UDC 537.1; 621.311
DOI 10.17816/transsyst201843s157-84

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RUSSIA INTEGRATED TRANSIT TRANSPORT SYSTEM (ITTS) BASID ON VACUUM MAGNETIC LEVITATION TRANSPORT (VMLT)

The Russian Federation is located at the crossroads of the trade routes of the Eurasian continent, where a significant volume of the transport flow of the world’s trade is formed. The transport potential of Russian territory, when implemented as an Integral Transit Transport System (ITTS), is comparable to the benefits from the traditional export of hydrocarbons and other raw materials. When analyzing the efficiency of transport systems, the key aspect is the energy approach. The concept of ITTS is considered to be based on all known transport lines and those, which are being developed now, including high-speed vacuum magnetic levitation transport (VMLT). The fundamental problems being discussed are about achieving the maximal speed, energy efficiency and throughput of VMLT. The preliminary findings presented were

Received: 16.10.2018. Revised: 10.11.2018. Accepted: 17.11.2018.
Transportation Systems and Technology. 2018;4(3 suppl. 1):57-84

doi: 10.17816/transsyst201843s157-84

obtained from experiments on the test model of the VMLT route. The conclusion is that there is a need for a deeper study of the properties of magnetic and superconducting materials in extreme high fields, power and speed regimes to search for fundamentally new technical solutions for the creation of VMLT.

Keywords: transport transit corridor, vacuum magnetic levitation transport, integral transit transport system, superconductivity, magnetic materials, energy efficiency.

INTRODUCTION

In the 21st century, the need for a full-fledged realization of Russia large-scale transit transport potential through technologies of trans-Eurasian high-speed land corridors, composed of conventional and designed transport systems (TS), including ultra-high-speed systems based on vacuum magnetic levitation transport (VMLT) was recognized. All available and being developed transport technologies in complex will be able to compile the Integrated Transit Transport System (ITTS) [1–3]. The internal economic results obtained from a truly innovative project, such as ITTS, are comparable with the export of raw materials, traditional for the previous period of the country [4, 5].

The objectives of this work are the follows: firstly, to consider the physical, geographical and technological aspects of the ground, air, maritime, and underwater transportation processes, and try to formulate general physical principles for comparing different types of transport technologies, in particular, the principle of energy efficiency of transport; secondly, to consider the principal limitations for speed and energy efficiency of both designed and already-in-use means of transport; thirdly, to give a brief overview of the current state of development of the fundamentals of VMLT, which ccan probably be a record, both in speed and energy efficiency, and could therefore form the basis for ITTS; fourthly, to describe the preliminary findings of the experimental study of the magnetic levitation process on the test model of the route on the basis of permanent and superconducting magnets.

1. TRANSIT POTENTIAL OF RUSSIA REALIZED BY ITTS PROJECT ON THE BASIS OF VMLT

The uniqueness of Russia in geographical terms is not only in the record area of its territory. In modern geoeconomic and geopolitical conditions, Russia’s uniqueness is increasingly expressed in the fact that that through its territory China can be directly connected with Western Europe by high-speed land transport corridors. At this historical stage, the creation of ITTS with land corridors linking East Asia and Western Europe gives Russia and all the peoples of Eurasia as well

Received: 16.10.2018. Revised: 10.11.2018. Accepted: 17.11.2018.

doi: 10.17816/transsyst201843s157-84

a chance for a qualitative leap in development. For Russia it will also allow to take a new place in the structure of the world.

ITTS will allow to link the South Siberian and Far Eastern regions on the new economic, political and social levels with the European part of Russia. This will ensure the coherence of the country and the regions will receive a powerful impetus for development. The connectivity of the Russian territory on the basis of new high technologies will ensure Russia's position as one of the leading centers of the multipolar world, the country's deep integration into the system of international relations through development and attraction of international traffic flows. Vital interests of Russia correspond to the needs of the Eurasian continent in the creation of transcontinental mainlines, which allow to organize the states located in Eurasia in a qualitatively new civilizational construction.

The Russian Federation is located at the intersection of the shortest trade routes between the countries of Western and Northern Europe, the Middle East and Central Asia, the Asian part of the Pacific region, where a significant proportion of international commodity flows is formed. More than 20 % of the territory of Russia is located beyond the Arctic Circle. At present, 95 % of gas, 75 % of oil, the bulk of nickel, tin, platinum, gold and diamonds are produced over the Polar Circle. The oil and gas potential of the coastal zone and the shelf of the Arctic seas is estimated at more than 100 billion tons, or about 30 % of the world's oil and gas reserves. At the same time, the Arctic is also the most important transport corridor. There are sea routes between the markets of Northwestern Europe and the Pacific region . With further global trade and economic relations actively developing, the accelerated promotion of the Eurasian countries to the world's leading positions in economic, scientific, technical, technological, social relations is possible only by establishing transportation routes of a fundamentally new, innovative type [6]

According to statistics data, in 1992 the overall trade turnover between China and five Central Asian countries (Kazakhstan, Uzbekistan, Turkmenistan, Kyrgyzstan, Tajikistan) was about $0.5 billion. In 2012, 20 years later, this figure, according to the Ministry of Commerce of China, rose to record $46 billion, so there wasan unprecedented 100 times increase. This incredible dynamics shows that in the future China will occupy more important place in the economic development of the Central Asian states. The Economic Silk Road Belt project or the Belt and Road Initiative (BRI), recently announced by China, are able to open new horizons for trade, economic and investment cooperation in various areas [7], inckuding Russia.

