2*.

Table 2

The main indicators of the Moscow – St. Petersburg project [37]

Communication/Parameters (as of 2030)	Passenger traffic, million passengers/year	Scope of movement, pairs per day	Required rolling stock fleet, units
Moscow — Saint Petersburg	16.32	33	27
Moscow — Twer	3.67	11	3
Saint Petersburg — Veliky Novgorod	1.44	5	1
Transit trains	0.67	3	–
Total	23.29	52	31

- Length: 679 km
- Travelling time (without stops): 2 h 15 min
- Maximum speed: 400 km/h
- Total investment: RUB 1.7 trillion
- Creation of more than 35,000 jobs during the construction phase
- Creation of more than 250,000 jobs after the high-speed railway is operational
- Order volume for the construction industry: about RUB 1.5 trillion over 7 years

[43] Unlike a conventional railway, which can be built initially as a single-track railway, without electrification, with a simplified set of signalling and communication systems, etc., an HSL line is built as a double-track line with a full range of infrastructure facilities due to safety features. An HSL can be built in start-up sections, which is often done, but each of them is a complete technical, technological and operational HSL complex.

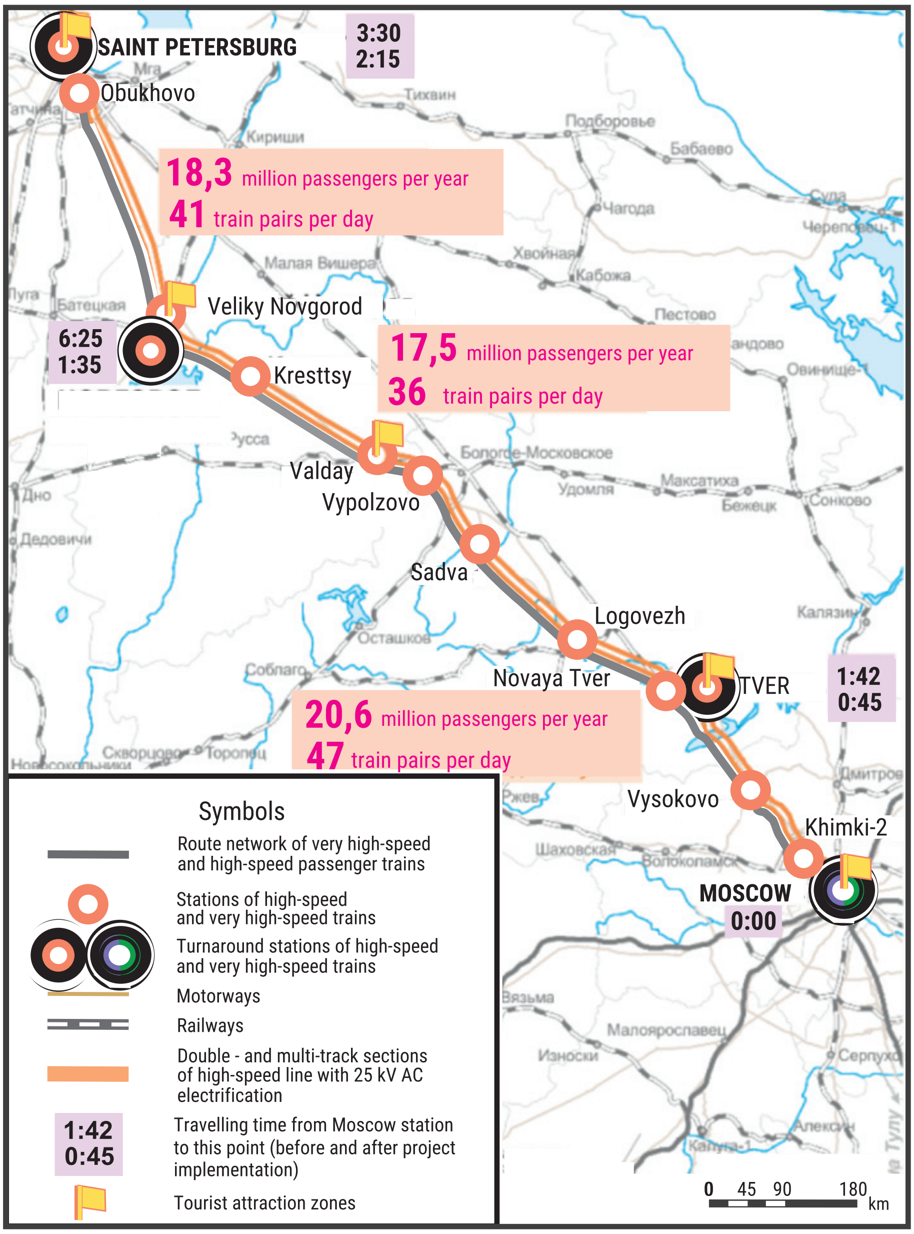

Fig. 15. The Moscow–Saint Petersburg HSL. Route variant from the preliminary materials of the project [37]

In the current situation, social and political support of the above projects from the society is of great importance. Lomonosov Moscow State University has started important work in this direction. On the initiative of the Dean of the Faculty of Political Science, Professor Andrey Yu. Shutov and the Head of the Department of Public Policy, Professor Vladimir I. Yakunin, a scientific and practical conference “A High Speed Day: Social and Political Aspects of the Implementation of High-speed Railway Traffic in Russia” was held on 19 December 2023. It was attended by specialists in this field, including one of the authors of this article.

The conference emphasised the need for the media to work actively to create a positive attitude in society towards these projects. The idea of uniting the efforts of professors, specialists, students of branch railway universities and classical universities in this direction was expressed, in particular, as a concrete proposal for co-operation between students and scientists of PGUPS and the Faculty of Political Science of Moscow State University.

CONCLUSION

In Russia, there are necessary and sufficient conditions for the creation of high-speed railway transport — the construction of the first specialised high-speed Moscow – Saint Petersburg HSL. In the near future, an extensive matrix of competencies for such a megaproject and a targeted programme of organisations and enterprises capable of implementing it should be formed.

The hard lesson Russia learnt as a result of sanctions has shown the price of an excessive focus on import purchases of machinery, equipment and components without creating its own production. Today, it is clear that the technological sovereignty of the country requires the development of many areas of production, including transport machine building, so that the "mistake" of abandoning the Sokol train project at the final stage of its implementation is not repeated. Russia needs high-speed rolling stock produced within the country, and it will be created.

The development of railway transport, specialisation and division of labour, including in scientific research and engineering creativity, which is increasing every year, have led to the emergence of many centres of competence in the field of railways in our country. PGUPS currently identifies several priority areas of scientific research, engineering development and training, which are presented in this article.

The project of the first specialised high-speed railway Moscow – Saint Petersburg should become a catalyst for uniting all railway centres of the country to guarantee the creation of the most advanced high-speed railway transport system in Russia in the format of a life cycle contract for high-tech products [38].

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Contribution of the authors: the authors contributed equally to this article.
The authors declare no conflicts of interests.
Заявленный вклад авторов: все авторы сделали эквивалентный вклад в подготовку публикации.
Авторы заявляют об отсутствии конфликта интересов.

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The article was submitted 10.01.2024; approved after reviewing 30.01.2024; accepted for publication 28.02.2024.
Статья поступила в редакцию 10.01.2024; одобрена после рецензирования 30.01.2024; принята к публикации 28.02.2024.