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НАУЧНО-ПРАКТИЧЕСКИЙ РЕЦЕНЗИРУЕМЫЙ СЕТЕВОЙ ЖУРНАЛ

Основная тематическая направленность журнала: материалы о научно-технических, организационных, экономических, экологических, правовых проблемах, истории, состоянии и перспективах развития транспортного комплекса стран БРИКС; о взаимодействии стран БРИКС по вопросам транспортного обеспечения и сотрудничества с другими государствами, мировыми транспортными системами, а также о подготовке персонала всех уровней для транспортной отрасли и развитии в данной сфере сотрудничества образовательных учреждений и транспортных предприятий разных стран.

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Академику РАН,
научному руководителю
Института проблем региональной
экономики РАН,
Почетному гражданину
Санкт-Петербурга

Окрепилову

Владимиру Валентиновичу

В ДЕНЬ 80-ЛЕТИЯ

Уважаемый Владимир Валентинович!

В день 80-летнего юбилея примите от коллектива Петербургского государственного университета путей сообщения Императора Александра I и меня лично самые искренние поздравления!

За более чем 50 лет профессиональной деятельности Вы добились выдающихся успехов в научной и академической сферах. Особой признательности заслуживают фундаментальные научные исследования, связанные с разработкой теоретических основ экономики качества и её роли в социально-экономическом развитии нашей страны. Огромным достижением для Санкт-Петербурга стала созданная Вами единственная в России научная школа экономики качества.

Разработки Вашей школы нашли применение в деятельности Европейской организации качества (ЕОК), Европейского фонда управления качеством (EFQM), Международной сети сертификации систем менеджмента (IQNET).

Активная публикационная и издательская работа позволяет Вам широко делиться своими идеями и опытом, приобретать сторонников и последователей, готовить высококвалифицированные профессиональные, научные и преподавательские кадры.

Неоценим Ваш решающий вклад в создание в Санкт-Петербурге уникальной многоуровневой системы непрерывного обучения кадров по экономике качества.

Ваша научная, преподавательская и общественная работа получила заслуженное признание и по достоинству оценена правительством Российской Федерации и Санкт-Петербурга.

На протяжении многих лет Вы сотрудничаете с нашим университетом и оказываете содействие в решении многих научных и организационных вопросов, участвуете в работе редакционной коллегии научного журнала «Транспорт БРИКС». Мы уверены в сохранении наших плодотворных контактов на многие годы.

Уважаемый Владимир Валентинович! В день юбилея желаю Вам крепкого здоровья, творческого долголетия, чтобы Вы, Ваши ученики и последователи продолжали приумножать потенциал российской экономики, науки и образования.

Ректор О.С. Валинский

Emperor Alexander I St. Petersburg State Transport University
To Academician of the Russian Academy of Sciences

Academic Adviser
of the Institute for Regional Economic Studies of the Russian Academy of Sciences,
Honorary Citizen of Saint Petersburg

Vladimir Valentinovich Okrepilov

ON THE DAY OF HIS 80TH BIRTHDAY

Dear Vladimir Valentinovich!

On the day of your 80th anniversary, please accept the sincerest congratulations from the staff of the Emperor Alexander I St. Petersburg State Transport University and myself.

Over more than 50 years of your professional career, you have achieved outstanding success in scientific and academic spheres. What deserves special appreciation is your fundamental scientific research related to the development of theoretical foundations of the economics of quality and their role in the socio-economic development of Russia, and the creation of Russia's only scientific school of the economics of quality, which was a major achievement for St. Petersburg.

The results of research and development efforts of your school have been applied in the activities of the European Organisation for Quality (EOQ), the European Foundation for Quality Management (EFQM), and the IQNET Association (the International Certification Network for management systems assessment).

Your active publishing work allows you to widely share your ideas and experience, gain followers and supporters, and train highly qualified professional, scientific and teaching staff.

Your decisive contribution to the creation of a unique multilevel system of continuous training of personnel for the economics of quality in St. Petersburg is invaluable.

Your scientific, teaching and public work has received well-deserved recognition and is duly appreciated by the governments of the Russian Federation and St. Petersburg.

For many years you have been cooperating with our university, assisting us in solving many scientific and organisational issues, and contributing to the work of the editorial board of the BRICS Transport scientific journal. We are confident that our fruitful contacts will continue for many years to come.

Dear Vladimir Valentinovich, on the day of your anniversary I wish you good health and creative longevity, so that you, your students and followers can continue to increase the potential of the Russian economy, science and education.

Rector Oleg S. Valinsky

On the 80th Anniversary of Academician Vladimir Valentinovich Okrepilov

Vladimir Valentinovich Okrepilov, Academician of the Russian Academy of Sciences, Scientific Director of the Institute for Regional Economic Studies of the Russian Academy of Sciences, the Honorary Citizen of St. Petersburg, was born on February 23, 1944 in Leningrad. He graduated from the Leningrad Mechanical Institute. From 1965, he worked as a mechanic, technician, production engineer, and senior design engineer at the Leningrad Radio Equipment Plant. From 1970 to 1979, he was engaged in public work. In 1979, he was employed as Chief Engineer at the Mendeleev All-Union Research Institute for Metrology. In 1986, he became Director of the Leningrad Centre for Standardisation and Metrology of the USSR Gosstandart (a government agency for standardisation); in 1990, he was employed as General Director of FBU Test-S.-Petersburg (a federal state-funded institution); in 2017, he became President of Test-S.-Peterburg LLC, in 2018, he acquired the position of Scientific Director of Test-S.-Peterburg LLC; since 2019, he has been serving as Scientific Director at the Institute for Regional Economic Studies of the Russian Academy of Sciences.

Rector of the Institute of Quality Management, a private educational institution of additional professional education. Head of a department at the St. Petersburg State University of Aerospace Instrumentation. Head of the UNESCO Chair at the Peter the Great St. Petersburg Polytechnic University. Head of the specialized department at the St. Petersburg State University of Economics. Author of more than 830 scientific works.

Doctor of Economics, Professor, Academician of the Russian Academy of Sciences. Member of the Presidium of the Russian Academy of Sciences (2002–2013); Deputy Chairman of the St. Petersburg Scientific Centre of the Russian Academy of Sciences (2001–2013). Member of the Bureau of the Department of Social Sciences of the Russian Academy of Sciences. Member of the Presidium of the St. Petersburg Branch of the Russian Academy of Sciences. Chairman of the Scientific Council "Regional Problems of the Economics of Quality" of the RAS Department of Social Sciences. Deputy Chairman of the RAS Scientific Council for Metrological Support and Standardisation.

Head of Russia's only scientific school of the economics of quality, which has repeatedly topped the list of leading scientific schools in St. Petersburg and Russia. The results of research and development efforts made by the school are used in activities of the European Organisation for Quality (EOQ), the European Foundation for Quality Management (EFQM), and the IQNET Association (International Certification Network for management systems assessment).

The main areas of fundamental scientific research of Academician Vladimir V. Okrepilov are related to the development of theoretical foundations of the economics of quality and their role in socio-economic development and improvement of the quality of life, and to the development of methods for quality management in various areas of activity.

Academician Vladimir V. Okrepilov has made a decisive contribution to the creation of a unique multi-level system of continuous training in the economics of quality in St. Petersburg.

He actively participated in the development of the Strategy of Social and Economic Development of St. Petersburg until 2030 and the Integrated Scientific and Technical Programme of the North-West Federal District of the Russian Federation until 2030. Member of the Council for Economic Modernisation and Innovations under the Chairman of the Federation Council of the Federal Assembly of the Russian Federation (2012).

Member of the Presidium of the Scientific and Technical Council of St. Petersburg. Chairman of the Expert Council of the St. Petersburg Industry Development Fund (a non-profit unitary organisation).

Expert of the Expert Council under the Government of the Russian Federation; listed in the Federal Register of Experts in Science and Technology.

Member of the Public Chamber of the Russian Federation (2014–2019) and the Public Chamber of St. Petersburg. Chairman of the Public Council of the Admiralteysky District of St. Petersburg. Chairman of the Public Council at the Committee for Industrial Policy, Innovation and Trade of St. Petersburg. Chairman of the Public Council at the Committee for Science and Higher Education of St. Petersburg.

Member of the Union of Russian Writers.

Editor-in-Chief of the journal "The Economy of the North-West: Problems and Prospects of Development". Founder of the electronic journal "The Economics of Quality".

Vladimir V. Okrepilov is the President of the Metrology Academy of Russia, one of the founders of the Academy of Quality Problems of Russia, and the President of its St. Petersburg branch.

Honoured Scientist and Engineer of the Russian Federation. Recipient of the State Prize of the Russian Federation in the field of science and technology;

awards from the President of the Russian Federation, the Government of the Russian Federation and the Government of St. Petersburg in the field of education; the Prize of the Government of the Russian Federation in the field of science and technology for 2010; the Prize of the Russian Academy of Sciences for the best works on popularisation of science in 2009.

Holder of government awards: the Order of Friendship of Peoples, the 4th Class Order for Merits to the Fatherland, the Order of Honour, the Order of Friendship, the Russian Federation Presidential Certificate of Honour, the Commendation from the Chairman of the Federation Council of the Federal Assembly of the Russian Federation. Holder of the honorary titles: the Honoured Scientist and Engineer of the Russian Federation, the Honorary Worker of Science and Technology of the Russian Federation, and the Honoured Metrologist, and certificates of honour of the Ministry of Industry and Energy of the Russian Federation; recipient of the State Prize of the Russian Federation in the field of science and technology, the Russian Federation Presidential Prize in Education, the Russian Federation Government Prize in Education, the St. Petersburg Government Prize in Education, the Russian Federation Government Prize in Science and Technology, the Prize of the Russian Academy of Sciences for the best works on popularisation of science; the holder of the Honorary Citizen of St. Petersburg title, the Honorary Badge for Merits to St. Petersburg, the Badge of Merit for Merits to St. Petersburg, the Badge of Merit of the Leningrad Region for Contribution to the Development of the Leningrad Region, the Certificate of Honour from the Governor of St. Petersburg, certificates of honour from the Governor of the Leningrad Region, an honorary diploma from the Legislative Assembly of the Leningrad Region.

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New ways to improve the efficiency of railway transportation of viscous petroleum products

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ABSTRACT The paper proposes a new approach to solving the problem of increasing the economic efficiency of railway transportation of viscous petroleum fuels (fuel oils) at low air temperatures. The physical properties of fuel oils allow them to be obtained when poured into the tank of a tank wagon in a stratified state, when their density in the upper part of the tank is significantly less than in its lower part. This blocks the natural convection of hot fuel oil on the cold walls of the tank, and it cools only due to the molecular thermal conductivity which is very small. Upon cooling down, a relatively thin highly viscous layer forms on the inner walls of the tank of a tank wagon, which acts as a heat-insulating shell, and the bulk of it (more than 90 %) retains high temperature and fluidity throughout the period of transportation. The thermal and hydrodynamic calculations were performed using modern computer technologies (the ANSYS 5.6 software package). The results obtained show that the need to heat up the fuel oil during unloading remains, but already requires significantly less time and heat energy. The proposed energy-saving technologies for the delivery of viscous petroleum products are especially relevant in Russia with its cold continental climate, long-haul transportation, and the current structure of the country's wagon fleet. The value of the results obtained lies in the fact that the proposal can be implemented on tank wagons in circulation with minimal change to their design. The technology of operation of the drain equipment at unloading points will not change either.

KEYWORDS: railway transportation; viscous petroleum products; thermogravitational convection; stratified state; thermal insulation of the tank of a tank wagon

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Научная статья

Новые способы повышения эффективности железнодорожных перевозок вязких нефтепродуктов

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АННОТАЦИЯ Предложен новый подход к решению задачи повышения экономической эффективности железнодорожных перевозок вязких нефтяных топлив (мазутов) при низких температурах воздуха. Физические свойства мазутов позволяют получать их при наливе в котел вагона-цистерны в стратифицированном состоянии, когда их плотность в верхней части котла существенно меньше, чем в нижней. Этим блокируется естественная конвекция горячего мазута на холодных стенках котла, и он охлаждается только за счет молекулярной теплопроводности, которая очень мала. При охлаждении на внутренних стенках котла вагона-цистерны образуется сравнительно тонкий высоковязкий слой, играющий роль теплоизолирующей оболочки, основная его масса (более 90 %) сохраняет высокую температуру и текучесть за все время транспортирования.

Выполнены тепловые и гидродинамические расчеты с применением современных компьютерных технологий (пакет программ ANSYS 5.6). Полученные результаты показывают, что необходимость разогрева мазута при выгрузке остается, но требует в разы меньших затрат времени и тепловой энергии. Предложенные энергосберегающие технологии доставки вязких нефтепродуктов особенно актуальны в условиях России с ее холодным континентальным климатом, большой дальностью перевозок и сложившейся структурой вагонного парка страны.

Ценность полученных результатов заключается в том, что предложение может быть реализовано на вагонах-цистернах, находящихся в обороте при минимальных изменениях их конструкции. Технология эксплуатации сливного оборудования в пунктах выгрузки также не изменяется.

КЛЮЧЕВЫЕ СЛОВА: железнодорожные перевозки; вязкие нефтепродукты; термогравитационная конвекция; стратифицированное состояние; тепловая изоляция котла вагона-цистерны

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INTRODUCTION

The paper presents a new approach to solving the problem of increasing the economic efficiency of transport operations associated with long-distance transportation of Viscous Petroleum Products (VPP) at low air temperatures. These liquid cargoes are the most important component of freight transportation by rail transport in Russia. Their share in the total freight turnover of the country's railways, including export traffic, is approaching 18 million tonnes per year. At the same time, the main traffic flows are formed in the regions of Western Siberia, Urals, and the Far East. It is there that Russia's oil fields are in a state of initial development and at the peak of their development. The main means of delivering VPP to the centre of the country is by railway (~65 %) and river transport (~25 %). The maximum volume of transportation is accounted for by furnace fuel oils under the M100, M40 and F12 brands.

During transportation, fuel oil cools down and turns into a highly viscous state, which makes it very difficult to unload. The standard solutions used to the problem, such as insulated tank wagons and heating up of oil cargo to restore its fluidity before unloading, require a very high consumption of various types of resources. For railway transportation, these include the use of specialized wagons with a large (up to 50 %) empty return mileage, low turnover due to the duration of the heat-up period, high cost of manufacturing and operation of tank wagons, consumption of thermal energy for draining and cleaning of tank wagons from high-viscosity VPP residues.

The paper proposes, for the first time, to make a rational use of the physical properties of the transported petroleum products themselves, such as high values of the volumetric thermal expansion coefficient, a low molecular thermal conductivity, and a sharp increase in viscosity during cooling. Giving reasonable consideration to these properties makes it possible to obtain and keep the main mass (more than 90 %) of VPP in a liquid state for a long time both in the ground storage tank and in the tank of a tank wagon. At the same time, only 5 % to 10 % of the total mass of the petroleum product located in close proximity to the inner walls of the tank passes into a highly viscous state.

A relatively thin, highly viscous layer with a low thermal conductivity is formed on them, which acts as thermal insulation of the contents of the tank from the external environment.

This provides a possibility of a sharp reduction in time and thermal energy input for unloading, which is only reduced to the dilution of this layer.

For railway transportation, the proposal can be implemented on tank wagons in circulation with minimal change in their design and maintaining the operating conditions of the drain equipment. What is to be changed is the technology of filling petroleum fuels used at a refinery.

The paper describes mathematical models of physical processes in M100 liquid furnace fuel oil in the tank of a tank wagon and the results of calculations of temperature distribution.

Options for the use of tank wagons with a steam heating casing and tanks for light general-purpose petroleum products are being considered [1–15].

PROBLEM STATEMENT AND METHODS OF ITS SOLUTION

There are a large number of development efforts aimed at accelerating the discharge of VPP and reducing the consumption of resources for the arrangement of discharge [1–3]. The flow of new papers and patent applications for inventions that has been going on for more than 50 years shows that the optimal solution to the problem has not yet been obtained.

The problem of VPP delivery is particularly typical of Russia with its cold continental climate, long duration of the cold season, a low degree of branching of the railway network in the northern and eastern regions of the country, and the established structure of its wagon fleet. Currently, fuel oil is poured into the tank of a tank wagon at a temperature close to +70 °C. These temperatures ensure a decrease in viscosity and a reduction in the VPP filling time, but heating VPP to higher temperatures is prohibited in order to preserve the performance characteristics of rubber sealing elements on the drain equipment of the tank of a tank wagon. The loss of these characteristics can cause a spill of large amounts of VPP, which will lead to large-scale environmental disasters.

Full-scale experiments to study the cooling of furnace fuel oil with an initial filling temperature T_n of +70 °C were carried out for three years and took place as early as the 1950s. They were focused on the average winter air temperature in the European part of the Soviet Union, T_g = –15 °C. From the beginning, the average value of the convective heat transfer coefficient α of 30 W/m² °C was also set for the heat-emitting surface of the tank of a tank wagon. The results of the experiments are shown in *Fig. 1* [5].