The urgency of BRI is also clear due to the fact that today’s Europe is actively looking for outlets for Asian markets and Asia is interested in the European market as well. To implement its BRI, China is creating such global financial development

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Transportation Systems and Technology. 2018;4(3 suppl. 1):57-84
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institutions as the Asian Bank for Infrastructure Investment ($100 billion) and the Silk Road Fund ($40 billion), whose capitals will be used to implement international infrastructure projects. In the coming decades such funds regarding national strategic projects will be beyond the means of any other country except China. Therefore, the unquestionable advantage of ITTS is its financial and economic security [7], which can be beneficial to Russia if it offers interesting and mutually beneficial options for the implementation of the BRI corridors through its territory.

The transition of society to a new technological paradigm determines the emergence of the corresponding system of economic relations, according to which time is one of the main efficiency criteria not only in the evaluation of information flows, but also in the traditional market of goods and services. Essentially, at present the economy of high speeds, which is extremely necessary for modern trade and transport communications, is being actively formed [8].

It is shown in works [2, 3, 9] that standard price of container (TEU) transportation on a route of SEA – Western Europe in the last 2 years fluctuates is within $ 600 – $ 1000. Cargo delivery time through one of the possible components of ITTS, - the route, which is proposed in [9] and constitutes an "under ice" transit transport corridor along the Northern Sea Route (NSR) across the Arctic Ocean, is supposed to be 15–20 days shorter than southern routes. At the same time, according to estimates, the delivery time via the ITTS land route on the basis of VMLT is almost 45 days shorter. Therefore, it can be assumed that even if the market price of such cargo delivery is higher, it will be profitable for the beneficiary of ITTS and the transit country. For the supplier this will also be very profitable as in addition to saving costs, faster delivery gives a number of competitive advantages in commodity markets. In particular, the profitability and competitiveness of the product increases due to the faster positioning of its innovative versions and updated positions of the model range in remote markets, so customer's satisfaction is also growing. The time of container turnover by NSR can be reduced (that makes possible for the supplier to confine with a smaller amount of TEUs), and there are some other reasons for preferring such transportations with faster cargo delivery.

The cargo in transit "freezes" together with the money spent for its production. At the hypothetical loan rate under consideration, even at 3.65 % per annum, 0.01 % of its amount is spent on its daily maintenance. Assuming an average cost of the goods in a container of $ 150 000, each day of the container's stay in transit costs the owner $ 15. For 15 days, it runs $ 225 for 1 TEU, for 46 days $ 690 for 1 TEU. It will be much more profitable for the cargo owner to pay the transit country, for example, an additional $ 200 – $ 500 for faster delivery than to spend an additional $ 225 – $ 690 for servicing the loan.

Received: 16.10.2018. Revised: 10.11.2018. Accepted: 17.11.2018.

Transportation Systems and Technology. 2018;4(3 suppl. 1):57-84
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Therefore, one can safely add at least $ 200 – $ 500 to a standard shipping price of about $ 800. For example, the amount for the transportation of one TEU equivalent on the route Shanghai-Northern Europe through the Arctic ocean for 10–15 days can be $ 1000 or $ 1300 through the ground Russian corridor "ITTS" the based on VMLT and it will be quicker than in 1 day. Given the unprecedented growth in the volume of Internet commerce, Russian international transport corridors (including options for the future Moscow-Kazan-Yekaterinburg railway with the prospect of its extension to Beijing) may become competitive only if they provide very fast and high-efficient delivery of goods, for example, from Vladivostok to the European Union borders.

2. THE TRADITIONAL AND INNOVATIVE TRANSPORT TECHNOLOGIES, COMPONENTS OF ITTS

Accelerating the pace of scientific and technological progress and the globalization of the economy at the beginning of the 21st century is already at variance with the inadequate and limited development rates and possibilities for modernization existing traditional transport systems. There is need to find the effective solutions to this problem, in which the cardinal increase in speed and throughput of transport systems is combined with an acceptable cost and low energy costs for carrying passengers and cargo.

As it is stressed in the paper [5], it is important to take into account that "the size of a large state is determined by the so-called transport theorem linking the size of its territory with the speed of the transport used, and the time through which the system must respond to emergencies arising at its periphery". It also notes that "Russia's prospects are determined by technologies that allow it to sew and master its vast expanses beyond the Urals on the basis of new high technologies." "It would be ideal to provide an economically justified flow of people and goods, for example, from Vladivostok to the center with supersonic speed and a travel time of only about an hour. Neither aircrafts nor conventional high-speed trains solve this task" [5].

Therefore, new approaches to the solution of this problem are urgently needed. These approaches are proposed and published from time to time, but at the same time, the authors of new transport systems try to replace all the transport diversity with the sole one, offering mono-technology. Thus, to solve the problem of year-round operation and increase the throughput of NSR, the authors suggest several options of "mono-technology" transport systems, for example, atmospheric magnetic levitation transport (AMLT), icebreaking fleet, innovative airship systems, the creation of an innovative ice submarine fleet or a system of transport ekranoplans (ground-effect vehicles).

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The problem of accelerating the social and economic development of the northern and eastern regions of Russia can be effectively solved by creating a whole form, which will determine its transition to the path of innovation, the widespread use of modern domestic technology and technique. This will make it possible to implement an industrial breakthrough in the Russian economy, the drive of the Eurasian integration [10].

We can also consider a broader problem of ensuring transport accessibility on the Eurasian scale. The unity of Eurasia will be assuredly ensured and the problem of distances will be solved if this territory is connected by a powerful transport system that should be adequate to the vast distances and diverse natural conditions of Eurasia: from the expanses of Siberia and the Arctic to the steppes of Kazakhstan. The transport system should have elements with extremely high speed, which will allow to "squeeze" distances, making distant economic centers close, as well as routes with high throughput.

To solve the strategic task of accelerated economic development of the Siberian, northern and Far Eastern regions of Russia, it will be possible to use the transport system within Russia itself, in territories east of the Urals. Thus, the new transportation system can begin functioning and give returns already at the first stages of its creation, immediately after putting into operation its main technical components – high-speed vehicles: vehicles not tied to roads, capable of acting autonomously both on land and on water. This technique was created in Russia: these are heavy ekranoplans and air-cushion vehicles that are not tied to roads. Their high speed and range of transportation, high carrying capacity, the ability to deliver goods without transshipment from one type of transport to another directly to the place where the consumer is located, make these machines indispensable both in Siberia and the Arctic and in Eurasia.

The creation of an innovative transport system based on ekranoplans is an alternative to the construction of airfields and roads in undeveloped areas, primarily for economic reasons. This shows a comparative assessment of the costs of implementing alternatives: traditional and innovative. Thus, the cost of construction of the 500 km Obskaya – Bovanenkovo (Polar Urals) railway constructed by Gazprom amounted to 130 billion rubles. 260 million rubles per kilometer. In the recount at the rate of 2007 – 9 million dollars per kilometer. Scheduled until 2017, the volume of traffic on this railway should be 250 thousand tons per year, i.e. 700 tons per day. This cargo flow can be provided by 6–7 Russian ekranoplans of the first generation "Lun", having a range of 2000 km and an aviation speed of 500 km/h. The cost of an ekranoplan of the "Lun" type does not differ from the price of a 500 ton Zubr air-cushion vehicle: $50 million. The construction of a group of ekranoplanes replacing the above-mentioned railway would cost 300–350 million

Received: 16.10.2018. Revised: 10.11.2018. Accepted: 17.11.2018.

doi: 10.17816/transsyst201843s157-84

dollars, which is much less than the cost of five billion. It is worth recalling that this road was built for 20 years, and the construction of the ekranoplan during mass production could take several months. It is not less expensive and long to construct highways and roads on permafrost [10].

So, there is reason to believe that for the development of the uninhabited territories of Russia, the transport support system should be created on the basis of new principles using innovative non-airfield bound means of transport: ekranoplans, air cushion vehicles, etc. In practice, the main mode of transport in these regions is aviation, namely, helicopters, because they also do not need airfields. However, helicopters cannot claim to be a full-fledged vehicle, since they are uneconomical, do not have sufficient cargo capacity and have a short flight distance. But there is an alternative: ekranoplans, since they allow one to solve the problem of economical delivery of goods weighing hundreds of tons with a sufficiently high speed for long distances. So, the effectiveness of the innovative scenario of the development of the transport system for the eastern regions of Russia is quite clear, as well as the promise of this system for solving the transport problem within the framework of the Eurasian Union [10].

But by our opinion, more effective will be the new strategic concept [1–4, 6]. The promising single ITTS must include as a consolidation of the optimal transport intermodality and original basic strategy of ultra-fast supersonic VMLT, all the necessary and adequate set of potentially related existing forms of transport and innovative TSs ("atmospheric" MLT, amphibious, "underwater\ice", ekranoplan, "flying container", aerostat, etc.), each of which is in its optimal functional place, from the standpoint of the general objective.

For the development of ITTS, it is necessary to analyze the transport systems of the future based on the criteria of speed, energy and their transport efficiency [1–4]. On this basis, data on existing and planned modes of operation should be analyzed, and each transport technology should be identified as its "most optimal economic niche" in the overall ITTS. At the same time, it is strictly necessary that the estimates of the transport efficiency of the newly proposed transport systems should be based on physically, technically and economically understandable and justified criteria for their mutual comparison.

3. LIMITATIONS OF VARIOUS TSS AND LIMITS OF THE QUALITY OF VMLT

For traditional ground vehicles, the main limiting factors are low speed, high energy consumption, insufficient transport efficiency, throughput and carrying capacity of transport highways. In particular, for the currentely used wheel-rail

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technology of railway transport, the problems with the successive achievement of two technological limits for the growth of the speed of rail vehicles [11–13] have arisen.

The first limit is associated with limiting the dynamics of acceleration and deceleration of the vehicle, depending on the adhesion of the wheel to the rail and the reliability of the current collectors of the constant and alternating current.

The second limit is connected with the limitation of the possibility of further raising the vehicle speed over 500 km/h due to the increase in aerodynamic resistance to its movement and energy costs proportional to the third degree of the speed achieved.

In the first case, the transition to contactless magnetic levitation transport traffic organization principles [11–14] is logical, in the second case – the transition to VMLT [1–4, 6, 15–18].

The disadvantages and unquestionable advantages of high-speed (about 500 km/h) magnetic levitation technologies realized in natural "atmospheric" environmental conditions, in comparison with traditional high-speed rail technology, are considered in detail in the works of Russian and foreign researchers [11–14]. In the technology of "atmospheric" magnetic levitation transport (AMLT), as the speed of motion increases, the aerodynamic resistance to the movement of the vehicle increases. With the already achieved record speeds of "atmospheric" vehicles over 1000 km/h, aerodynamic resistance plays a major role, and with the further increase in speed, it becomes possible to heat and destroy the structure of the vehicle.