Fuel oils obtained from various oil fields of the Russian Federation differ by the content of paraffin fractions and have a solidification temperature range from +25 °C to +35 °C, at which they are not discharged by gravity. This temperature range is marked by a large dotted line in Figure 1, which also shows the average travel time of oil trains in the European part of Russia (~140 hours) [6] and the average time of transition of VPP to a highly viscous state (~23 hours in tank wagons without thermal insulation of the tank).

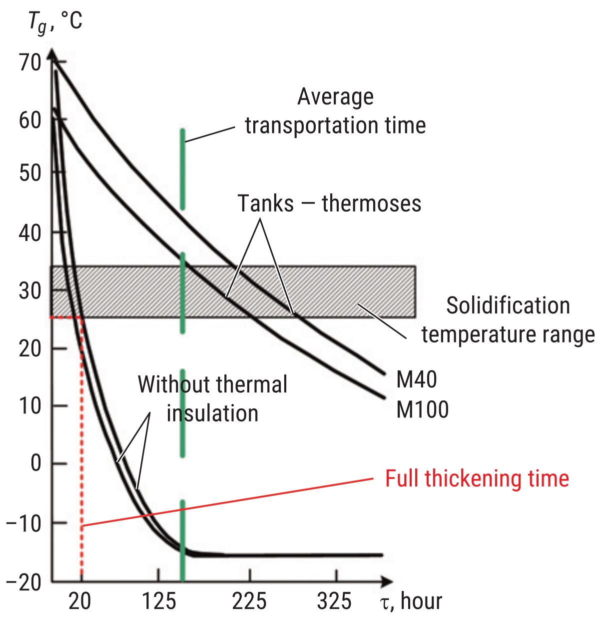


Fig. 1. Cooling of M40 and M100 fuel oils in tank wagons with and without thermal insulation of the tank [5]

Full-scale experiments have shown that after 15–20 hours of transportation at an air temperature T_g of –15 °C, the average volume temperature of VPP in a tank without thermal insulation decreased to +10 °C. At these temperatures, the viscosity of M40 and M100 fuel oils is so high that their discharge by gravity becomes impossible. In insulated tanks, it takes about 180 to 200 hours before fuel oil cools down to these temperatures.

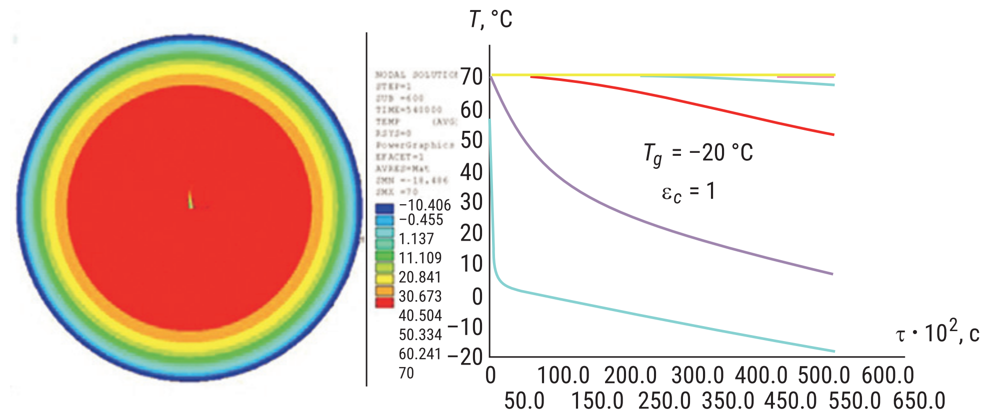
Hence, it was concluded that the heat-insulating shell of the tank does not provide the expected effect of maintaining a high temperature and fluidity of VPP necessary for draining, and it was decided that it would be more expedient to deliver petroleum fuels in a highly viscous state and warm them up before the discharge. At the same time, heating of VPP remains a laborious and lengthy operation, which causes a low turnover of tank wagons, requires expensive equipment, areas, buildings and facilities, not to mention high consumption of thermal energy. According to Russian Railways, over 660 thousand tonnes of oil equivalent are spent annually for draining and heating of oil cargoes, and the total idle time of tank wagons under draining exceeds 1 million wagon-hours, which is equivalent to about RUB 3.5 billion in monetary terms (in 2022 prices).

INNOVATION PROPOSAL

Below we propose a new and unconventional approach to solving the problem of accelerated unloading of VPP with a low energy input, even at enterprises with limited resources. It is based on the possibility of long-term maintenance of fuel oil in a ground tank or the tank of a tank wagon in a stratified state. A stratified state is a nonequilibrium, but hydrodynamically stable state of a liquid, in which its density in the lower part of the container is significantly higher than in its upper part.

Thermogravitational convection (TGC) of hot and still low-viscosity fuel oil is initially suppressed after it is poured into the tank of a tank wagon.

After the suppression of TGC, fuel oil transported in winter time does not freeze throughout the volume of the tank of a tank wagon, but it solidifies to a highly viscous state on the inner surface of its shell. The tank acquires a shell formed from the fuel oil itself with rather good thermal insulation properties. The volume of the shell is about 6 to 8 % of the internal volume of the tank. The bulk of the fuel oil (about 92 to 94 %) retains a high temperature and fluidity for a long period of time, which is sufficient for draining by gravity. The standard operation of heating the delivered fuel oil during unloading will remain necessary, but will require significantly less time and energy.



a *b*

Fig. 2. Results of calculations of temperature fields in the mass of M100 fuel oil along the section of the tank of a tank wagon in the absence of TGC: *a* — overall picture of the temperature distribution after 5.7 days of transportation at an air temperature T_g = −20 °C; *b* — curves of temperature change at different distances from the axis of the tank (model of a quasi-solid body, convection coefficient ε_c = 1)

An important point here is that fuel oil is discharged at a high temperature and fluidity. For the first time, it becomes possible to transport it through pipelines made according to temporary technological schemes, for example, when bypassing barrier sites on a destroyed railway network or when delivering fuels to watercraft without berthing.

The proposed method requires some change in the technology of filling VPP into the tank of a tank wagon carried out at a refinery, rather than in the unloading technology.

First of all, we should note the physical characteristics of petroleum fuels: bunker fuel oils (F-5), furnace fuel oils (M100), and high-viscosity cracking residues (M200). It can be seen from *Table 1* that all of them have a large coefficient of volumetric thermal expansion β_{VPP} of about 10^{-3} 1/deg (almost five times greater than that of water). They also have a low thermal conductivity λ_{VPP} ranging from 0.105 to 0.12 W/m°C, only slightly higher than that of asbestos fibre ($\lambda_{asbest} \approx$ 0.09 W/m°C), which is a typical thermal insulation material. The combination of these properties makes it possible to significantly reduce the time and consumption of heat for managing the discharge of VPP.

It should be noted that the problem of cooling a cylinder streamlined by an air flow from the outside is one of the canonical problems of mathematical physics which was solved back in the nineteenth century. The necessary analytical expressions, tables and graphs are available in the literature [8, 9]. Based on this, let us imagine fuel oil in a tank wagon with a tank diameter *D* of 3 m as a quasi-solid body with a thermal conductivity λ_{VPP} of 0.105 W/m°C and an initial temperature of +70 °C. Let us assess its cooling time to the discharge temperature of +40 °C.

To solve this problem, computer calculations were performed showing the radial temperature distribution; the calculation results obtained using the ANSYS 5.6 software package are shown in *Fig. 2*.

These give a picture of the temperature distribution over the section of the tank of a tank wagon that is streamlined by an air flow with a temperature T_g of –20 °C and a velocity u_g of about 20 m/s. As you can see, after 140 hours (~6 days) of transportation, the bulk of M100 fuel oil (highlighted in red, orange, yellow and green colours) will retains a high temperature and fluidity sufficient for unloading, and only a thin layer at the very walls of the tank will solidify

Table 1

Physical characteristics of petroleum fuels (fuel oils) [4]

Petroleum fuel	Density, ρ_0, kg/m³	Specific heat capacity, C, J/kg°C	Kinematic viscosity in the temperature range +40...60 °C, $\nu \cdot 10^6$, m²/s	Coefficient of thermal conductivity, λ, W/m²°C	Coefficient of thermal expansion, β, °C⁻¹	Temperature of unloading (by gravity), *T*, °C
F-5, F-12 bunker fuel oils	900–950	1880	96–43	0,120	$9{,}31 \cdot 10^{-4}$	+30...+40
M100 furnace fuel oil	970–984	1860	825–400	0,105	$9{,}57 \cdot 10^{-4}$	+50...+60
M200 fuel oil	998–1010	1848	3674–668	0,102	$9{,}57 \cdot 10^{-4}$	higher +60

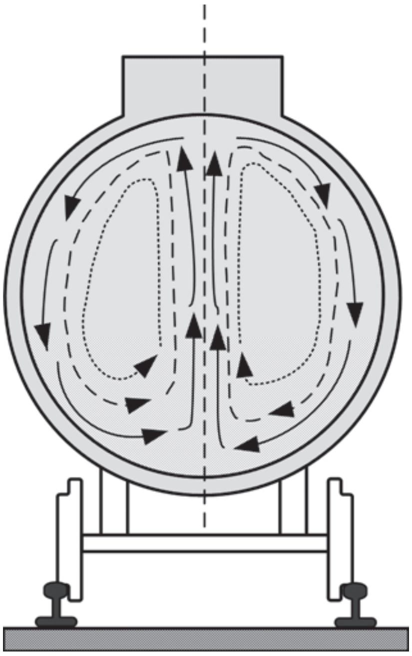


Fig. 3. Schematic representation of liquid currents inside a tank wagon during thermogravitational convection and symmetrical cooling of the walls

(highlighted in turquoise, light blue and dark blue colours).

The graphs show the curves that characterize the change in fuel oil temperature over time at various distances from the axis of the tank of a tank wagon.

This result is in sharp contradiction with the data of field experiments shown in *Fig. 1*. Consequently, the model of the medium as a quasi-solid body turned out to be erroneous. In reality, there are internal movements of low-viscosity VPP, which can be considered as mixed natural and forced convection.

Being an integral part of it, thermogravitational convection (TGC) occurs when the wall layers of the liquid are cooled by the cold walls of the tank, accompanied by an increase in the density of VPP.

The cooled wall layers of the liquid move downward, displacing the liquid upward in the central areas of the tank. A diagram of the currents of the circulating fluid movement in a horizontal cylinder at TGC is shown in *Fig. 3*; the arrows indicate the directions of the currents, and the density of the lines shows the areas with the highest speed of movement [22].

Being the second component of the process, forced convection is a secondary factor. This is observed only when the tank wagon is moving and only in the upper layers of petroleum products, and since the tank of a tank wagon is usually filled to 90 to 95 %, the air layer above the free surface of the liquid, where waves develop, turns out to be too thin to cause intense mixing of the liquid [28].

EVALUATION OF THE RESULTS OF HYDRODYNAMIC CALCULATIONS

All works on TGC note that the most intense currents occur in a thin, near-wall layer of liquid [10], as shown in *Fig. 3*. Therefore, TGC is described using the laminar boundary layer model [10]. This model was also used in the calculations for M100 fuel oil. The equations of hydrodynamics and convective heat transfer [26] were solved by the finite element method using the ANSYS 5.6 software package.

When performing the calculations, the following conditions were set:

- when poured, M100 fuel oil had an initial temperature Tn of +70 °C;
- the outside air had a temperature T_g of –20 °C;
- the external heat transfer coefficient α was 15 W/m²°C;
- filling of the tank lasted 45 minutes, taking into account the transition to a steady state of internal currents in VPP.

The images shown in *Fig. 4, a, b* show the thickness of the laminar flow descending along the tank wall δ_{max}

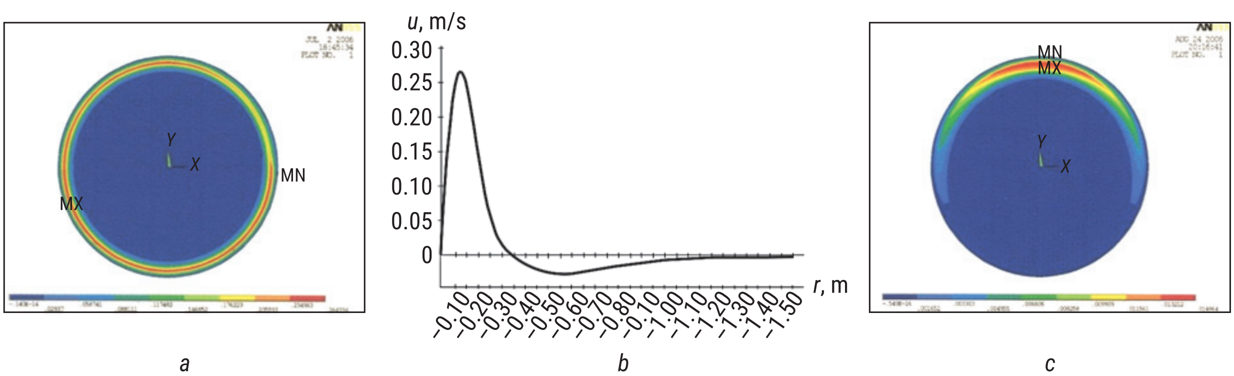


Fig. 4. Distribution of velocities of the circulating movement of M100 fuel oil during thermogravitational convection inside the tank of a tank wagon: *a*, *b* — during the first 45 minutes after filling the tank wagon; *c* — 360 minutes after pouring VPP into the tank

of about 0.30 m, with the highest flow velocity u_{max} of about 0.27 m/s observed at a distance δ of about 0.13 m from the tank wall. At a distance *r* of more than 0.3 m, countercurrents rising upwards are formed, closing the circulation vortices schematically shown in *Fig. 4, b*. In the centre of the tank, at distances *r* exceeding 1 m from its wall, a fixed core is formed, where the liquid remains motionless.

It follows that at the flow rates u_{max} of about 0.27 m/s, TGC is the main reason for the rapid cooling down of fuel oil in the entire volume of the tank of a tank wagon, which confirms the results of field experiments shown in *Fig. 1*. A sharp decrease in the rate of cooling of the oil cargo 20 to 23 hours after it is poured into the tank is also understandable. It can be seen from *Fig. 4, a* and *b* that in the first 45 minutes TGC is observed throughout the entire section of the tank, and then, as can be seen from *Fig. 4, b*, after 360 minutes the process noticeably shifts upwards. It can be expected that after 20 hours of cooling, the increase in the viscosity of VPP will completely extinguish TGC, and this will fully confirm the course of the experimental curve shown in *Fig. 1*.

It can be concluded that when TGC is suppressed, a liquid petroleum product will cool down as a quasi-solid body by molecular thermal conductivity at λ_{VPP} of about 0.12 W/m°C, and the temperature distribution in it will correspond to the picture shown in *Fig. 2* [16–27].

OBTAINING THE STRATIFIED STATE OF LIQUID PETROLEUM FUELS

Let us look at several ways to delaminate hot liquid petroleum products and obtain a temporary thermal insulation shell of a tank, specifically for the tank of a tank wagon, from a highly viscous oil product itself [17]. (Compare with a layer of ice on the surface of a reservoir that thermally insulates liquid water located under it).

The first method is implemented in a specialized tank wagon, model 15-1566, for viscous liquid cargoes with a steam heating casing rigidly mounted on the bottom of the tank [7, 19, 20, 24]. The model was developed back in the 1960s, has been modernized many times, and is now widely used (*Fig. 5*). The parameters of the tank of the tank wagon are given in *Table 2*.

Fig. 5. Tank wagon with a steam heating casing, model 15-1566: 1 — tank of the tank wagon; 2 — steam heating casing of the tank

The model has a chamber of about 2.8 m³ in volume between the walls of the tank and the casing; the thickness of the chamber is about $4.5 \cdot 10^{-2}$ m.

When unloading VPP, steam is supplied to the chamber to heat up the tank walls and a relatively thin layer of solidified petroleum product which is in thermal contact with them. The layer melts, dramatically reducing its viscosity, and the entire bulk of VPP with a low temperature and high viscosity slides over this layer and is poured into a receiving pit below ground level.

Next, the tank wagon leaves the discharge facility, and heating and sending the drained petroleum product to storage becomes a responsibility of ground services.

The idea is good, but the fuel oil facilities of an enterprise receiving VPP should have expensive and energy-consuming equipment (heated fuel oil pipelines of great length). This means that the problem of heating up VPP during the discharge and distribution to ground storage and associated resource costs remain unresolved.

According to the proposed new technology, before being poured into the tank of a tank wagon, fuel oil must have a temperature exceeding the boiling point of water (100 °C). The above mentioned difficulties related to maintaining the performance of the rubber sealing collar on the drain device shown in *Fig. 6* can be resolved by a simple act [12, 13].