On April 16, 2015, the magnetic cushion train of the Japanese company Central Japan Railway set a speed record, accelerating to 590 km per hour. In March 2016, a speed record of AMLT using airjet thrust was set - more than 1000 km per hour, and the most of the drive power of the vehicle was forced to spend on overcoming the aerodynamic friction.

Let us dwell on the problem of the maximum achievable parameters of VMLT, which was proposed in Russia more than 100 years ago [15]. Since the article emergence [19], many authors have noted that VMLT has very high limiting velocities, possibly limited from above by the first cosmic velocity (orbital velocity) at 7.9 km/s. At the same time, VMLT, in case of successful application of energy recovery, probably needs a record low necessary energy consumption for transporting of a unit of payload mass. Unfortunately, traditional vehicles, including AMLT, are forced to expend a lot of energy, both during acceleration and cruising speed, and during braking. It should be noted that at present it is considered that the maximal quality characteristics of VMLT are not established, and probably depend on a lot of physical, technological, geophysical, biological and system factors that have not yet been taken into account. Consequently, the

Received: 16.10.2018. Revised: 10.11.2018. Accepted: 17.11.2018.

doi: 10.17816/transsyst201843s157-84

study of these limitations represents an interdisciplinary fundamental scientific research and technological problem.

Obviously, a broad search for the most effective solutions to the problem of cardinal increase of the speed and throughput of the vehicle at low energy costs is necessary [1–4, 6]. To achieve this goal, it is proposed to consider a large-scale infrastructural project for the creation of such ITTS based on VMLT, combining energy efficiency, sustainability, speed (including supersonic) of travel of passenger and cargo vehicles that are unattainable in other approaches, as well as high throughput and safety with an acceptable cost of freight and passenger transport [1–4, 6, 16–18].

4. STRATEGIC CONCEPT OF ITTS BASED ON VMLT

The strategic concept of the promising unified ITTS must include ultra-fast supersonic VMLT as consolidation of the optimal transport intermodality and original basic strategy, all necessary and adequate set of potentially related existing forms of transport and innovative TSs (AMLT, amphibious, non-airfield, "underwater\ice", ekranoplan, "flying container", aerostat, etc.), each of which is in its optimal functional place, from the standpoint of the general objective.

Considering the large-scale project of ITTS, the technology of VMLT is an example of convergence of magnetic, superconducting and vacuum technologies for surface land transport, which allows in the future to reach hypersonic speeds at high throughput of the main overpass and record low energy costs due to emerging opportunities, maximize the degree of energy recovery of the vehicle.

The basic principles of the symbiosis of two key ideas − the concept of transport on magnetic suspension in an artificially created vacuum medium inside a sealed pipeline – were first formulated, developed, tested and published by B.Weinberg [15], and later developed in [1–4, 6, 16–18, 35, 36]. Magnetic levitation "atmospheric" transport AMLT is the first stage of development of ultra-high-speed land transport.

In the strategic perspective, wide application for freight and passenger transportation by AMLT and VMLT will open up new opportunities for the creation of intercontinental transport routes, the development of a number of new technological solutions in the field of energy, fiber optic, superconductivity, cryogenic technology, which can significantly change the environmental situation.

For example, a new transport concept of powerful and cost-effective so-called "energy pipelines" on the basis of VMLT was proposed [6]. According to preliminary calculations, they will be able to supply various classes of energy carriers (oil, gasoline, diesel fuel, oil products, etc.) with the speeds of about 6500

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km/h (1800 m/s), at distances of thousands and tens of thousands of kilometers with almost no significant transport losses and with energy costs less than 0.004 kWh/t-km [6, 16–18].

In comparison with the trains of high-speed rail system (HSR), the material capacity of VMLT in terms of one passenger will be less than 1/20 of the material capacity of HSR and the specific energy consumption of VMLT is record low. The cost of creating and maintaining a vacuum is also not too high. According to [16-18], the transportation of 1 800 passengers over a distance of 1km will require energy costs within only about 1 kWh, and in the cargo version, about 0.004 kWh/t-km of cargo.

Recently, Russian developers have proposed innovative, cost-effective and energy-saving design principles of engineering structural elements, various types of power superconducting cables for power supply of equipment systems of VMLT networks as well as experimentally confirmed effective methods of noise-resistant control and monitoring network equipment based on various principles of long-range fiber optic diagnostics and cryogenic fiber sensors [20, 21]. These technologies work steadily and reliably in difficult conditions of combined action of vacuum, low (cryogenic) temperatures, strong influence of constant and variable electric and magnetic fields along the entire length of the route. As noted above, the concept of VMLT represents a synergy of magnetic levitation, superconducting and vacuum technologies for land transport, which allows to reach the vehicle speed of 6 500 km/h and above [18].

Thus, one can conclude, that today the only economically and technically acceptable solution to the problem of energy-efficient speed increase of both high-speed (up to 500 km/h) and ultra-high-speed (from 500 km/h to 6 500 km/h, and mpre) sustainable land transport is the replacement of the wheel-rail system with a magnetic suspension system and the replacement of the natural environment with an artificially created one, in which the aerodynamic resistance of transport will be relatively small. Due to the practical straightness of the route, the time of delivery of passengers and cargo will be minimal. In our opinion, the best solution here can be the creation of ITTS based on VMLT.