Table 2

Parameters of the tank of a tank wagon, model 15-1566 [11]

Area of the heat-emitting surface, m²	Tank wall thickness, m	Thickness of the casing walls, m	Specific heat capacity of steel, J/kg °C	Heat capacity of steel λ, W/m°C	Tank weight with the casing, kg	Increase in the weight of the container, kg	Volume of the chamber under the casing, m³
110	10–2	$3 \cdot 10^{-3}$	527	42.6	9,087	1,630	2.8

a *b*

Fig. 6. Tank wagon's drain device: *a* — general view; *b* — axonometric view of the device; 1 — rubber sealing collar [29]

Fig. 7. Application of thermal insulation from rigid polyurethane foam [23]

Before filling the tank of a tank wagon with hot fuel oil, process water with a temperature of about plus 50 °C is supplied to the chamber. (At very low air temperatures (minus 50 °C), it provides preheating of the empty tank to temperatures of the order of plus 5 to 10 °C, which solves the problem of thermal stresses in the tank welds). An extension pipe with a length of 0.10 m to 0.15 m is attached to the tank of the tank wagon, and a flange with a bolted connection to the flange on the drain device is welded to its free end. When pouring hot VPP, the first masses of the product are spread over the cold bottom of the tank and cooled down on it. The extension pipe with an internal volume of about 3 litres is filled with already cooled fuel oil. But as it has a low thermal conductivity (*Table 1*), it will create thermal insulation of the rubber sealing collar from the hot VPP inside the tank of the tank wagon. Filling becomes possible at a temperature of fuel oil T_{VPP} of about +120 °C to +150 °C, i.e. exceeding the boiling point of water. When fuel oil with such a temperature is poured into the tank of the tank wagon, the water under the steam heating casing will heat up and boil, with the water mass m_W being 2,800 kg.

This requires a lot of heat, which leads to a sharp cooling of the fuel oil in the lower part of the tank.

The amount of cooling water is estimated from the heat balance equation. Let us assume that in the lower part of the tank, the mass of fuel oil (m_{VPP}) being cooled down from the initial temperature $T_{VPP.0}$ of +150 °C to T_{VPP} of +100 °C when the boiling of water stops is 30 tonnes. However, the water under the casing is additionally cooled down to the temperature of the water drain T_W of +30 °C. The thermophysical properties of water in liquid and gaseous states are shown in *Table 3*.

Using the values indicated in *Table 1* and *Table 3*, we obtain the heat balance equation as follows

$$\Delta T = \frac{(r_W + C_W 70)\cdot m_W}{C_{VPP} m_{VPP}} =$$

$$= \frac{(2238 + 4,2 \cdot 2,8 \cdot 70)\cdot 2800}{1,86 \cdot 30 \cdot 10^3} \approx 122\,°\text{C}.$$

It follows that the transfer of heat to 2.8 tonnes of water in the chamber under the casing will cause cooling of 30 tonnes of fuel oil in the lower half of the tank of a tank wagon by 122 °C. At the same time, the average temperature of the fuel oil in the upper half of the tank $T_{VPP.1}$ will remain equal to about 150 °C, and the temperature in the lower half $T_{VPP.2}$ will drop to about 28 °C, i.e. the difference of temperatures of VPP in the upper and lower halves of the tank (ΔT) will be about 120 °C.

It is known that density of fuel oils of various grades is temperature dependent as follows [14]

$$\rho(T) = \frac{\rho_{20}}{1 + 0,0023(T - 20)},$$

where ρ_{20} is the density of fuel oil at temperature T = +20 °C, and T is the temperature of fuel oil, °C.

By using this equality, it is easy to establish that the density of fuel oil in the upper half of the tank of a tank wagon turns out to be almost 8 % lower than that in its lower part. This must be the reason for blocking TGC. The results of computer calculations and the dynamics of cooling down of M100 fuel oil in a stratified state are shown in *Fig. 8, b, d*.

For the second option of VPP stratification, a general purpose tank without a steam heating casing can also be used [5, 16]. A polyurethane foam shell with a thickness of 0.03 m to 0.05 m is applied to the upper

Table 3

Physical properties of water

Boiling point T_b, °C	Specific heat of water vaporization r_w, kJ/kg	Specific heat capacity, C_w, kJ/kg °C	Specific heat sink from oil cargo when filling the tank, kJ/kg
+100	2,238	4.2	3,000

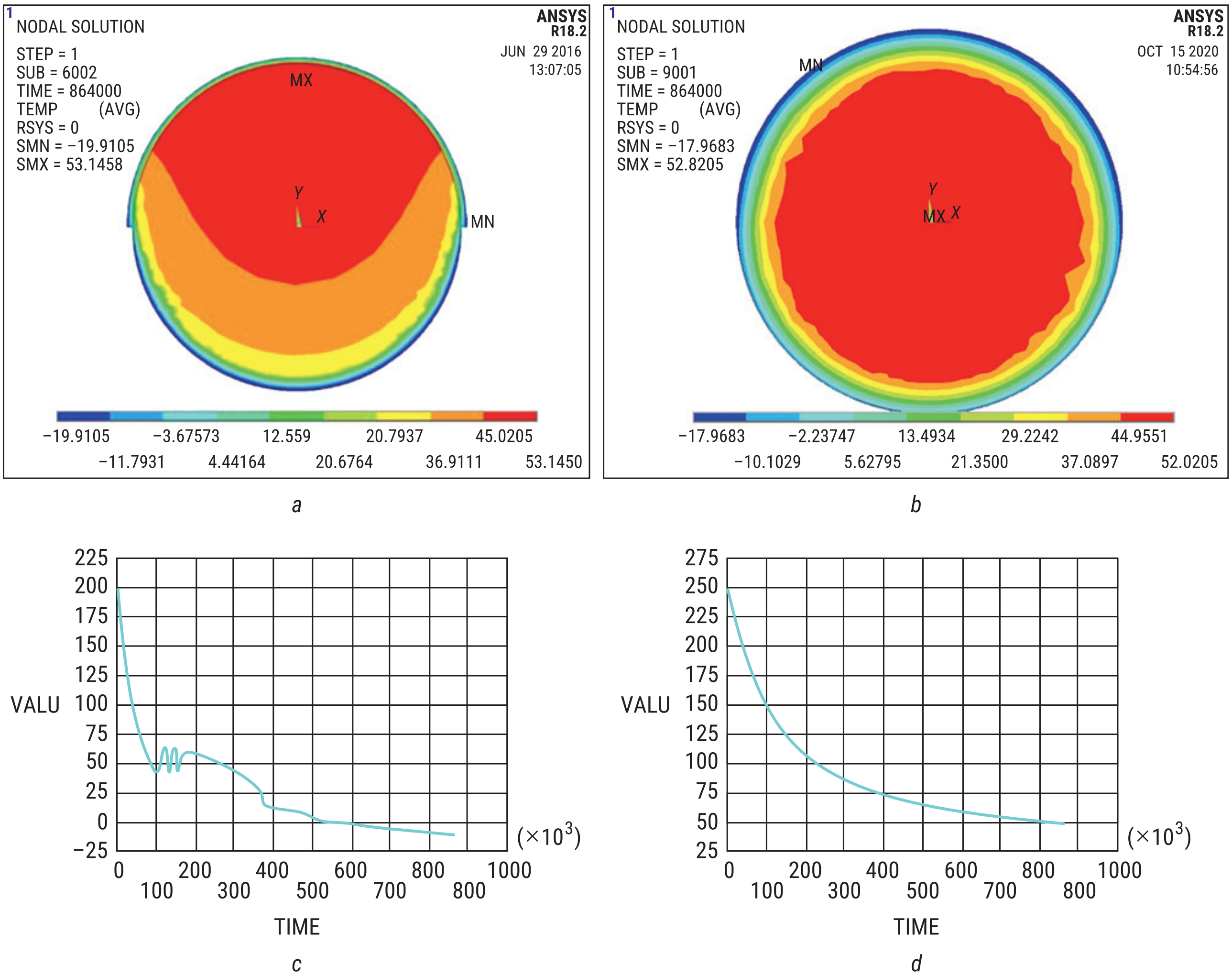


Fig. 8. Temperature distribution in stratified M100 fuel oil (transportation at an initial temperature of VPP T_0 = +150 °C, air temperature T_g = −20 °C, and the external heat transfer coefficient α_{ex} = 15 W/m²°C: *a* — when transported in a general-purpose tank wagon with the thermal insulation of the upper half; *b* — when transported in a tank wagon with a steam heating casing; *c* — cooling curve for fuel oil in the lower part of the tank in the area of the drain pipe; *d* — cooling curve for fuel oil in the central part of the tank

part of the tank. It is created by mixing two polyurethane components that are supplied under pressure to a dispersing nozzle (*Fig. 8*). When they are mixed, polyurethane foams to form an integral structure without joints and seams, regardless of the complexity of its shape.

Practice has proven that the effectiveness of the rigid polyurethane foam shell continues for up to 10 years. At the same time, the shell is easily removed mechanically (with a scraper) as necessary due to wear or according to individual requirements, for example, when necessary to control the strength characteristics of the tank walls by ultrasonic methods.

The thermal insulation can be applied and removed in a depot environment. The application time of the shell by a single worker is about two hours. The cost of the thermal insulation shell material is about RUB 50 thousand per tank.

The change in the technology of filling petroleum products boils down to the following.

Currently, the filling of VPP is carried out from one container, where the fuel oil is at a temperature of +70 °C. According to the new technology, the tank of a tank wagon is filled in series and from two containers: one third of the tank is filled with fuel oil with a temperature of +50 °C, and the remaining two thirds are filled with fuel oil with a temperature of +100 °C to +110 °C. Higher temperatures are not allowed, since polyurethane foam melts at temperatures from +130 °C to +150 °C. Melting causes deformation and shrinkage of the shell. The specified temperature difference of 30 to 40 °C provides the stratification of hot fuel oil.

The main advantages of the method are the possibility of transporting VPP in non-specialized general-purpose tank wagons. They have a significantly lower empty mileage than specialized rolling stock, a lower tare weight, and lower cost of manufacture and operation.

The results of computer calculations of temperature fields in the bulk of fuel oil transported in a stratified state shown in *Fig. 8* show that the layers of VPP adjacent to the shell of the tank cool down the fastest with the transition to a highly viscous state. These layers cool down when passing into a highly viscous state, but at the same time they form a heat-insulating shell of the tank that emerges spontaneously from the transported petroleum product itself. The thickness of solidified layers of VPP that form the shell depends on the ambient temperature and, under severe winter conditions, does not exceed 10 cm, and their weight does not exceed 15 tonnes, i.e. no more than 20 % of the contents of a 65-tonne tank wagon. The major portion of the transported VPP (highlighted in red, orange and yellow) with a total weight of up to 50–55 tonnes will retain a high temperature and fluidity throughout the transportation time [28].

Unloading of the delivered VPP from the tank of a tank wagon is carried out by the method currently in use. Steam is supplied to the chamber through the inlet fitting on the steam heating casing to heat up and melt the layer of thickened petroleum product forming a heat-insulating shell; the rest of its mass has a temperature sufficient to discharge by gravity.

The discharge of M100 fuel oil from a general-purpose tank wagon can also be carried out by recirculation. It can be seen from *Fig. 8, a* that it remains necessary to dilute not the entire contents of the tank, but a relatively thin solidified layer formed in the lower part of the tank [28, 29].

CONCLUSIONS

We have proposed a new method of transporting viscous petroleum products at low air temperatures by their pre-conversion to a stratified state. The achieved positive effects from the use of the declared technical proposal are summarized below:

- a sharp reduction in the time and input of thermal energy required for heating when unloading VPP from a tank wagon by reducing the oil product cooling rate during transportation and maintaining fluidity of more than 80 to 90 % of its total mass in the tank of a tank wagon;
- when unloading a petroleum product, only a thickened layer which is less than 20 % of its total mass in the tank wagon needs to be thinned;
- reduction in the amount of thermal energy for additional heating of petroleum products in aboveground pipelines that provide their transportation to storage facilities.

The method can be implemented by using rolling stock in circulation.

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Passenger Rolling Stock of Indian Railways in the First Half-Century of Their Operation

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ABSTRACT In India, as in many countries, railways originated as industrial gauge tracks for the transportation of ore, timber, stone, and other building materials. These were the first industrial railways in India to deliver supplies to construction sites, in particular, Chintadripet in Madras (1835), Red Hill Railroad line (1837), Godavari Dam Construction Railway (1845), and others. Initially, the promoters of the construction of railways, based on the general social and economic situation in the country, did not count on the development of passenger traffic, taking into account the virtually impoverished situation of the vast majority of the population. Efforts were focused on freight transportation. The colonialists proceeded from the need to develop railways as an important exploitation tool for exporting the country's natural resources to the parent country and to the world market. Throughout almost the entire period of British colonial rule, passenger transportation was intended for a narrow stratum of colonizers and a few of the richest representatives of the country's indigenous population. By the 1860s, there was a system of dividing passenger traffic on the railways of India into four classes. Saloon coaches were used to serve the ruling elite. The difference in travel conditions in luxury saloon coaches and first-class compartment carriages in comparison with third- and fourth-class carriages was huge. It reflected the social class structure of Indian society. At the same time, railway passenger transportation did not affect the interests of the majority of the population at all, as with their level of wealth they could not afford to travel by rail at all, remaining outside the line of progress in transport of the 19th century.

KEYWORDS: history of Indian railways; origin of passenger transportation; types of passenger rolling stock; classes of passenger services

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Обзорная статья

Пассажирский подвижной состав железных дорог Индии в первые полвека их работы

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АННОТАЦИЯ В Индии, как и во многих странах, железные дороги зародились как промышленные колейные пути для перевозки руды, леса, камня, других строительных материалов. Именно такими были первые рельсовые промышленные дороги, обеспечивавшие строительные площадки, в частности, Chintadripet in Madras (1835), Red Hill Railroad line (1837), Godavari Dam Construction Railway (1845) и др.

Первоначально организаторы строительства железных дорог, исходя из общего социально-экономического положения в стране, не рассчитывали на развитие пассажирских перевозок, принимая во внимание фактически нищенское положение подавляющей части населения. Колонизаторы исходили из необходимости развития рельсовых дорог как важного инструмента эксплуатации колонии для вывоза в метрополию и на мировой рынок природных богатств Индии. Пассажирские перевозки на протяжении практически всего периода колониального владычества британцев ориентировались на узкий слой колонизаторов и немногочисленных богатейших представителей коренного населения страны.

К 1860-м годам сложилась система разделения пассажирских перевозок на железных дорогах Индии на четыре класса. Для обслуживания верхушки правящей элиты использовались вагоны-салоны. Разница условий проезда в роскошных вагонах-салонах и купейных вагонах первого класса в сравнении с вагонами III, IV классов была огромной и отражала социально-классовую структуру индийского общества. Железнодорожные пассажирские перевозки не затрагивали интересы бóльшей части населения, которая по уровню своего достатка не могла позволить себе поездки по железным дорогам, оставаясь за чертой достижений прогресса на транспорте XIX столетия.

КЛЮЧЕВЫЕ СЛОВА: история индийских железных дорог; происхождение пассажирских перевозок; типы пассажирского подвижного состава; классы пассажирских перевозок

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THE BEGINNING OF PASSENGER TRANSPORTATION ON THE INDIAN RAILWAYS

India's transportation communications were underdeveloped before the construction of railways. The few and poorly maintained overland roads could not be used during the monsoon period[1]. Waterways were limited to the sea coast and the Indus and Ganges River systems, important trade arteries connecting the north of the country to the western and eastern sea coasts, respectively.

The Indian railways were established as colonial railways, conceived as a project designed primarily to meet the needs of Anglo-Indian ties. Colonial character colors the entire history of Indian railways until almost the middle of the 20th century [1].

The founders of the first railways, the merchants of London and Manchester, intended to use rail transportation to reduce transportation costs and facilitate British traders' access to Indian raw cotton [2]. The Metropolis saw railways as a means of transporting British troops and supplying them with supplies.

Initially, the traction of trains on India's small railways was done by animals. The first steam locomotive began operation in 1837 on the Red Hill Railway which was built by Arthur Cotton to haul granite in the area near Madras for the construction of the Red Hill Bridge.

April 16, 1853, when the first public railway was inaugurated, is considered to be the birthday of rail transport in India. A train of 14 coaches, which accommodated about 400 passengers, travelled 33.8 km along the railway between Bori Bunder (Bombay, now Mumbai) and Thane [3, 4]. This was the first section of the future Great Indian Peninsula Railway (GIPR) built with a gauge of 5 feet 6 inches (1,676 mm), which became standard for most of the country's railway network.

Almost throughout the 19th century, rolling stock for the Indian railways was manufactured in Britain and delivered to India by sea. The colonial authorities protected the interests of British industrialists and prevented the admission of equipment from other countries to the Indian railway market: "Imperial preference excluded most other suppliers" [5].

Naturally, the rolling stock of the Indian railways repeated the design of steam locomotives and cars used on the UK railways. The exclusive focus of this study is on the development of passenger car fleet. At the same time, the authors understand the importance of the topic of the development of the design of locomotives and freight wagons, realising that this requires a detailed review.

Initially, the UK, which was the undisputed trendsetter in this field of engineering in the first decades of the existence of railways in the world, built two-axle passenger cars on wooden frames with wooden bodies. The creators of the first passenger cars proceeded from two design lines. The first one continued the technical idea realised in closed carriages of horse stagecoaches. In fact, the first passenger railway cars were these carriages placed on a railway track.

The second line is the construction of open platforms for transportation of goods that were horse-drawn and were used on dirt roads. With the development of railway tracks, they were put on railway wheels. When organizing passenger services, seats

[1] Monsoon or rainy season is from June to September when humid south-westerly air masses arrive over much of the country; during the south-west monsoon season most parts of the country receive up to 80 % of the annual rainfall.

Fig. 1. India's first passenger coaches. Train pulled by oxen. The middle of the 19th century [6]

Fig. 2. Passenger rolling stock of the first railways. Liverpool and Manchester Railway coaches — the first class. England. 1830. The National Railway Museum. York, England. The coach has three isolated compartments with individual doors that open outwards. The exterior colouring of the car emphasises the continuity with the design of a stagecoach body: the impression is that three carriages are placed on the carriage frame [7]

Fig. 3. Enclosed coach with two separate compartments with doors opening outwards. Bodmin & Wadebridge Railway – Cornwall's first steam railway. 1834. One of the three surviving coaches from England's first railways. The National Railway Museum, York. Photo: Hugh Llewelyn [8]

Fig. 4. Bodmin & Wadebridge Railway third-class open carriage. Cornwall's first steam railway, 1834. One of the three earliest surviving coaches of England's first railways. The National Railway Museum, York. Photo: Hugh Llewelyn. [8]. Figure 6 shows coaches of this type of the Liverpool and Manchester Railway

(wooden benches) were installed on these platforms, which were actually intended for freight, to turn them into passenger coaches. Often, they were not equipped with a roof, but only had a light canvas cover, or did without it.

The two constructional types of passenger cars considered were used on all first railways of the world: in the USA (Baltimore & Ohio, 1830; South Carolina Railroad, 1831), in France (St. Etienne, 1831), on the Belgian railway (1835), the German railway (1835), in Austria (1837), and in Russia on the Tsarskoselskaya railway (1837) [4].

Very few full-scale samples or images of the first passenger coaches of the Indian railways have survived (*Fig. 1*). The authors used British models to illustrate the design solutions, especially since most of the rolling stock of India in the 19th century was produced in Metropolis. Some examples are taken from the history of passenger rolling stock of other countries (*Fig. 1–4*).

In most of Europe, in the United States, Australia, etc., the predecessors of regular passenger transport by rail were horse-drawn stagecoaches[2] — closed carriages pulled by three, four, or sometimes up to six horses,

[2] In Great Britain, regular carriage transport for a fixed fee, which later turned into stagecoaches, began in the 17th century. By the end of 1797, there was a developed system of 42 stagecoach routes in Great Britain [11]. In the early 19th century, numerous stagecoach routes operated on a regular basis in France, a number of German states, Russia, the USA, Australia, and many other countries.

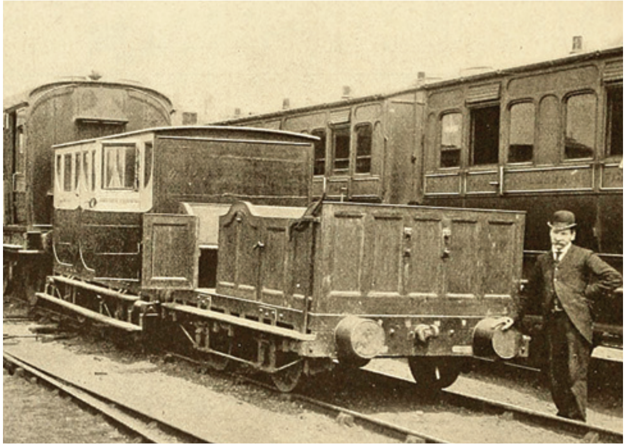

Fig. 5. A photograph dated 1896 (a fragment) and signed "The oldest rolling stock in England from the Bodmin & Wadebridge Branch, London & South Western Railway, in use for fifty years", may show the same or similar carriages to those in the National Railway Museum (Fig. 2 and 4) [8]. Possibly, this shows the same or similar carriages as those in the National Railway Museum (Fig. 3, 4)

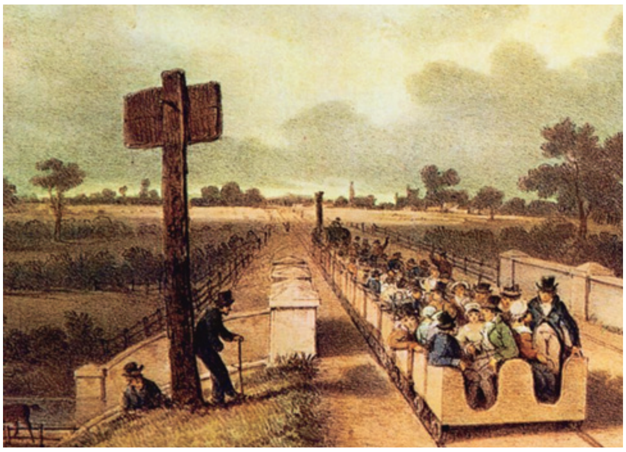

Fig. 6. Third-class open carriages on the Liverpool & Manchester Railway. "View of the Liverpool & Manchester Railroad" (crosses Bridgewater's canal). Print. lithograph. Fragment. (Clayton). Science Museum Group Collection. The Board of Trustees of the Science Museum [9]

which travelled along designated routes and according to an announced schedule.

The authors failed to find in the available sources any description to conclude that any carriages similar to stagecoaches (European, American, Australian, etc.) that would operate on the principles of European stagecoaches traveling between stage stations with the change of horses, were in use in India on a regular basis for passenger transportation. On the Internet, the authors found several photos taken in India by English photographers, probably at the end of the 19th century, which show open carriages resembling stagecoaches with camels harnessed to them[3].

In European countries, the United States, and Australia, stagecoach travel was available to everyone for a set fee. Depending on the class of transportation, carriages had seats for four or six passengers inside. In stagecoaches, in addition to seats inside the body, passengers could sit on the roof of the carriage[4] where the fare was cheaper (*Fig. 8*)[5].

The first railways also attempted to transport passengers in seats placed on the roofs of carriages. However, unlike stagecoaches, on which travelling on the

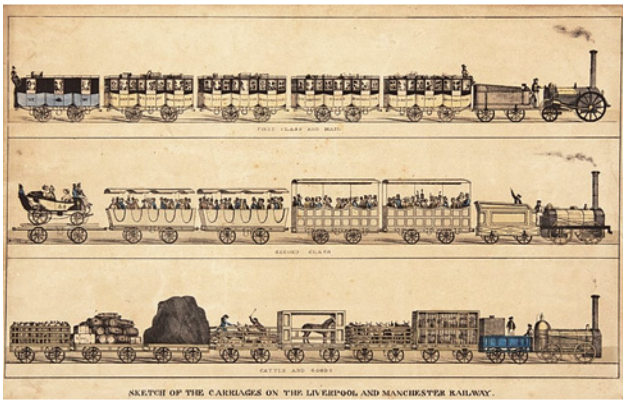

Fig. 7. Lithograph titled "Sketch of carriages on the Liverpool & Manchester Railway" and subtitled "First Class and Mail", "Second Class" and "Cattle and Goods", by W. Crane, Chester, c. 1830.
Let's pay attention to the fact that the middle picture shows an open platform included in the train, on which a crew with passengers is installed. This type of travel was available to wealthy people who travelled by train in their own carriage without horses, which were hired at the terminal station [10]

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[3] Photos are available at: https://www.dreamstime.com/vintage-photo-twin-camel-stagecoach-jaipur-state-rajasthan-india-asia-vintage-photo-twin-camel-stagecoach-jaipur-image238579899 and https://www.bridgemanimages.com/en-US/english-photographer/camel-carriage-india-b-w-photo/black-and-white-photograph/asset/877775

[4] In France, and then in other countries, these relatively cheap seats, compared to those inside the carriage, received the joking name "imperial" (French: Impérial) as "elevated above all, located in the carriage above all". In Russia, imperial was a place on the roof of a stagecoach or horse-drawn tram carriage. According to modern English-Russian dictionaries the word "imperial" is defined, as its first meaning, as seats on the roof, seats on the first floor of a stagecoach, omnibus, bus of a railway carriage.

[5] According to numerous published materials, in particular engravings, drawings and photographs, postal stagecoach carriages often carried up to 8–10 passengers on their roofs.

Fig. 8. James Pollard (1792–1867) Coaching: Stage Coach & Opposition Coach in Sigh. Aquatint, hand-coloured. 1819. The Yale Centre for British Art. The drawing shows that in addition to the coachman, the top of the stagecoach, including the roof, accommodated nine passengers[6]

Fig. 9. A preserved historic double-decker double-axle carriage with the imperial of the French railways. The ground floor of the carriage has four eight-seat compartments occupying the full width of the carriage body, each with individual exterior doors. The 36-seat imperial (first floor) is an open compartment (without side walls) with wooden benches[7]

Fig. 10. Bombay, Baroda and Central India Railway's third-class double-axle double-decker open carriage. (Image: Getty Images) 1860s. A section of the carriage clearly shows that the first floor, where the stairs led to, has a low ceiling, which allowed passengers to bend down to pass or sit on the benches [12]

roof was a common, widespread and, one could even say, mass phenomenon, the idea of passengers travelling on seats located on the roofs of railway carriages was not particularly widespread, with the exception of France. Steam locomotives spewed smoke and sparks, which made the passengers' stay on unprotected roofs not very pleasant and even dangerous[8].

Nevertheless, in France, double-decker carriages, rather than just roof seats, became quite common. Until the 1870s, more than 200 such carriages were in use.

Open double-decker wooden third-class coaches with a roof and unglazed windows, which were common on the first railways in India, were used by the poorest passengers (*Fig. 10*).

DEVELOPMENT OF PASSENGER CARRIAGE DESIGN WITH ISOLATED COMPARTMENTS AND SEPARATE EXTERNAL DOORS

At the initial stage of railway development in most countries, and until the end of the 20th century in India, carriages commonly had isolated compartments, which were not connected to each other: there was no passage along the carriage. The first carriages built on the example of stagecoaches usually had three or four sections (compartments) with seats across the body that were designed for three or four people, depending on the class of the carriage. In the first-class carriages, there were upholstered armchairs, the second class offered hard wooden armchairs, and the third–class coaches had wooden benches. No passage (corridor) along the carriage was arranged, with each compartment having its own individual external doors for boarding and alighting of passengers, which made it possible for a passenger to go out to a platform during a train stopover at a station or to an "open field" during the journey (*Fig. 2, 11–13*). Let us place a special focus on such carriages, as they were popular with passengers in India until the end of the 20th century.

The operation of compartment coaches with outside doors for each compartment posed a number of problems for both operators and passengers. These problems eventually led to a decline in the number of such carriages on most of the world's railways in the late 19th century. India was among the last countries to abandon them — here they were in use and popular with passengers until the late 1990s. Let us consider

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[6] Yale Center for British Art. URL: https://upload.wikimedia.org/wikipedia/commons/d/d7/James_Pollard_-_Coaching%2C_Stage_Coach_%5E_Opposition_Coach_in_Sight_-_B1985.36.834_-_Yale_Center_for_British_Art.jpg

[7] URL: https://en.wikipedia.org/wiki/Bilevel_rail_car#/media/File:France_Paris_Champs_Elysees_Wagon_a_imperiale.JPG

[8] The early railways attempted to carry passengers' luggage on the roofs of carriages, but fire precautions had to be observed. The burning of luggage from locomotive sparks on the roofs of the first railway carriages in the UK was not uncommon, so guards were placed on the roofs to prevent fires. Figure 2 shows the roof railings for luggage and the guard's position.

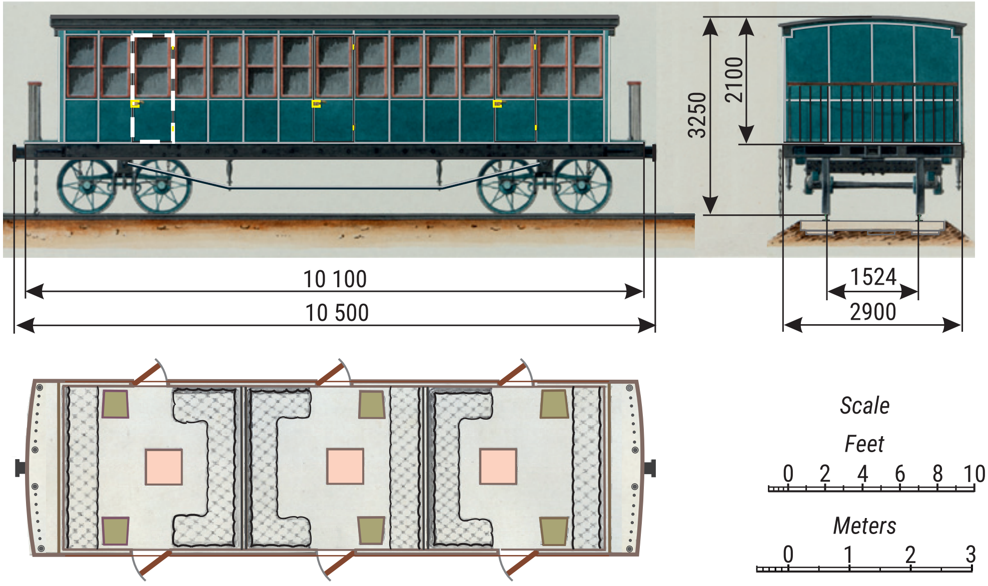

Fig. 11. Small first-class coach with separate compartments with doors for each compartment opening outwards. The St. Petersburg – Moscow Railway. 1851. For clarity, the figure outlines the outer door of the left compartment with a dotted line [13]

Fig. 12. First-class compartment (separated from other compartments in the coach) with its own external doors. The historic Bluebell Railway. The Bluebell Railway is a heritage line. UK. The authors have already noted the lack of handles on the inside of the doors to open the door lock. In order to open the door, a passenger had to turn the handle on the outside of the door by sticking his hand out through the open window[9]

Fig. 13. First/second class mixed metre-gauge coach of the Indian Railways with separate compartments, without a passage (corridor) along the coach body, with each compartment having its own external door. First class compartments – the two outermost doors on the right are labelled "A" and "B" (the letters are shown below the Roman numerals indicating the compartment class). The Nilgiri Mountain Railway is recognised by UNESCO as a world cultural heritage site. The coach has a route plate with the name of the city to which the train is travelling: Mettupalaiyam (in the Coimbatore district of the Indian state of Tamil Nadu). The coach was built in the 1960s. The historic railway is operated for excursion and tourist activities[10]

the disadvantages of such coaches and then turn to the peculiarities of their perception by affluent Indian passengers, many of whom believed that these coaches had significant advantages.

Firstly, in such carriages, the compartments were completely segregated while the train was in motion. It was virtually impossible for either train staff or passengers to walk along the carriage or the train. This made it difficult to serve passengers and protect them while travelling. This design delayed the start of equipping trains with toilets for decades, as it was necessary to place a toilet in each compartment. Although some sources say that it was possible to get from one compartment to another or from one carriage to another

[9] Radlinski, Bob. Photo. 2015. URL: https://www.flickr.com/photos/httpwwwflickrcomphotosbobrad/21908250260

[10] Nilgiri Mountain Railway. Typical rolling stock at Mettupalaiyam. URL: https://www.flickr.com/photos/megaanorak/34004624278; The Nilgiri Mountain Railway. URL: https://www.tamilnadutourism.tn.gov.in/destinations/the-nilgiri-mountain-railway

using the outer step, while holding on (or rather clinging) to the handrails, but it is hardly believable (see *Fig. 9*, *13*).

On the first railways with a short length of routes and frequent stops this disadvantage, apparently, did not bring inconvenience to passengers and service personnel.

A serious problem of carriages with separate compartments was to ensure safety of passengers during the train journey. It is known that stagecoach passengers were often attacked by robbers up to the 19th century [11]. This began to happen to passengers of the first trains, not only in the Wild West of the North American United States, but also in relatively peaceful countries of Europe. Travellers in compartment coaches were ideal targets and easy prey for robbers. There is a lot of historical evidence of how robbers riding horses would catch up with a train, open a compartment door, jump inside the coach, rob the passengers and disappear [14, 15].