5. ENERGY CRITERION OF THE EFFICIENCY OF THE TRANSPORTATION VEHICLE

“We live in the era of upheavals and drastic changes in energy and material economic fundamentals. The era of cheap energy is coming to an end”, ”Some people hope that new technologies such as artificial intelligence, the Internet of

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things and blockchain will extempt workers and minimize production costs.... These optimists do not take into account the colossal infrastructure that will be needed to deploy these innovation technology. Meanwhile, its creation requires even more energy. We should admit that we will not be able to maintain the current level of economic growth. Reaching the current or higher level of energy supply of the economy via using renewable energy in the coming decade will be extremely difficult or even impossible.We will have to take measures to reduce the energy costs of transport" [23]. The realization of any transport project is closely linked and complementary worthy with the development of related energy project: together they make up an inseparable technical and economic unit. Due to the usage of additional generating capacities of 165 GW, by 2020 the transport of Russia will have consumed 54 GW, which is more than current capacities of all hydroelectric power stations of the country [24].

This is why energy economy issues are becoming key factors in choosing the most effective basic systems in any transport system. The optimal composition of the additional transport subsystems included in the ITTS can be determined, among other things, from the analysis of their energy efficiency. Some results of the TSs comparison are given in Tables 1 and 2 (see [1–4, 6] for more details on energy efficiency). The main energy criterion for transportation here is the criterion of specific energy costs for the transportation of a unit of cargo weight per unit of distance. This criterion can be denoted as specific energy consumption (SEC). The value of SEC is determined by the formula:

$$w(\text{SEC}) = N / M \text{ x } V, \tag{1}$$

where N is the useful power of the traction machine (traction motor) of the transport system, in kilowatts (kWs), M-weight of cargo in tons, V is the speed at which the load is carried by the transport system in meters per second (kilometers per second).

With the help of the SEC figure it is possible to solve the problem of determining the perspective directions of development of various modes of transport, including VMLT. Table 1 presents the results of a comparison of the main conventional and advanced modes of transport, including land, sea (water) and air/ Below theis is an estimation of VMLT based on the data [22, 25].

As can be seen from table 1, without taking into account "VMLT", the best parameters of energy efficiency (if not always with comparable speed of transportation) has, according to the selected criterion, the classical type of sea (water) and railway transport. However, the efficiency of VMLT is almost an order of magnitude better than railway transport and better than sea (water).

Received: 16.10.2018. Revised: 10.11.2018. Accepted: 17.11.2018.
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Table 1. SEC (specific energy consumption) performance of transport systems

№	Transport system	Type of transport	Power. MW	Velocity, m/s	Cargo weight, T	w (SEC), kJ/T*km
1	Boeing -747	Avia	71	253	64	4 380
2	Ekranoplan «Lun»	EP	137	138	120	8 333
3.	Ekranoplan «Orlenok»	EP	11	111	20	4 966
4.	Hovercraft «Bora-Samum»	Hovercraft	30.87	28	200	5 512.5
5.	Hovercraft «Jeyran»	Hovercraft	23.25	26	76	11 902.8
6.	Hydrofoil «Vikhr»	Marine	3.5	19.4	26	7 009
7.	Freight train	Railway	4.4	20.0	2000	110
8.	Heavy-weight train with 2 3-section electric locomotives «Ermak»	Railway	19.68	13.56	6 000	235.25
9.	Heavy-weight train with locomotive «Vityaz»	Railway	5.0	16.7	4 000	74.85
10.	HSR mainline (TGV)	Railway	8.8	83.3	50	2 173
11.	Transrapid	MLT	3.53	111	15	2120
12.	Trailer truck	Auto	0.338	22.2	20	761
13.	STY	String	0.040	3.3	4	120
14.	Baltic motor car ferry	Marine	17.6	10.8	3345	487
15.	Tanker Batillus	Marine	190.7	8.3	65500	36.2
16.	Tankers Admiralty Shipyards	Marine	3.36-25.0	6.7-8.2	7 000-70 000	43.4-71.8
17.	Tanker «Oleg Koshevoy»	Marine	1.18	5.4	4 696	46.53
18.	Tanker «Kazbek»	Marine	2.9	6.27	11 800	39.19
19.	Tankers («Prague», «Lisichansk», «Series»)	Marine	13.35-13.98	8.9-9.62	34 640-48 370	32.82-47.3
20.	VMLT (evaluation)	VMLT	0.5 (Impuls 18 sec.)	180	0.4	14.05

Legend of table 1: EP – ekranoplan, HSR – high-speed rail, TGV – Train à Grande Vitesse, STY – string transport of Yunitsky.

The applied energy indicator can be used in the evaluation of the implementation of the transit transport resource of Russia, for example, for some of the transport corridors listed in Table 2.

As a criterion, it is advisable to use the total energy costs for the movement of a ton of cargo from the point of departure to the point of arrival (in kilojoules per ton), i.e. P =w x L (dimension kJ/ton), where L is the distance. The results of comparison of two modes of delivery (sea and rail) for Europe-Asia transit are given in Table 2 on the basis of data [22]. Here is an assessment of a similar Russian transit China-

Received: 16.10.2018. Revised: 10.11.2018. Accepted: 17.11.2018.

Transportation Systems and Technology. 2018;4(3 suppl. 1):57-84
doi: 10.17816/transsyst201843s157-84

Western Europe with the help of the transport system VMLT. From the tables, the advantage of VMLT in all compared parameters is obvious, and target parameter

- P – total energy consumption,
- VMLT is almost 10 times better.