By the middle of the 19th century many signalling systems were proposed to signal the train crew not only in case of a threat to the train operation or technical malfunction, but also about an attack of bandits. Various mechanical systems were proposed, including red flags that would unfold when a guard or a passenger pulled a cord to signal the train crew (or signal lights facing the locomotive that would light up red in the night time), electric bells installed in the locomotive cabin that were activated by buttons placed in compartments of carriages, and so on. All these devices were very unreliable and often failed.

The most effective device was the so-called "signal rope", which was stretched along the whole train from the last coach to the locomotive where it was attached to the handle of the locomotive horn. The rope was supported on the walls of the carriages by special rings and any train attendant, guard or passenger could pull it by sticking their hand out of the window. Pulling the rope would turn the handle of the locomotive steam whistle which signaled the Locomotive driver. These signalling devices appeared in England in the 1830s and were used on many railways around the world in the first decades of the 20th century [16]. However, it happened that bandits, having caught up with the train, would cut the signalling rope in the first place...

Another problem for countries with long cold weather seasons (many European countries, northern areas of the USA, and Canada) was that in the autumn-winter period passenger compartments with doors opening directly outside (no vestibules, entrance platforms, corridors, etc.) were very cold[11].

Clearly, for much of India, the problem of carriage heating was not only irrelevant, but it was opposite as railway passengers suffered from heat. Throughout the existence of passenger railway transport in India and other countries with similar climates, these issues were key to improving train travel conditions.

Just like horse-drawn stagecoaches, the first English and later Indian coaches had doors that opened outwards. This was not essential from the point of view of maintaining a proper air temperature inside the carriage, but from the point of view of passenger safety it required attention. Passengers could inadvertently open the carriage door while moving. To avoid this, in English and later Indian carriages the catch handle that opened the outer door was usually installed only on the outside of the carriage, so as not to accidentally open the door on the move (*Fig. 14*).

In spite of all the above-mentioned disadvantages, the design of a carriage with totally separate compartments and doors opening outwards became widespread on the Indian railways in first- and second-class coaches. These coaches continued to be used in India almost until the end of the 20th century. By that time, most countries of the world had almost completely switched to the use of coaches with longitudinal inner corridors and end entrance platforms (vestibules). In India, until 1908, the outer doors of all passenger coaches opened outwards, which was very dangerous for passengers [17].

The advantage of compartment coaches with external doors for each compartment and without a longitudinal corridor is that it is possible to use the whole width of the coach body for the arrangement of spacious compartments. The corridor inevitably "eats up" 60 to 80 cm of the coach body width.

Historians of the Indian railways note another important factor. For first- and second-class passengers who, as a rule, were very rich people, it was of great importance that with such a compartment arrangement they were completely isolated from the other passengers in their carriage, and more importantly, from the others on the train. Privacy was important for high-ranking passengers[12].

[11] Initially, pseudo-heating of passenger coaches was provided by placing heaters in the form of metal boxes with heated bricks under the feet of passengers in first- and second-class coaches (often at an extra charge). The bricks were replaced at stations as they cooled down. In the 1850s–1870s, stove heating began to be installed in first- and second-class coaches on the railways of Europe, including Russia, as well as in the USA, followed by steam heating with steam supply from locomotives or special steam carriages with boilers.

[12] URL: http://dipakrc.blogspot.com/2015/08/classes-of-accommodation-in-indian_16.html

Fig. 14. Preserved third-class standard gauge carriages with compartments occupying the width of the carriage body on the historic Isle of Wight Steam Railway, UK. The individual outside doors of each compartment open outwards. The photo clearly shows that the side of the door facing the inside of the carriage (the right photo, an enlarged detail of the door) does not have a handle to open the door lock (2), it is only available on the outside (1), which is clearly visible in the left photo. On the right photo: 3 — a traditional for British carriages strap for lifting the movable glass of the door window; 4 — the movable glass of the carriage door window [18]. To open the door the passenger had to stick his hand out of the window and turn the handle of the door lock from the outside to open it

Fig. 15. India Railways — Great Indian Peninsula Railway - GIPR First Class passenger coach with separate compartments and individual entrance doors (no corridor). The door on the far right is probably for a single compartment; the door on the far left labelled “Servants” leads to a service room; the door on the right is probably to the largest compartment designed for several passengers. On the photo you can see that the upper part of the carriage is covered with wooden boards, the so-called “planking”. There was a gap between the planking and the wall which was blown with air to reduce heating of the upper part of the coach by sun rays. The end of the 19th century[13]

Looking ahead, the last, very worn-out broad-gauge first-class coaches with separate compartments (no corridors) and individual external doors built in the 1940s–1950s were withdrawn from service on the Indian Railways in the early 2000s. They did not have air-conditioning but were more attractive to wealthy passengers than the newer-built first-class coaches with air-conditioning systems where compartments opened to a common longitudinal corridor of the coach, which could not provide privacy for the journey [5].

[13] Historical Railway Images. URL: https://www.flickr.com/photos/124446949@N06/48030146788/in/photostream

THE MELTING LUXURY OF ICE... THE FIRST AIR CONDITIONING DEVICES FOR RAILWAY COACHES

Among the various factors determining the comfort of travelling in railway carriages, one of the most important is the air temperature. While in a large part of the countries, the efforts of builders of railway passenger coaches were directed towards solving the issues of heating the rolling stock for most of the year, India faced the exact opposite task.

When the British swaggered into India in the 18th century, they were paralyzed by the sun-charred summers of the country they had colonized.

In letters to their homeland, they wrote that many longed to escape to the mountains for the summer. Others, lost in the bustling cities, indulged in sentimental whining. *Plain Tales of the Raj*, for example, records the grumbling of a certain gentleman named Reginald Savory, "The wind drops, the sun gets sharper, the shadows go black and you know you're in for five months of utter physical discomfort" [19].

The British found various coping mechanisms to tame the season's cauterizing heat. They slept sashed and scarved in water-drenched garments. The wealthiest with power and influence had their servants slosh ice from northern India's rivers and then drew it to the plains at tremendous expense. They hired *abdars*[14] to cool water, wine, and ale with saltpetre. They hung wet tatties (mats) made of cooling khus (a type of grass) on their windows and doors. Ice pits were built and small pots of water placed outside on wintry nights. In the morning, the coating of ice that formed was sliced away and stored in the pits, but this ice was usually too gritty and slushy to be consumed [19].

Only an understanding of this discomfort of the Indian heat for the British colonisers makes it possible to determine the root causes of the newcomers' attempts to arrange artificial cooling of their dwellings and then of train coaches. Travelling around the country to deal with various military, political, organisational, administrative, commercial and other issues was an important part of the service of British colonial officials, military officers, and businessmen. Travelling in trains made the hardships of unbearable Indian summers and sultry monsoons manifest with all their acuteness. The owners and management of the first railway companies began to take various measures to improve ventilation of saloon coaches, first- and, in some cases, second-class carriages. They even made the first attempts to provide primitive cooling of passenger compartments and saloons. Of course, it was not about third- and fourth-class coaches.

In the 1870s (and according to some sources even earlier), experiments of equipping passenger coaches with air cooling devices began. Air cooling is a key issue of comfort in trains in countries with hot climate. The presence or absence of air-conditioning systems in passenger coaches in the Indian railways at present serves, figuratively speaking, as the main divide between two large groups of service classes: the first group is air-conditioned coaches denoted as "AC" (air conditioning[15]) in the class list and in the travel documents and the second group is coaches without these installations.

The first devices for cooling, humidification and dust cleaning in coaches, the so-called Saunders system, which was actually the first air conditioners[16], began to be installed in first-class coaches on the Great Indian Peninsula Railway in 1872 [20].

The operation of the system is based on the method known since ancient times in Persia, China, and India, which was used to cool the air in dwellings. It uses the technology which is known today as evaporative cooling technology[17]. Wealthy homes in India also used another method[18], which is realised in Saunders' de-

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[14] Abdar is a table servant in wealthy Indian families and to British military and colonial officers, who was hired to cool down drinks

[15] The use of the abbreviation "AC" for air conditioning units in English texts leads to an amusing situation where its meaning in translations into other languages is distorted, because in English the abbreviation "AC" is most often understood as "alternating current". As a result, translations often translate the original text "AC railway carriage" (a railway carriage with air conditioning) as "alternating current railway carriage".

[16] Saunders. It can be assumed that this is the surname of the inventor of the system, but the authors have not been able to find reliable information on that.

[17] It is successfully applied in dry and hot climates and is based on the effect of air cooling by water evaporation. For this purpose, shallow cellars (wells) were built under houses, in which they placed many porous ceramic vessels filled with water which formed a water film on the outer walls of the vessels. The cellar was connected by an air duct to the dwelling, from which a high ventilation pipe removed warm air by natural draught. This caused rarefaction in the room, as a result of which the air from the cellar was sucked into the room, and the dry and hot outside air was sucked in. It evaporated moisture from the surface of the vessels, as a result of which it cooled and moistened before it entered the dwelling.

[18] The idea is that the air from outside the building, which has a naturally high temperature, is channelled into the interior, while being forced (blown by draught, primitive fans or punkahs) through an artificial curtain of tattis (mats) called "khus khus". They are woven from the roots and stems of several common plants, notably Saccharum Munja, Bambus nana, Vetiveria Zizanioides, and Setariapumila. Sources note that in khus khus mats, these plants can be used both all together and in various combinations.

vices, which were used to equip first- and sometimes second-class coaches. A wide air duct was laid along the coach body, with funnels extending to the end walls installed at each of its opposite ends. During the journey, the inlet socket of the air duct on the end wall of the coach directed in the direction of movement was opened, and the one at the opposite end was closed. The air was forced by the pressure of the moving train into the duct and distributed to compartments, passing through water-wetted khus khus mats. The Saunders' system also included ventilation baffles on the roof of the carriage, which, when the train was in motion, created a draft and sucked air from the interior. The resulting rarefaction increased the supply of air to them via khus khus mats [5].

In addition to these relatively complex systems, primitive devices using ice were used to cool the air in first- and, rarely, second-class coaches on the Indian railways[19] almost from the first years of their existence. For the purposes of ice delivery, distribution and sale, railway companies created administrative, transport and logistics structures that usually used the facilities of ice trading companies opened in India in the late 1830s.

Let us recall that attempts to deliver ice, which was a "melting luxury" in the hot tropical environment of India, as the Russian researcher S.E. Sidorova aptly put it [21], from the Himalayas to palaces of the nobility were made since the 17th century. It required colossal expenses and was a rare phenomenon. The late 18th and early 19th centuries, largely under the influence of the needs of English colonisers, who suffered immensely from the dry hot climate [19], saw the active development of "cooling technologies" of abdars using saltpeter[20] and sulphuric acid that were known from antiquity and passed from generation to generation, and also the art of making ice (art is the word, as it is difficult to call it otherwise) in porous clay vessels which were placed in the hollows of the soil in the morning hours. Thin plates of ice that formed on the surface of the vessels were called hooghly ice[21].

The real "ice revolution" in India, as well as in a number of other countries with hot climates, was brought about in the 1830s by Frederic Tudor (1783–1864), a Boston businessman who made ice an ex-

Fig. 16. Harvesting morning hooghly ice in ice pits at Allahabad. Fanny Parks. Wanderings of a Pilgrim in Search of the Picturesque (1850)[22]

pensive but basically affordable commodity for the wealthy classes of colonisers and rich Indians.

On 6 September 1833, the sailing ship *Tuscany* docked in the port of Calcutta and its arrival created a furore and became news that overshadowed other events for a while... On board was a cargo that aroused admiration, surprise, and delight in the British colonists watching it unloaded. And for many Indians, who had never seen snow or ice before, this spectacle created amazement, incomprehension, and even fear and awe. They came into contact with (literally "touched") something supernatural.

Blocks of transparent ice were unloaded from the holds of the *Tuscany*. More than three months ago, on May 12 of the same year 1833, the ship set sail from Boston, USA, with 180 tonnes of ice on board, which was harvested in winter on the lakes of Massachusetts and stored in icehouses. On the ship *Tuscany* the ice was loaded into storage tanks in the form of huge boxes with double wooden walls and double bottom. The space between the walls was filled with insulating material — crumbs from cork oak processing waste, sawdust, etc. On the way from Boston to Calcutta, about 80 tonnes of ice turned into water, which was pumped overboard with pumps, but about 100 tonnes reached their destination[23].

[19] As well as in other regions with hot climates, including a number of US states.
[20] Ammonium nitrate is a common fertiliser with a low price which is mixed with water in the mass proportion of water and nitrate of 60 % to 40 %. When dissolved in water, nitrate absorbs a large amount of heat. While table salt when dissolved lowers the temperature by 3 degrees, the same amount of saltpeter will lower the temperature by 23 degrees.
[21] Named after the locality of Hugli-Chuchura or Hooghly-Chinsurah in the state of West Bengal, where this production was first created.
[22] American Ice in British India: the art of keeping cool! *By The Heritage Lab*. 2022. URL: https://www.theheritagelab.in/icebritish-india-art/
[23] The first unloading of ice was indeed a sensational event. Many Indian loaders, as well as curious onlookers, got "burns" trying to hold shards of the never-seen-before substance in their hands. Funny things happened — several rich people who had bought ice demanded their money back when it melted.

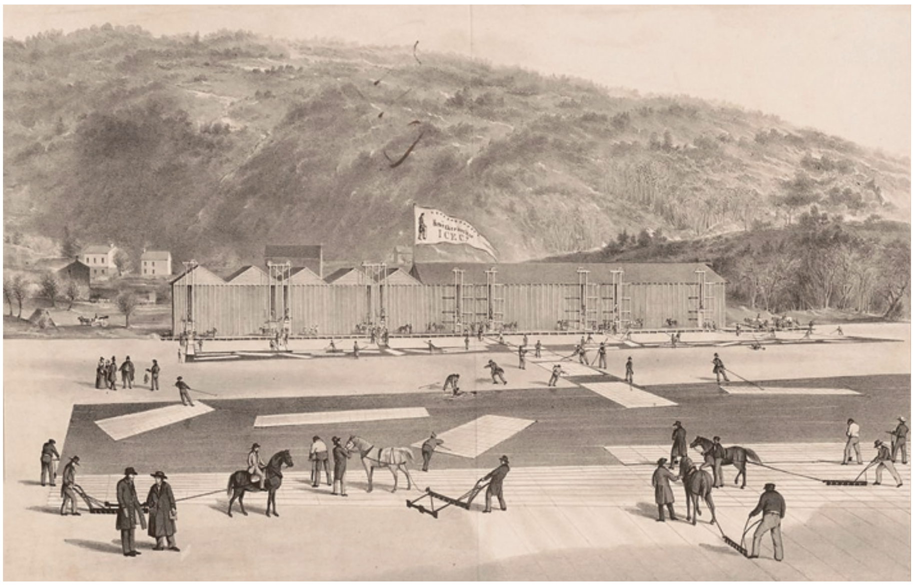

Fig. 17. Ice harvesting at Rockland Lake, NY, USA. Around 1846. The Library of Congress/LC-DIG-PGA-06287[24]

This voyage of the *Tuscany* marked the beginning of the successful supply of ice harvested in winter on New England lakes near Boston to India which continued until almost the 1890s. In his system of harvesting, storing, selling, and shipping ice Tudor materialized an idea that was initially derided by many. The ice trade earned him an enormous fortune and the title "Ice King"[25] [22, 23].

At that time, India exported more goods to the US than it imported. As a result, ships were sent to the US fully loaded and returned, as a rule, half-empty. This virtually worthless carrying capacity utilised by Frederic Tudor made it possible to minimize the cost of shipping ice from the US to India. Tudor built large icehouses in Calcutta, Mumbai (Bombay), and Chennai (Madras) where he stored ice delivered from Massachusetts.

The simplest way to cool the air in a coach was to place an open galvanised metal box with pieces of ice weighing about 50 kg in total in a compartment, which, with the doors and windows tightly shut, reduced the indoor air temperature. Passengers in first- and second-class coaches could pay for and pre-order ice to be delivered to their compartment by the arrival of the train at most major stations in India.

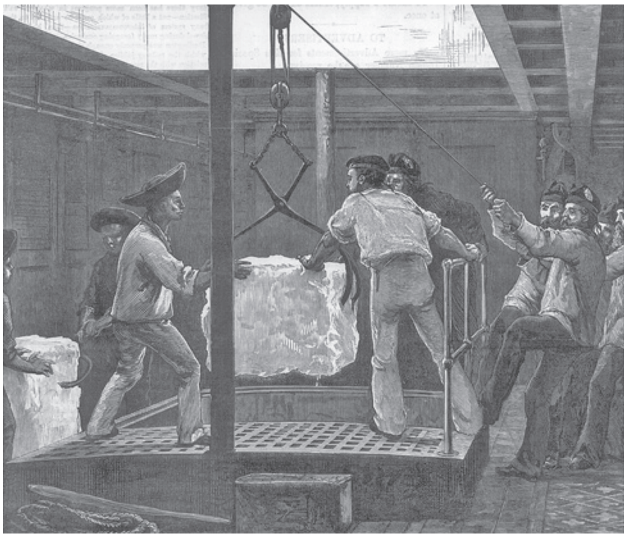

Fig. 18. Sailors unload ice from the ship. Around 1875[26]

In the mid-1880s, electric fans began to be used in homes in advanced countries. At the turn of the 1890s and 1900s, with the spread of electric lighting in trains electric fans appeared in the compartments of Indian coaches. The air jet from a fan was directed at ice boxes

[24] How ice shipped all the way from America became a luxury item in colonial India. URL: https://scroll.in/article/720912/how-ice-shipped-all-the-way-from-america-became-a-luxury-item-in-colonial-india

[25] Frederic Tudor began his research in the first decades of the 19th century by attracting talented inventors to his business. He created a system for harvesting and storing pure fresh lake ice using special tools and the then best heat-insulating materials and built huge icehouses for storing its reserves. By the 1840s, Tudor had created, figuratively speaking, an ice empire that supplied ice to many countries of North and South America, South-East Asia, and Australia. Tudor delivered the purest ice even to England, where by that time the industrial revolution with its thousands of steam engines and steam locomotives had already destroyed the virgin purity of natural ice of rivers and lakes.

[26] The British Couldn't Take India's Heat, So They Imported Ice From New England. URL: https://www.atlasobscura.com/articles/how-did-people-get-ice

Fig. 19. Landing Ice at Bombay. Engraving Published in the Graphic, Nov. 1880[27]

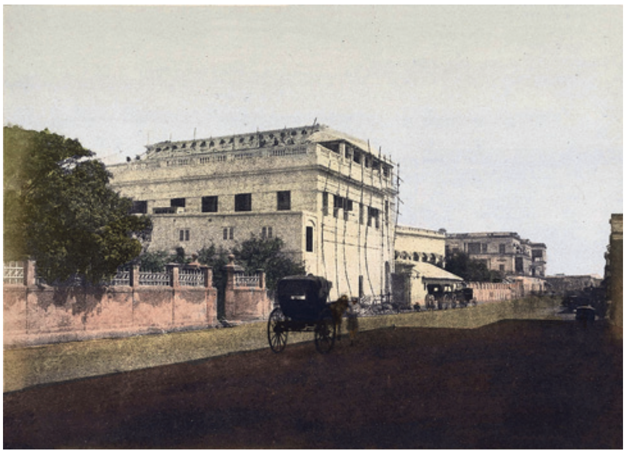

Fig. 20. The Calcutta icehouse built by Frederic Tudor. Hand-coloured print of the Calcutta icehouse from the Fiebig Collection: Views of Calcutta and Surrounding Districts, taken by Frederick Fiebig in 1851[27]

to accelerate the circulation of cooled air. This method was used as late as the late 1950s. In those years, ordering artificial ice for carriages was cheaper than travelling in carriages equipped with air conditioning systems which had appeared by that time. The fare for these coaches was about twice as high as in ordinary carriages [5].

During the first half a century of its existence, the Indian railways became an efficient transport system forming the basis of the economic life of the colonial country which was aimed at draining the colony of its wealth in every possible way for the benefit of the mother country and robbing the indigenous population. By the 1860s, the Indian railways operated 77 steam locomotives, 228 passenger coaches, and 849 freight cars. All of them were delivered from Great Britain by sailing ships along the route around the Cape of Good Hope [1]. At the end of 1864, the length of Indian railways (in total, including railways of different gauges) was 4,739 km [24].

CONCLUSION

During the first half-century of the existence of railways in India, an efficient system was established for providing comfortable travel for colonial officials, local government officials, British servicemen and wealthy Indian businessmen. By the beginning of the last decade of the 19th century the level of service in first- and second-class carriages on railways in India became quite comparable with the comfort of travelling on the railways in its parent country and other leading countries, and the first air cooling systems began to be used in passenger carriages.

As the volume of railway passenger traffic increased and broader masses of the Indian population, most of whom were in poverty, got access to it, the gap between the conditions of travel in palaces on wheels — saloon coaches and first- and second-class carriages, on the one hand, and third-class and even more so fourth-class carriages, on the other, widened. The latter, according to contemporaries, actually differed little from cattle wagons.

By the end of the first fifty years of Indian railways, these ugly cattle wagons used for carrying people were almost universally withdrawn from service. But as passenger traffic from the poorest sections of the population increased manifold by that time, third-class coaches became so crowded that they soon surpassed the abolished fourth-class coaches in terms of the lack of comfort, unsanitary conditions, and safety for passengers.

At the turn of the 19th and 20th centuries, third-class coaches of the Indian railways became a symbol of injustice, despotism, and the horrors of British colonial rule.

In his book *The Third Class in Indian Railways* written in 1917, the great thinker and politician Mahatma Gandhi presented these coaches as a model of Indian colonial society and unfolded his programme of political struggle for the country's independence, repeatedly using them as an example and symbol in his publications.

The next and final part of the review of the history of Indian railways will show the development of the country's passenger coach fleet in the last decades of British colonial rule and after the country acquired independence.

[27] American Ice in British India: the art of keeping cool! *By The Heritage Lab*. 2022. URL: https://www.theheritagelab.in/icebritish-india-art/

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Experience of Russian-Chinese industrial cooperation on the construction of the Moscow metro

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ABSTRACT The commissioning of the Big Circle Line in Moscow, some sections of which were laid jointly with Chinese underground builders, provided the first experience of interaction with foreign construction contractors on the Moscow Metro. The paper investigates this experience which is of value for the development of such works in the future. The analysis was carried out on the basis of scientific and technical documentation on certain facilities, the progress and results of construction and installation works, and information on other events. The paper describes the facilities where construction and installation works were carried out by joint efforts and shows the peculiarities of interaction between Russian and foreign (Chinese) metro builders on a number of sections of the Big Circle Line of the Moscow Metro. The achieved results are demonstrated by the example of individual underground stations. The study reveals the peculiarities of material and technical support of works on the sections constructed by Chinese construction contractors. The mutual exchange of experience, technologies, and work management practices along with the application of various tunnel boring machines from both countries (Russia and the PRC) has yielded fruitful results, demonstrated the possibility and efficiency of the direct engagement of foreign tunnel builders at Russian sites in close cooperation with their Russian counterparts, and revealed a scheme for rational division of labour, work management, and logistical support of works.

KEYWORDS: Big Circle Line; Chinese metro builders; metro construction; Moscow Metro; Russian metro builders; tunnel boring machine

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Научная статья

Опыт российско-китайского производственного сотрудничества на строительстве Московского метрополитена

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АННОТАЦИЯ В связи с вводом в Москве в эксплуатацию Большой кольцевой линии, проложенной на отдельных участках совместно с китайскими метростроителями, получен первый опыт взаимодействия с зарубежными подрядно-строительными организациями на Московском метрополитене, исследованный в статье и представляющий ценность для развития таких работ в перспективе.

Анализ проведен на основе научно-технической документации по отдельным объектам, хода и результатов строительно-монтажных работ, информации о других событиях.

Охарактеризованы объекты совместного производства строительно-монтажных работ, показаны особенности взаимодействия отечественных и зарубежных (из КНР) метростроителей на ряде участков Большой кольцевой линии Московского метрополитена, на примере отдельных подземных станций продемонстрированы достигнутые результаты. Выявлены особенности материально-технического обеспечения работ на участках, сооружаемых китайскими подрядными строительными организациями.

Взаимный обмен опытом, технологиями, организацией работ, применения разнообразных тоннелепроходческих механизированных комплексов обеих стран (России и КНР) дал плодотворные результаты, продемонстрировал возможность и эффективность участия зарубежных тоннелестроителей непосредственно на российских объектах в тесном взаимодействии, выявил схему рационального разделения труда, организации и материально-технического обеспечения работ.

КЛЮЧЕВЫЕ СЛОВА: Большая кольцевая линия; китайские метростроители; метростроение; Московский метрополитен; российские метростроители; тоннелепроходческий механизированный комплекс

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INTRODUCTION

Cooperation between Moscow metro builders and their foreign counterparts has a long history and is characterised by great diversity. There were periods when Russian metro builders were directly involved in design and construction works in foreign countries (the Prague Metro [1], the Budapest Metro [2], and the Calcutta Metro [3, 4]); provided advisory assistance to their foreign colleagues (the Beijing Metro [4], the Bucharest Metro [5], and the Belgrade Metro [5]); and trained specialists. For long periods in recent times, cooperation has been limited to the exchange of experience and technology transfer, including within the framework of and as part of events held by the International Tunnelling Association, to the purchase of imported tunnel boring equipment, and so on.

In recent years, the scale and pace of metro construction in the capital of the Russian Federation have increased to an unprecedented extent. The programme for the development of urban transport adopted by the Moscow Government provides for the intensive expansion of its underground component — the underground, the first line of which was put into operation in May 1935 [6, 7]. The Moscow Metro is among the leading underground railway systems in the world in terms of construction rates and a number of operational indicators. Over the past 12 years, the expansion of the capital's underground is characterised by the unprecedented scope and timing with the maximum involvement of scientific, technical, material and labour resources along with the intensive application of achievements of the world's metro construction industry.

As a result, the length of the Moscow Metro has grown 1.5 times. More than 200 kilometres of new tracks, 109 stations and 11 motor-car depots have been put into operation. The works are carried out in the shortest possible time and with high quality. A large-scale pool of research, design, construction, installation and auxiliary organisations is involved. According to the plans of the Moscow City Government, 25 more stations and 58 kilometres of interstation sections are to be put into operation in the near future (by 2027).

In the current context and as part of the strengthening and expanding of cooperation with friendly countries, a decision was made to involve foreign contractors in metro construction works. Chinese metro builders pioneered the initiative, which is natural given the achievements of China in this field along with the long-standing professional ties between Russian and Chinese metro builders who have been cooperating since the very beginning of the emergence of the metro in China [4].

The pace of metro construction in the PRC [8–10] shocks the global specialist community. The first metro in Beijing began to be built three decades later than in Moscow, in 1965. And if in 2006 the capital of the PRC had 114 kilometres of metro, in 2012 there were 442 kilometres, and by 2015 the metro length reached 708 kilometres. By 2020, the task was set to bring the length of the metro in Beijing to 1,050 kilometres, and this is only in one city. The length of the metro network in China exceeds 8.7 thousand kilometres. The underground operates in 47 cities of the country. This is the result of the Chinese Government's programme to build a metro system in every regional centre with a population of more than 1.5 million people. China Railway Construction Corporation Limited (CRCC)[1] plays an important role in the implementation of the programme. CRCC has a 75-year history and is a major construction corporation supervised by the State-owned Assets Supervision and Administration Committee of the State Council of the People's Republic of China (SASAC). This mega-scale construction company is one of the most powerful and largest general construction groups in the world, operating not only within the PRC, but also in more than 130 countries and regions around the world, engaging in contracting, planning and design consultancy, among others. CRCC Corporation has a complete production chain including research, planning, survey, design, construction, supervision, operation, maintenance, investment and financing, and plays a leading role in the design and construction of tunnels and urban railway transport in particular. It employs 267,000 professionals, operates four corporate design institutes, and has accumulated vast experience both at home and abroad which was recognised by many international professional awards and distinctions. CRCC Corporation has extensive experience with information modelling technologies. The company has developed high-quality and modern software for these purposes.

What is of interest is the nature and management of joint works between Russian and Chinese metro builders in the complex urban transport conditions of the Russian metropolis, in the close proximity of the operating underground network and in difficult engineering and geological conditions.

MATERIALS AND METHODS

Within the framework of the Agreement between the Government of the Russian Federation and the Government of the People's Republic of China on the Encouragement and Mutual Protection of Capital Investments, CRCC's subsidiary in the Russian Federation, CRCC Rus LLC, participates in the construction of the Moscow Metro. To date, 11 tunnels of the south-western and eastern sections of the Big Circle Line (BCL) have been built in Moscow under the existing stations Michurinsky Prospekt and Prospekt Vernadskogo, under the motorways Michurinsky Avenue, Leninsky Avenue, and Vernadskogo Avenue, under the railway tracks of the Kaluga direction of the Moscow railways, the Nagatinsky Backwater of the Moscow River, and the Kolomenskoye Museum Reserve; six tunnels of the Kommunarskaya metro line, including under underground utility mains and city motorways — the Moscow Ring Road and Kaluga Highway. The Chinese company built five metro stations in excavations of up to 30 metres deep in dense urban areas.

[1] URL: https://english.crcc.cn/

A special place is occupied by the participation of CRCC Rus LLC in the construction of the largest project of Moscow metro builders, the Big Circle Line. The competition was open, everyone could take part in it. The Chinese firm won. In January 2017, a contract was signed between Mosinzhproekt JSC and CRCC Rus LLC, under which Chinese specialists (mainly employees of CRCC's 16th Department) built three stations of the BCL in Moscow. The Chinese specialists were involved in the construction of Aminievskaya station (including interstation tunnels with tunnelling structures and dead ends behind the station), Michurinsky Prospekt and Prospekt Vernadskogo stations: a double-track tunnel from Nagatinsky Zaton station to Klenovy Bulvar station and further to the transition chamber, and single-track tunnels towards Kashirskaya station. CRCC Rus LLC performed the main construction (tunnelling) works, while finishing work, installation of equipment, installation and testing of traffic control systems and other precise transport systems were carried out by Russian contractors.

To meet these needs, CRCC Rus LLC has set up in-house production of high-precision tunnel lining in Russia. For this purpose, 12 sets of tooling moulds for 6.0/5.4 metre diameter lining and four sets of tooling moulds for 10.5/9.6 metre diameter lining were used. More than 14,000 tunnel lining rings with a diameter of 6.0/5.4 metres and 1,500 tunnel lining rings with a diameter of 10.5/9.6 metres were manufactured and installed.

For the purposes of construction of metro facilities in Moscow, CRCC Rus LLC manufactured in the PRC in accordance with the customer's specifications and delivered to Russia six tunnel boring machines (TBMs): five units with a diameter of 6.25 metres and one unit with a diameter of 10.8 metres. Technical characteristics of the machines are as follows (data for a 10.8 metre diameter TBM are given in parentheses): rotor diameter, m: 6.28 (10.8); diameter of tunnel boring machine shell, m: 6.25 (10.84); length of tunnel boring machine head part, m: 9.5 (11.4); total length of tunnel boring machine, m: 87 (68); total weight, tonnes: 460 (1,700); power, kW: 1,750 (6,000).

For the purposes of transportation from the PRC to Russia, the panel systems were disaggregated into 14 and 40 elements for the TBMs of 6.25 metres and 10.8 metres in diameter and of 2 to 130 tonnes and 5 to 180 tonnes in weight, respectively.

In addition, CRCC delivered to the Russian Federation five Zoomlion T8030-25U full-swing tower cranes[2] of increased lifting capacity: with the maximum lifting capacity of up to 25 tonnes, maximum boom length of 50 metres, and maximum crane height of 45 metres, and two grapple rigs for the construction of enclosing structures using the "wall-in-soil" technology.

For tunnelling of the south-western section of the Big Circle Line, CRCC Rus LLC used five TBMs (ZTE6250 DZ397 "Maria"; ZTE6250 DZ398 "Daria"; ZTE6250 DZ399 "Evgenia"; ZTE6250 DZ400 "Galina"; and ZTE6250 DZ401 "Polina"). Three-kilometre tunnelling work on the BCL section between Nagatinsky Zaton and Klenovy Bulvar stations was performed by a 10-metre long TBM ("Pobeda" (Victory) as a symbol of the long-standing friendship between Russia and China based on mutual support and trust, and as a reflection of the countries' contribution to the victory in the Second World War). The TBM was designed by Chinese colleagues according to the technical specifications developed by Mosinzhproekt in accordance with the hydrogeological conditions at the construction site and taking into account the accumulated experience of using 10-metre shields in Moscow. This method of tunnelling allows for avoiding the construction of tunnelling structures and ventilation shafts and thus does not require additional construction sites to be cleared, which is important considering that this section of the line passes near the Kolomenskoye Museum Reserve.

Interaction between Chinese and Russian specialists in metro construction was not limited only to solving production problems. The exchange of scientific and technical experience is of great value, too. On November 15–18, 2019, the 1st International Conference on Exploration and Utilization of Underground Space (EUUS2019)[3] organised by the Institute of Rock and Soil Mechanics of the Chinese Academy of Sciences (IRSM-CAS) and the State Laboratory of Geomechanics and Geotechnics (SKLGME) with the participation of 30 research institutes and enterprises was held in Wuhan, China. The Russian delegation represented by Mosinzhproekt took part in the conference and made a presentation on the analysis of parameters determining the value of the excess excavation ratio in mechanised tunnelling [11]. Based on the analysis of engineering, geological and technological factors, Mosinzhproekt specialists have developed recommendations for determining the excess excavation ratio depending on the type of soil and diameter of a TBM [12, 13].