Table 2. Overall figures of specific energy consumption and delivery time for different transport cargo systems and routes [22]

№	Transit Type	SEC kJ/T*km	L , (km)	P, (kJ /T)	Goods delivery time (days)
1	Railway (Russian transit) (China – Finland)	110	10 000	1.1 x 10^6	12 (7)
2	Sea (China – Finland)	54.3	21 000	1.14 x 10^6	28
3	Railway (Russian transit) (South Korea – Western Europe)	110	11 000	1.2 x 10^6	14
4	Sea (South Korea – Western Europe)	54.3	22 000	1.2 x 10^6	30
5	Railway (Russian transit) (China – Western Europe)	110	11 000	1.21 x 10^6	15
6	Sea (China – Western Europe) (Shanghai – Amsterdam)	54.3	23 000	1.25 x 10^6	27-46
7	VMLT (Russian transit) (China – Western Europe) (Shanghai – Amsterdam)	14.05	11 000	1.54 x 10^5	0.1

The legend in Table 2: L is the approximate length of the path, P is the energy consumption per unit of mass.

6. TRANSPORT CORRIDORS OF ITTS

Let us focus on some of the main geographical routes that can become the main transport corridors of ITTS.

DZUNGARIAN CORRIDOR [2, 3]. It currently serves as a railway corridor between China and the West. Among the possible transport corridors, the primary purpose of which is the implementation of high-speed communication between Beijing and Moscow, for many reasons, the Dzungarian corridor, located along the route that had a historical prologue eight centuries ago, is immediately distinguished. This route is the most direct and the most geographically natural from the point of the fastest transportation of passengers and cargo from China to the European part of Russia and back.

THE NORTHERN SEA ROUTE (NSR). In the message of the President of the Russian Federation to the Federal Assembly, the prospects of the NSR are noted

Received: 16.10.2018. Revised: 10.11.2018. Accepted: 17.11.2018.
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doi: 10.17816/transsyst201843s157-84

as follows: – " The Northern sea route is going to be the key to the development of the Russian Arctic and the regions of the Far East. By 2025, its freight traffic will increase tenfold and reach 80 million tons. Our task is to make it a truly global, competitive transport artery" [27]. In 2018, the SMP started deliveries of Russian liquefied natural gas by ice-free sea transport.

In addition to the existing traditional competitive transport capabilities of ITTS, in our opinion, as options for extra innovative transport subsystems, there can be used other systems of ground-lift planes, innovative airships, magnetic freight transport in the port infrastructure and, especially, the recently proposed very interesting option of the submarine/subice fleet, (with vessels, the hull of which are made of heavy-duty "nanoconcrete"), allowing to make year-round navigation on the NSR faster and cheaper [9].

TRAIN ROUTES: THE BAIKAL AMOUR MAINLINE (BAM) AND TRANS-SIBERIEAN RAILWAY (TRANSSIB). In the same speech with regards to BAM and Transsib it is said: "For six years, the capacity of BAM and Transsib will increase by one and a half times, up to 180 million tons. Containers will be delivered from Vladivostok to the western border of Russia in seven days. This is one of the infrastructure projects that will give a quick economic return. The need for cargo transportation in this direction is very high, so all investments will contribute to the development of these territories and will be paid off very quickly. The volume of transit container traffic on our railways should increase by almost four times. Our country will become one of the world leaders in the transit of containers between Europe and Asia" [27].

This can be achieved for a period of T=180 000 000 tons/170 000 tons/h =1 059 h, i.e. in about 45 days, or not more than 1.5 months, with appropriate time of freight haulage of 1 TEU of 3 hours or less than a day from Vladivostok to the western border of Russia. With a full load of the route, the VMLT can transport to 365/45 = 8.111 times more cargo in a year (which is approximately 8 times more). Having accepted the cost of transit of goods received from the carriage of a freight equivalent of 1 TEU of $ 1000, we will receive annual revenues from the VMLT analogue of the BAM and TRS routes in the amount of 8x180 000 000 t / (15t / eq.1TEU) x 1 000 dollars. It equaled 96 billion dollars a year.

To sum up, it can be said that ITTS based on VMLT would not probably have competitors because ,despite the large capital costs, it has excellent energy efficiency and speed. However, its creation raises a large number of fundamental issues that will need to be solved by bringing together experts, both fundamental science and engineers of various industries from material science and physics of magnetic phenomena to geology and geophysics.

Received: 16.10.2018. Revised: 10.11.2018. Accepted: 17.11.2018.

doi: 10.17816/transsyst201843s157-84

7. INVESTIGATION OF VMLT PRINCIPLES

In a number of countries, including Russia, experimental work is under way to study the principles and fundamental capabilities of VMLT [2, 3, 16, 32, 33, 35]. The Moscow Aviation Institute (National Research University) has carried out theoretical calculations and experimental work and has created models of "atmospheric" AMLT vehicles (Fig. 1) [30, 31].

At the Khristianovich Institute of theoretical and applied mechanics SB RAS the computational and experimental modelling of the processes of VMLT were carried out [32, 33]. In particular, the following preliminary results were obtained:

1. The lower boundary of the optimal values of operating pressures in the tunnel of the vacuum transport system, using the existing traditional technical solutions, are estimated in the range of 25÷80 Pa.

2. The main contribution to the aerodynamic resistance is the wave resistance of the VMLT pod. The bottom pressure and friction resistance to the pod walls give a significantly smaller contribution. In case of the pod movement in the channel, two fundamentally different variants of the gas-dynamic flow can be realized.

Here the ratio of the squares of the pod and the channel is an important parameter: θ = SD/Sd, where SD is the area of the channel, Sd – the area of the pod. In some critical areas (when θ = θc) the nature of the flow is changing.