Let's take a closer look at the works performed at the BCL facilities.

The section from Prospekt Vernadskogo station to Aminievskaya station (including Michurinsky Prospekt

[2] Crane market. URL: https://cranemarket.com/specs/tower-cranes/zoomlion/t8030-25u

[3] First International Conference On The Exploitation And Utilization Of Underground Space (EUUS2019) In Wuhan, China. *EarthScienceMatters*. URL: https://www.earthsciencematters.com/first-international-conference-on-the-exploitation-and-utilization-of-underground-space-euus2019-in-wuhan-china/

station) of the BCL is 4.63 kilometres long. Engineering and geological conditions of the construction site are classified as Category III (complex): geological processes are widespread and have a determining influence on the choice of design solutions, construction and operation of facilities.

All three mentioned stations are shallow-buried and were built in an excavation for single-track tunnels.

The shallow-buried Aminievskaya station is located within the south-western section of the BCL. Its depth is 15 metres. It is designed as a three-bay structure with two rows of columns and an island platform 163 metres long and 12 metres wide (*Fig. 1*). The axis of the station is orientated parallel to the nearby Aminievskoye Highway. The station is designed to provide pedestrian connections with the railway platform and, via an underground passage, with the opposite side of Aminievskoye Highway.

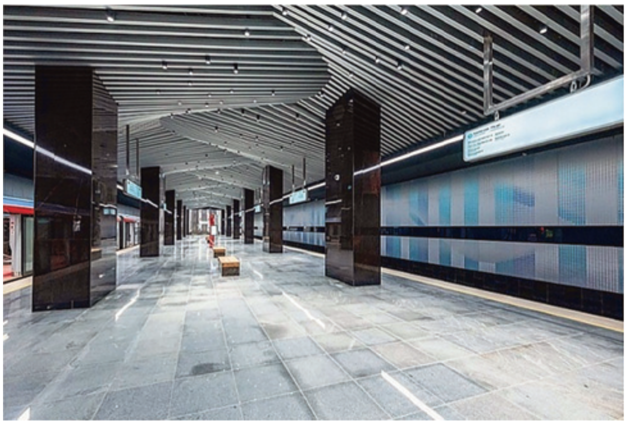

Fig. 1. Interior of the station platform at Aminievskaya station of the BCL (photo by Mosinzhproekt JSC)

The length of the section between Aminievskaya station and Michurinsky Prospekt station is about 1,473 metres. The tunnel route passes under the railway tracks, the Ochakovka River and Michurinsky Prospekt station of the Kalininsko-Solntsevskaya line of the Moscow Metro. The depth of the section ranges between 19.5 and 34.3 metres.

Prospekt Vernadskogo station (*Fig. 2*) has a depth of 17.3 metres. The engineering and geological conditions of the project construction site are classified as Category III of complexity (complex). It is designed as a three-bay structure with two rows of columns on a 12-metre-wide island platform. There are four underground levels. In the central part of the platform, there are stairs for transfers.

Fig. 2. Prospekt Vernadskogo station of the BCL (photo by Mosinzhproekt JSC)

Michurinsky Prospekt station (*Fig. 3*) has a unique layout due to the complex topography of the site and an elevated transfer link to the newly built Michurinsky Prospekt station of the Kalininsko-Solntsevskaya line. It is one of the deepest among shallow stations (with a depth of 19.4 metres and seven underground levels). It is designed as a three-bay structure with two rows of columns on a 14-metre-wide island platform. The architectural solution is dedicated to the Russian-Chinese friendship.

Fig. 3. Michurinsky Prospekt station of the BCL (photo by Mosinzhproekt JSC)

Lifts were installed at all of the three stations — no station complex in Moscow is now built without them.

In addition to the described station complexes of the Moscow Metro, CRCC Rus LLC successfully completed the excavation of 9 tunnels with a diameter of 6.25 metres on the south-western section of the BCL, including the application of unique measures to ensure safe completion of excavation works in the area of the existing structures.

Works were carried out along the Kaluga Highway in the Greater Moscow area (Kommunarka district) from Ulitsa Novatorov station to Stolbovo station in the section from Ulitsa Novatorov station to Kommunarka the tunnelling period, geotechnical monitoring [15] and scientific and technical support of construction were carried out [12, 16, 17].

The tunnels between Aminievskaya station and Michurinsky Prospekt station were built with the help of six-metre-long TBMs “Evgenia” and “Daria”. The tunnel from Aminievskaya station to Site No. 6 in front of Davydkovo station was built by a similar TBM, “Maria”. The same-type TBMs, “Galina” (ZTE6250DZ400) and

"Polina", were used for tunnelling between Prospekt Vernadskogo and Ulitsa Novatorov stations.

All the above-mentioned shields ensured tunnelling by a subsidence-free method in difficult subsurface and hydrogeological conditions in a dense urban setting of Moscow, including the use of unique measures to ensure safe completion of tunnelling works.

Since 2017, CRCC Rus LLC has in total completed the following scope of work in Moscow: tunnelling of interstation tunnels with the use of 6.25 metre diameter TBMs: 15 tunnels with a total length of 19,800 metres, the same operations with the use of 10.8 metre diameter TBMs: 2 tunnels (2,700 m); construction of the main structures of station complexes at 5 stations (225,000 m^3). In addition, CRCC Rus LLC carried out design works for the south-western section from Prospekt Vernadskogo station to Kuntsevskaya station of the BCL.

RESULTS

The experience of the joint efforts of Russian and Chinese metro builders in building new lines and constructing underground stations of the Moscow Metro has demonstrated the efficiency and effectiveness of such cooperation. A rational distribution of design and construction works was practiced taking into account the capabilities and experience of the parties, as well as different regulations in force in the cooperating countries (the Russian rules SP 120.13330.2022 "Underground Railway Systems" and the Chinese norms [18]), customary design and technological solutions, and peculiarities of machinery and equipment. This opens up great prospects for further industrial cooperation.

Large social and economic effects in Moscow have also been achieved. For example, the launch of the new stations Aminievskaya, Michurinsky Prospekt and Prospekt Vernadskogo of the Big Circle Line will save local residents up to 40 % of their daily travelling time in the city; the burden on the existing metro stations will be significantly relieved: by 25 % at Prospekt Vernadskogo station of the Sokolnicheskaya line and by 35 % at Michurinsky Prospekt station of the Kalininsko-Solntsevskaya line.

CONCLUSION

The mutual exchange of experience, technologies, and work management practices along with the application of various tunnel boring machines from both Russia and China has yielded fruitful results, demonstrated the possibility and efficiency of the engagement of foreign tunnel builders directly at Russian sites in close cooperation with their Russian counterparts, and revealed a scheme for rational division of labour and work management.

Cooperation between Russian and Chinese metro builders has great prospects.

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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.

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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.

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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].

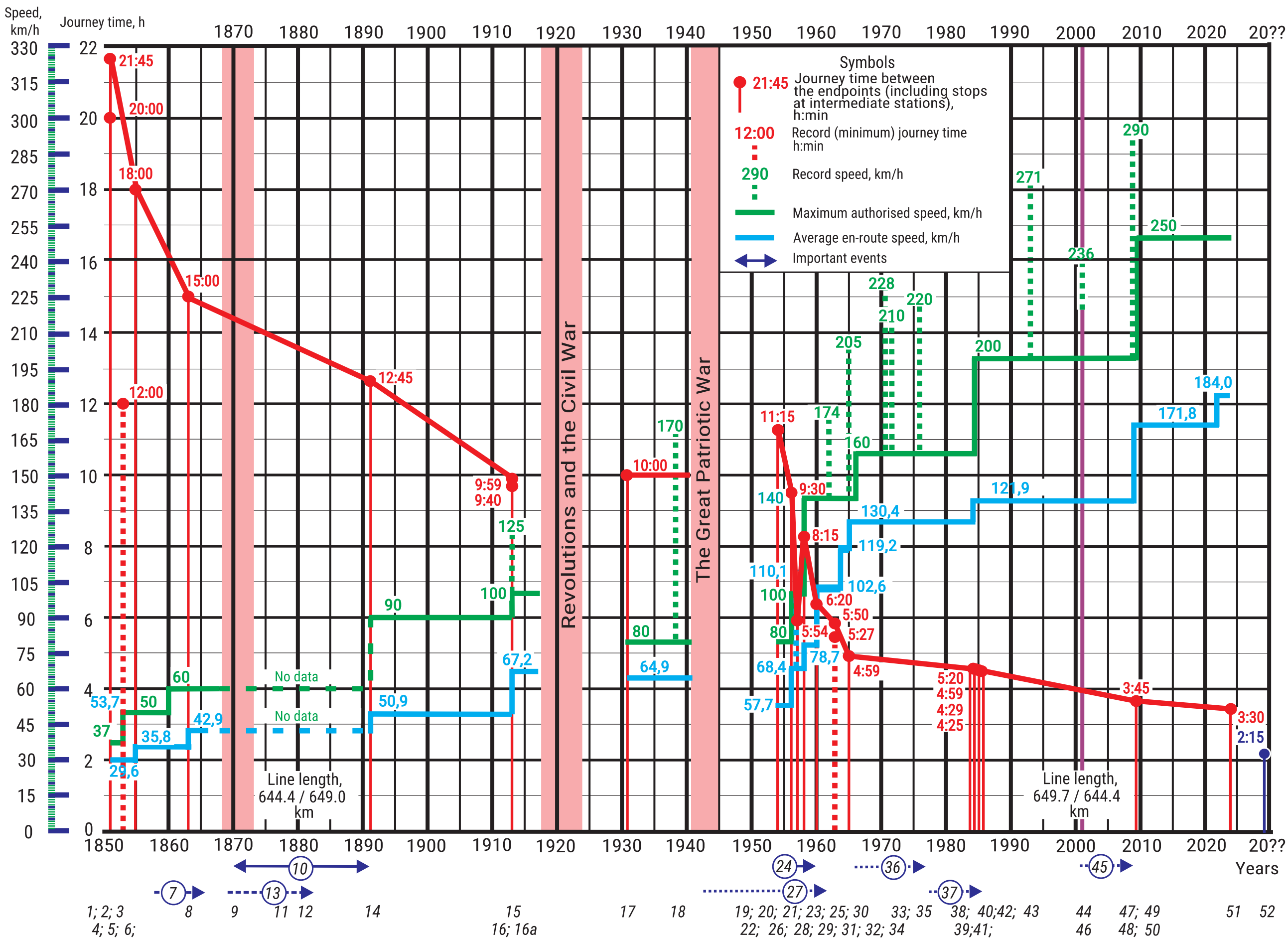
Continued of Table 1

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.

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[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.

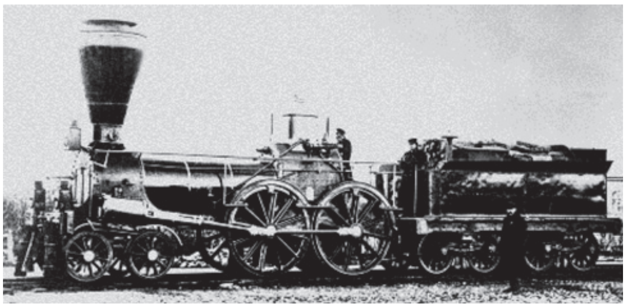

Fig. 1. One of the first passenger steam locomotives of type 2-2-0 of the Saint Petersburg–Moscow railway, 1860s [11]

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]

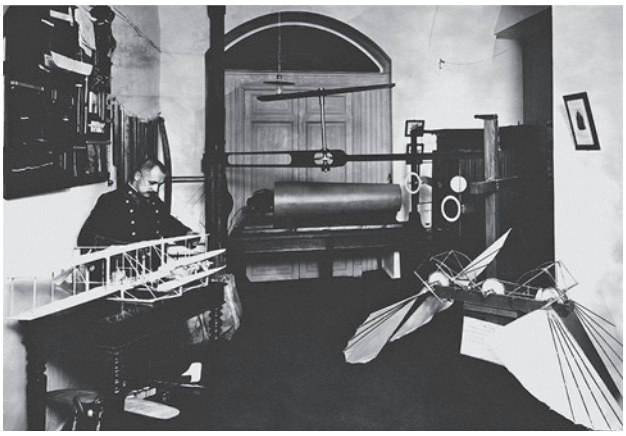

Fig. 3. Aerodynamic laboratory of Nikolay A. Rynin Emperor Alexander I Transport University, St. Petersburg, the turn of the 19th and 20th centuries [11]

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].

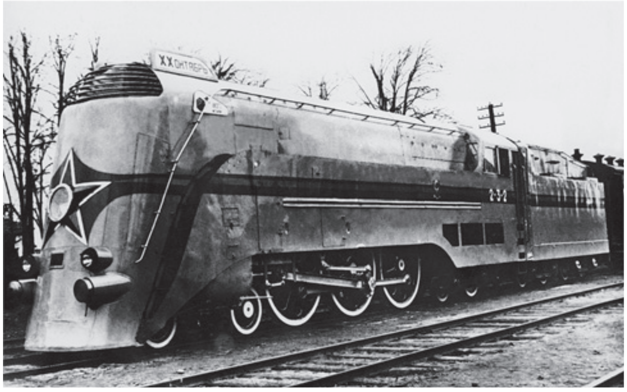

Fig. 4. The first of high-speed steam locomotives of 2-3-2 type by the Kolomna Plant, 1937 [11]

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.

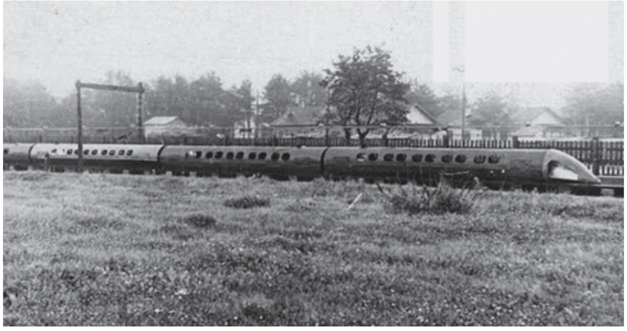

Fig. 5. Experimental ball-bearing electric trough train by Nikolay G. Yarmolchuk on the experimental sharodrom — this was the name of the field testing ground for the new train. Moscow, 1933 [11]

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 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-

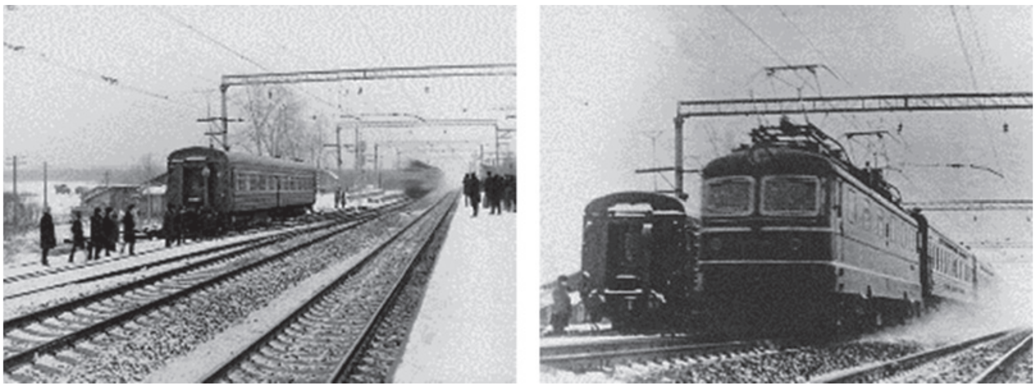

Fig. 8. Testing of a turnout designed by the Design Bureau of the Main Railway Department of the Ministry of Railways and Leningrad Institute of Railway Engineers (LIIZhT) with a movable frog core at Pomeranye station of Oktyabrskaya Railway. A train running at a speed of 228 km/h, 26 February 1971 [11]

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.

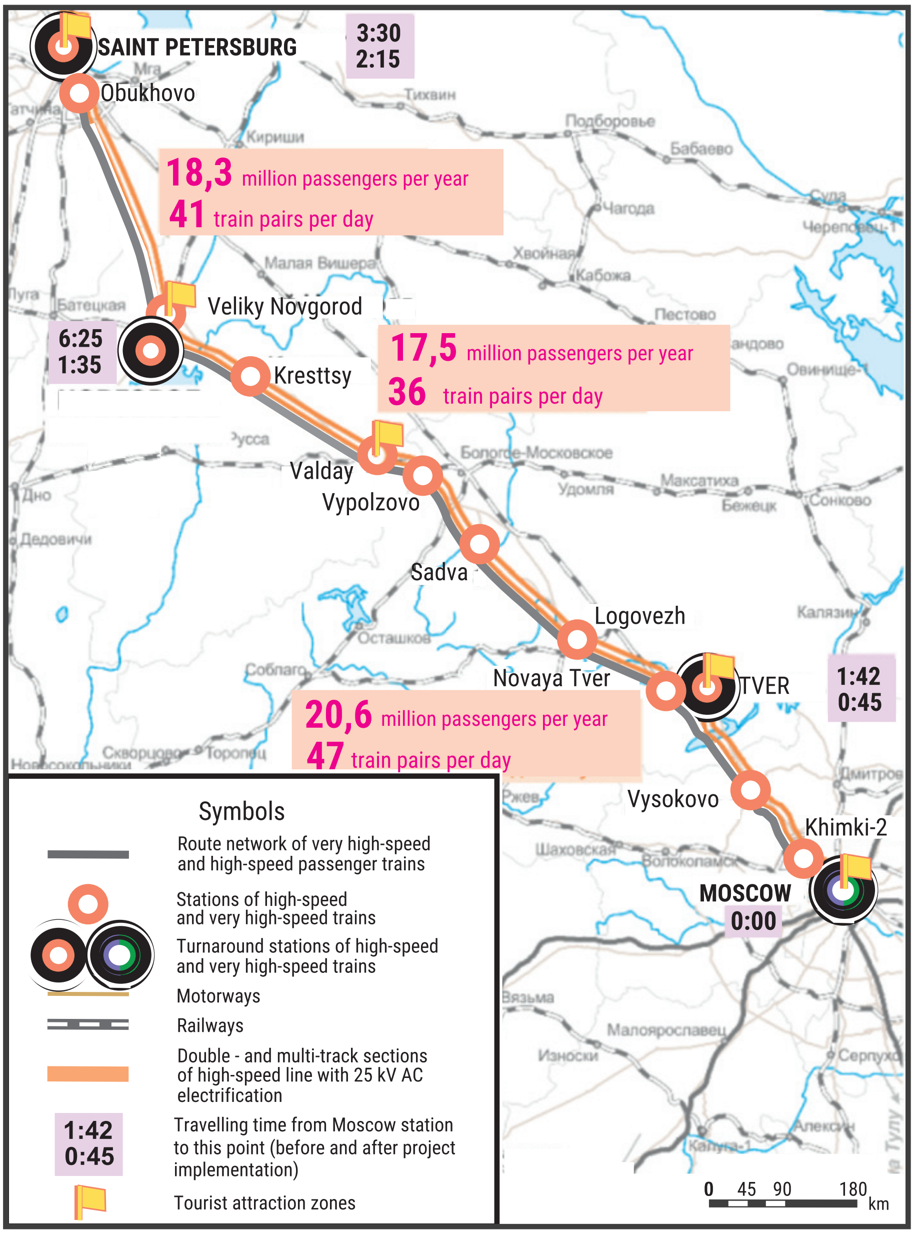

Fig. 15. The Moscow–Saint Petersburg HSL. Route variant from the preliminary materials of the project [37]

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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The specific features of the values and meaning domain and motivation of future specialists in the transport industry

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ABSTRACT Currently, the problem of training highly skilled, competitive specialists equipped with competencies necessary for their future professional activity is of particular relevance. This is key to building a talent pipeline in the transport industry in general and in the railway sector in particular where the activities of the majority of workers involve providing safety and continuity of operations. One of the topical issues is to study their values and meaning domain and motivational attitudes to their future profession as an opportunity to develop techniques of psychological and pedagogical support aimed at forming stable internal motives and optimizing the professional development of future specialists in the transport industry. The purpose of the study is to explore the specific features of the values and meaning domain and motivation of future specialists in the transport industry. In order to study the purpose-in-life orientations, personality traits and motivation of future specialists in the transport industry, a study was conducted with the participation of 50 people aged 20 to 24 years. The following methods were used: the Purpose-in-Life (PIL) Test by D. Crumbaugh and L. Maholick adapted by D. A. Leontiev; the questionnaire for the assessment of personality traits of a professional (LOP) by I.G. Senin and V.E. Oryol; and the Motivation for Success and Fear of Failure (MUN) method by A. A. Rean. The results for interpretation were obtained by mathematical and statistical data processing using correlation analysis (the Pearson correlation criterion). The sense of purpose in the students is associated with the ability to identify significant conditions for achieving goals and everything that happens to them contributes to their personal growth. The more the students perceive their lives as emotionally intense and interesting, the less they tend to perceive their educational and professional activities as a source of stress. Conclusions: Students with clear goals for the prospects of their future professional self-realisation tend to show internal motives for achieving results to a greater extent. The feeling of meaningfulness and productivity of the students' lives is associated with tension they experience in the learning process, conscious control of their actions and behaviour.

KEYWORDS: values and meaning domain; purpose-in-life orientations; personality traits; motivation; specialists of the transport industry

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Научная статья

Особенности ценностно-смысловой сферы и мотивации будущих специалистов транспортной отрасли

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АННОТАЦИЯ В настоящее время особенно актуальна проблема подготовки высококвалифицированных специалистов, конкурентоспособных, обладающих необходимыми компетенциями в рамках будущей профессиональной деятельности. Ключевое значение это имеет для формирования кадрового резерва в транспортной отрасли, в частности на железнодорожном транспорте, где деятельность большинства сотрудников связана с обеспечением безопасности и непрерывным производственным процессом. Один из важных вопросов — изучение ценностно-смысловой сферы и мотивационного отношения к будущей профессии, как возможность разработки технологий психолого-педагогического сопровождения, направленной на формирование устойчивых внутренних мотивов специалистов транспортной отрасли.

Цель исследования — изучить особенности ценностно-смысловой сферы и мотивации будущих специалистов транспортной отрасли. В исследовании приняли участие 50 юношей в возрасте 20–24 лет, студенты технического и экономического направлений подготовки. Использовались: методика «Смысложизненные ориентации» (СЖО) D. Crumbaugh, L. Maholick в адаптации Д.А. Леонтьева; опросник диагностики личностных особенностей профессионала (ЛОП) И.Г. Сенина, В.Е. Орла; методика «Мотивация успеха и боязнь неудачи» (МУН) А.А. Реана.

Результаты для интерпретации получены с помощью математико-статистической обработки данных с применением корреляционного анализа (критерий корреляции Пирсона).

У студентов целеустремленность связана с умением выделять значимые условия для достижения целей и все происходящее с ними способствует их личностному росту. Чем более эмоционально насыщенной и интересной студенты воспринимают свою жизнь, тем меньше они склонны воспринимать свою учебно-профессиональную деятельность как источник стресса.

Студентам с четкими целями перспектив будущей профессиональной самореализации свойственно в большей степени проявлять внутренние мотивы на достижение результата. Ощущение осмысленности и продуктивности жизни студентов связано с напряжением в процессе обучения, сознательным контролем своих действий и поведения.

КЛЮЧЕВЫЕ СЛОВА: личность; ценностно-смысловая сфера; мотивация; мотив; смысложизненные ориентации

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INTRODUCTION

In modern realities, it is usual for a person to face increasingly complicated tasks of defending their values and forming a reality of new meanings. This is largely due to the fact that the unstable situation in the world along with changes in socio-economic relations in society dictate new requirements for the quality of training of future professionals. As a branch of social production, transport, with railway transport being one of its most important segments, makes its special demands. The quality of training and subsequent professional self-realisation of prospective specialists in the transport industry depend on a deep and subtle understanding of their aspirations, meanings, and motivation as students. In turn, the levels of discipline, responsibility, and effective performance of employees directly affect the efficiency and safety of the transport process.

Professional activity of transport industry specialists is associated with the impact of many extreme factors. According to Article 14 of the Federal Law No. 426-FZ dated December 28, 2013 “On Special Assessment of Working Conditions”, these factors include high intensity of work due to information load; noise; vibration, etc. All this increases the risk of disruption of adaptive processes in the human body and contributes to the development of various diseases and reduced professional longevity.

In this regard, professional activity in the transport industry places high demands on the psychological qualities of its specialists. This activity has a special influence on employees, affecting their subjective world, shaping their personality traits, values and meaning domain, motivation, etc.

Based on studying the problem of the values and meaning domain and motivation in scientific research, it can be stated that a degree to which the personality structure of a future transport industry specialist is developed affects their level of self-regulation in extreme situations. The level of self-regulation is largely provided by the adaptation to the conditions of professional activity of railway transport specialists and depends on their value and purpose-in-life orientations and motivation, which is reflected in high-quality performance of their professional tasks.

The relevance of this article is caused by the problem of insufficiently clear idea of the future profession in students at all stages of training in higher education. The knowledge of stable internal motives, values, and personality traits will allow us to identify the main directions of psychological and pedagogical support of students in order to assess the psychological constructs that influence the success of future specialists in the transport industry in mastering the profession [1–3].

The analysis of the empirical study results allowed us to assume that in the student years, an individual’s system of life meanings and motivation has a complex structure. Its complexity is determined by the inclusion of various elements of personality: life-meaning attitudes, personal motives, personality traits, values and others. This age period is characterised by an active search for oneself and one's place in modern society; it is accompanied by certain crisis periods and corresponds to the stage of professional formation of a personality in higher education [4–6]. One of the most important tasks of the higher education system is to train a competitive specialist equipped with high-level professional competences, who is capable of defending their system of values and has stable internal motivations.

Many Russian and foreign psychologists have been engaged in the study of personality's purpose-in-life orientations and motivation, including A. Maslow [7], L.S. Vygotsky [8], A.N. Leontiev [7, 8], A.S.L. Rubinstein [8], V.V. Stolin [8], A.R. Luria [8], D.A. Leontiev [8], and others.

According to A. Maslow, a person's essence moves him or her in the direction of personal growth and self-sufficiency [7]. According to E. Erikson, there are some mandatory, consecutive stages in the development of personality, which everyone should pass in their development [8]. Works by D.A. Leontiev combine personality characteristics and life meanings, indicating that aspects of purpose-in-life orientations are a product of personality [8].

Currently, the study of personality, purpose-in-life orientations and motivation is found in works by G.V. Milovanova [7], S.N. Sorokoumova [8], N.V. Bogdan [9], E.A. Garayeva [10], O.V. Gribkova [11], A.P. Kozhevina [12], O.A. Kozhevnikova [13], E.S. Legostayeva [14], M.G. Nikitskaya [15], V.V. Sharok [16], M.S. Yanitsky [17, 18], G. Droessiger [19], and others.

For example, E.A. Garayeva believes that students' motivation is manifested in the awareness of subjects, current needs for self-development and self-discovery that are satisfied through the fulfilment of learning tasks and encourage them to study academic disciplines and master the skills for their future professional activity [10].

M.S. Yanitsky's research offers the "value types" characterised by the orientation towards value systems that are different in their origin and level of development and are distinguished by significant features in the levels of meaningfulness of life, internality, and self-actualisation [17, 18].

The study of the peculiarities of the values and meaning domain and motivation of future transport industry specialists was of special research interest due to the complexity of this structure and practical significance. The study of these psychological constructs that, according to many authors, have a distinct specificity in terms of time perspective, life strategy of an individual, and the regulation of social behaviour opens up the possibility of predicting social behaviour, developing techniques of psychological and pedagogical support, the formation of a hierarchy of values, internal motives, etc. [17, 18].

The aim of the research is to study the peculiarities of the values and meaning domain and motivation among future specialists in the transport industry. The target of the study was students in different training areas.

The hypothesis of the study is that there are differences in the structure of connections between the purpose-in-life orientation scales, personality traits and motivation in students in technical and economic areas of training.

The study involved 50 participants, including 25 students in technical areas and 25 students in economic areas of training (hereinafter referred to as the "students"); these were young men aged from 20 to 24 years old. The study was conducted at the facilities of the Emperor Alexander I St. Petersburg State Transport University (PGUPS).

Empirical data was collected using a set of psychological testing techniques, including the Purpose-in-Life (PIL) Test by D. Crumbaugh and L. Maholick adapted by D.A. Leontiev; the questionnaire for the assessment of personality traits of a professional by I.G. Senin and V.E. Oryol; and the Motivation for Success and Fear of Failure method by A.A. Rean.

MATERIALS AND METHODS

The results for interpretation were obtained by mathematical and statistical processing of data using correlation analysis (the Pearson correlation criterion).

The practical significance of the results of the study lies in the fact that a comprehensive analysis of the values and meaning domain and personality traits in students will allow for determining the mechanisms of maintaining motivation in future specialists of the transport industry. The results of this work can also be useful in planning and managing the educational process, namely for gaining a deeper and clearer understanding of purpose-in-life orientations and motivation of students in order to improve the effectiveness of education and the quality of training of specialists in the transport industry.

RESEARCH RESULTS

The analysis of correlation dependencies in the studied sample has shown that students in technical and economic areas of training have a greater number of correlations in all of the methods. Only significant differences were considered in the study. The analysis of the methods applied has revealed a positive relationship between the indicators of the Goals in Life, Life Process and Motivation for Success scales ($r = 0.45$;

$p \leq 0.05$) among students of technical areas of training. It can be assumed that the more explicit the goals a student sets for himself or herself are and the more he or she is satisfied with the quality of their life, the more he or she is motivated to achieve constructive, positive results ($r = 0.45$; $p \leq 0.05$).

In this group of respondents, the established negative relationship between the indicators of the Life Process and Neuroticism (N) scales may indicate that the more the students perceive their lives as emotionally rich and interesting, the less they tend to perceive their educational and professional activities as a source of stress ($r = -0.43$; $p \leq 0.05$). The presence of a positive relationship between the indicators of the Life Process and Extraversion (E) scales in the questionnaire on personality traits of a professional ($r = 0.46$; $p \leq 0.05$) can be interpreted as follows: the more the students perceive their lives as emotionally rich and interesting, the more sociable, assertive, active and optimistic they are. A positive relationship between the indicators of the Life Process and Conscientiousness (C) scales ($r = 0.53$; $p \leq 0.01$) shows that the perception of life by the students as emotionally rich and interesting correlates with their conscientiousness, discipline, and control of their own actions.

The correlation analysis in the group of students in economic areas of training established a negative relationship between the indicators of the Life Performance or Satisfaction with Self-actualisation and Neuroticism (N) scales ($r = -0{,}59$; $p \leq 0{,}01$), and the Conscientiousness (C) scale ($r = 0{,}49$; $p \leq 0{,}05$) . The results of the study can be interpreted as follows: the higher the students' sense of meaningfulness and productivity of a passed segment of life, the less they tend to perceive their educational and professional activity as a source of tension and stress. These students tend to consciously regulate their behaviour and be disciplined persons.

In this group of subjects, the correlation analysis revealed a positive relationship between the indicators of the Life Performance and Motivation for Success scales ($r = 0.42$; $p \leq 0.05$). The higher the students' sense of meaningfulness and productivity of a passed segment of life, the more their actions are aimed at achieving constructive, positive results.

According to the results of the revealed positive relationships between the indicators of the "Locus of control — Self (I am the master of my life)" scale in the Purpose-in-Life Test and the Extraversion (E) scale in the questionnaire on personality traits of a professional ($r = 0.43$; $p \leq 0.05$), and the Motivation for Success scale in the Motivation for Success and Fear of Failure method ($r = 0.41$; $p \leq 0.05$) in the students in economic areas of training, it can be assumed that the higher the students' sense of controllability of their lives, the more sociable, active, and optimistic they are, and the more their internal motives are aimed at achieving constructive, positive results.

A positive relationship between the indicators of the "Locus of control — Life or Controllability of life" and Conscientiousness (C) scales ($r = 0.44$; $p \leq 0.05$) suggests that the more the students are convinced that their life is controllable and they are free in making decisions, the more disciplined they are and the better they exercise control over their own actions.

CONCLUSION AND DISCUSSION

The analysis of literary sources on the problem of studying the specific features of the values and meaning domain and motivation has shown the complexity of this structure due to the inclusion of various elements of personality, such as life-meaning attitudes, personal motives, personality traits, values, etc. These psychological constructs determine the life strategy of an individual and provide a forecast of his or her social behaviour, which is consistent with the scientific works by M.S. Yanitsky, M.G. Nikitskaya, and S.N. Sorokoumova.

According to the results of the study, the following conclusions can be drawn:

The students in technical areas of training who have clear goals for their future prospects more often show internal motives for achieving constructive, positive results.

Those students who perceive their life as emotionally rich and interesting tend to feel tension in training to a lesser extent; they are more sociable, active and optimistic.

The higher the students' sense of meaningfulness and productivity of a passed segment of life, the less they tend to perceive their educational and professional activity as a source of tension and stress, the more they show discipline and control over their own actions, and the more their actions are aimed at achieving results that are based on their desires.

One of the promising directions for future research will be to analyse and compare the psychological constructs studied in this paper among novice and experienced specialists of the transport industry.

The practical significance of the study lies in the fact that the comprehensive analysis of the values and meaning domain as a multidimensional construct, taking into account its various components, will help to determine the level and mechanisms of maintaining sustainable internal motives for success in mastering profession, will determine the meaningfulness of professional self-determination, and will ensure the improvement of the quality of training of future specialists of the transport industry.

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