The case is favorable (θ > θc), when the thickness of the gap between the inner wall of the channel and the wall of the pod is sufficient to "swallow" the whole air captured by the pod. In this case, the total resistance of the pod may be even slightly lower than in free flight due to the greater pressure in the aft of the pod (the result of the interference of the pod and channel).

a b

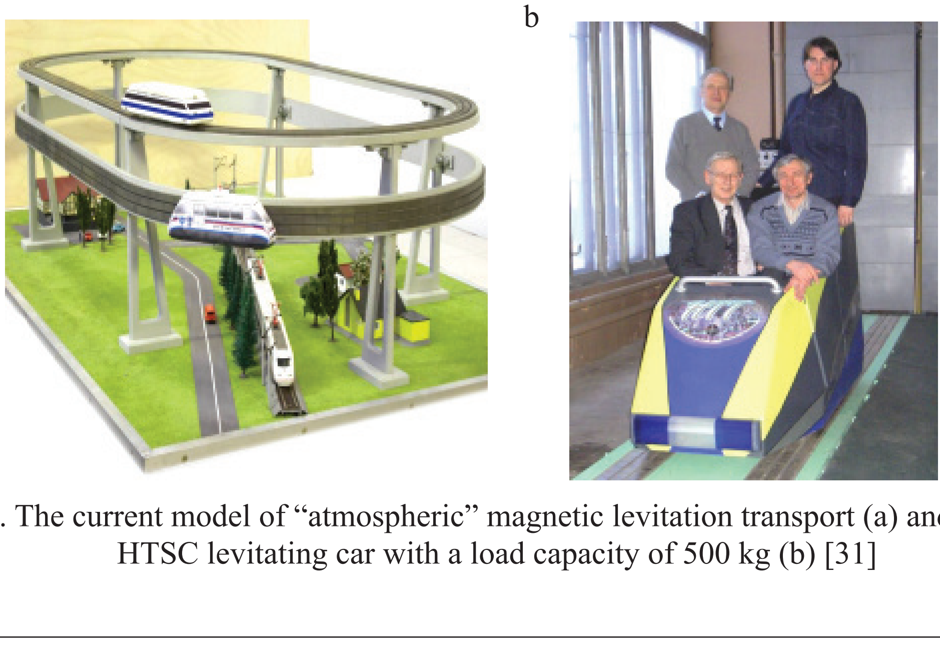

Fig. 1 . The current model of "atmospheric" magnetic levitation transport (a) and magnetic HTSC levitating car with a load capacity of 500 kg (b) [31]

Received: 16.10.2018. Revised: 10.11.2018. Accepted: 17.11.2018.
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The second variant of implementation of VMLT IS unfavorable from the point of view of aero-thermodynamic characteristics. The gap between the channel and the pod is so narrow (θ < θc) that all captured gas is not "swallowed". A flow formed is somewhat similar to the movement of a semipermeable piston in the pipe. The pod pushes most of the gas in front of it. A shock wave in front of the pod forms. Resistance of the body increases sharply.

The number of conservative pods of VMLT, simultaneously located in the vacuum channel, is the determining parameter that affects the optimal pressure of operation of the vacuum transport. The greater the density of the pod is, the lower the pressure limit follows. Conversely, the fewer transport pods on the way there are, the greater the pressure energetically and economically justified is.

3. To improve the overall transport efficiency of vacuum transport it is necessary to conduct a comprehensive optimization of its parameters on the basis of new and innovative technical solutions for each case .

At present, the appropriate experimental installations have been developed and created, where several cycles of computational and experimental studies are planned to be held. A preliminary experimental study of the aerodynamics of the simplest model of a vehicle vacuum levitation transport system in the overpass under conditions of rarefied air flow with Mach numbers from M=0.1 to M=5 on the aerodynamic installation "MAU" in Khristianovich ITPM SB RAS was carried out. Flight simulation is supposed to be performed according to the reversed scheme, when the stationary model is blown by the air flow with the specified parameters.

In the initial, simplified version, the tests will be carried out in the mode of the attached pipeline, with the entrance of the channel-overpass docked to the nozzle of the aerodynamic installation. The output of the channel, the nozzle (200 mm), is connected to a vacuum tank with a volume of 220 m3. The schematic diagram of the experiment and the experimental stand are shown in Fig. 2. To perform the tests, a model of the vehicle with built-in two-component load cells will be made. Currently existing ballistic installation with preliminary calibration experiments is done at a flow rate of up to 400 m/s. In the future it is planned to carry out experiments directly with the same layout using the magnetix track pods, levitating above, with drain-free cryostat and superconducting units inside.

8. THE MODEL OF A MAGNETIC LEVITATION TRANSPORT ON THE BASIS OF HIGH-TEMPERATURE SUPERCONDUCTORS AND RARE EARTH PERMANENT MAGNETS

Researcher’s attention in many countries is attracted to magnetic levitation technologies based on high-temperature superconductors (HTSCs) of the second order, which have the advantages of stable passive levitation, low energy

Received: 16.10.2018. Revised: 10.11.2018. Accepted: 17.11.2018.

doi: 10.17816/transsyst201843s157-84

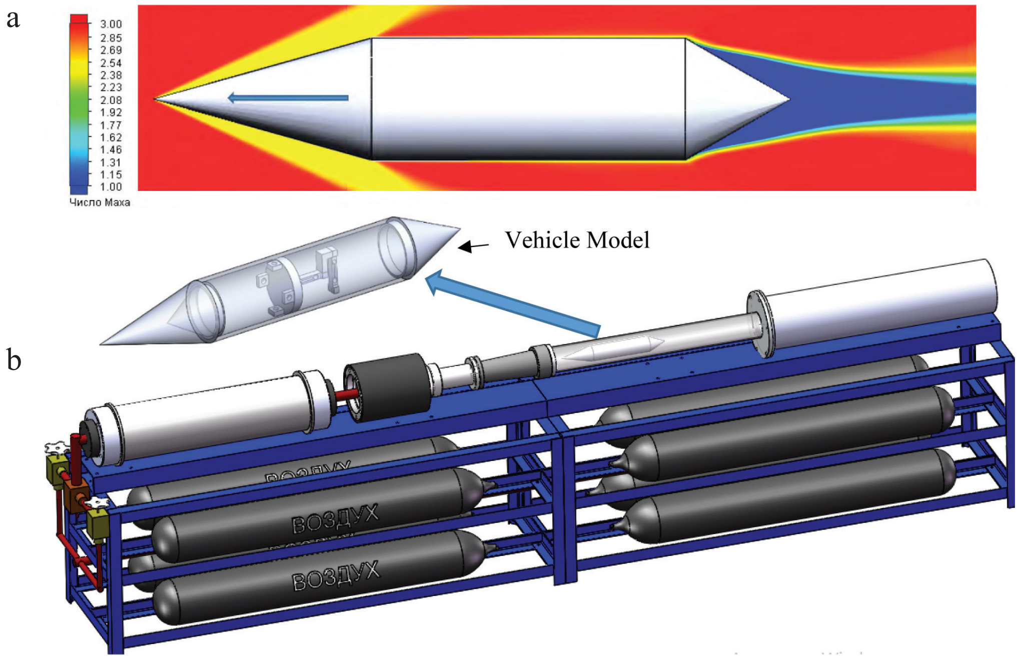

Fig. 2. Thermo-aerodynamic theoretical and experimental modeling of the movement of the layout of pods of VMLT in the rarefied atmosphere. a – calculation of the velocity and pressure of the gas flowing around the model of the pod of VMLT, b – schematic view of the experimental setup for the study of hypersonic air flow around the model of the pod of VMLT [33]

consumption, low noise, potentially high speed and pollution-free operation [28–31, 34–51]. The superconducting ceramics Y-Ba-Cu-O (YBCO), which allows one to create high magnetic fields and demonstrates the superconducting properties at liquid nitrogen temperatures (77 K), is relatively technological and not expensive, is used as a basis in many works. These materials have been used in almost all experimental models of vehicles (manned and unmanned), developed to date. In particular, they were used in the first manned model of a magnetic levitation vehicle tested at Southwest Jiaotong University, China in 2000 [38], as well as in the first AMLT prototype of vacuum magnetic levitation transport in 1914 & 2014 [15, 35] and in a full-scale, 200 m long and in HTSC-based model, built at the Federal University of Rio de Janeiro, Brazil, in 2014 & in Italy [39,40]. A number of important effects have been revealed in numerous fundamental studies of the magnetic levitation process using permanent magnets and bulk YBCO HTSC [34, 41–44].

In recent years, new bulk high-temperature superconductors based on GD-Ba-Cu-O ceramics (GdBCO) with excellent superconducting and mechanical properties have been developed [42-44]. In 2014, it was reported that the permanent superconducting magnet with a trapped magnetic field of magnitude 17.6 T was created, which was assembled from two cylindrical bulk superconductors GdBCO, 24 mm in diameter and 15 mm in height [43]. This result exceeds the achievements of the captured field in YBCO bulk superconductors [44].

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However, many fundamental questions in the field of HTSC materials for magnetic levitation remain insufficiently studied. For example, among them there are the effects of dynamic force interaction between bulk superconductors and permanent magnet guideways (PMGs) [45]. It is very important to determine the maximum possible speed of the future VMLT based on HTSC, to identify the impact of mechanical force and the variable component of a strong magnetic field, manifested in rapid motion and fluctuations on the VMLT route. In particular, the effect of weakening of the levitation force in the systems with bulk superconductors and permanent magnets, moving at a speed of 400 km/h or more was studied in [45–50]. However, at present, such issues as possible instability of superconducting properties and energy loss in systems based on superconductors of the 2nd order with strong fluctuations of power mechanical effects, rapid relative movement of magnets and superconductors and rapid changes in the magnetic field remain untreated.

In Kotelnikov Institute of Radio Engineering and Electronics of RAS with the participation of specialists from Moscow Aviation Institute [30, 31] the experimental small-scale (1.2 m long) model of the AMLT route was made, based on rare earth magnets (REM) PMGs of NdFeB alloy and HTSC ceramics of Y-Ba-Cu-O (Fig. 3, 4).

A distinctive feature of the experimental model of the AMLT track was the implementation of continuous movement of the cryostat with a levitating HTSC element over the three PMG lines (Fig. 3, 4). The original technical solution implemented in the development of the present model is called "magnetic force mirrors" - the elements, for example, of the massive REMs installed on the ends of PMGs. The effect of the “magnetic force mirrors” was to reflect the mobile superconducting HTSC objects - VMLT pods - at the ends and to "multiply" the effective length of the route in above 100 times. The “magnetic force mirrors” present the idea of "energy magneto-kinetic storage and recuperator batteries".

The field measured at the ends of the magnets is approximately 0.3 T. The weight of the cryostat is about 0.27 kg. The resistance to motion is small, allowing the cryostat, once set in motion at a speed of several m/s, to make more than 100 non-stop passes of the track, elastically reflected from the "magnetic force mirrors”.

Cross-sectional view of the model of the AMLT on the base of HTSC is schematically shown in Fig. 3b. Three lines of permanent magnets (NdFeB), oriented as shown in the figure, are fixed on a strip with a length of 1.2 m. At the ends of the strip, as shown in Fig. 3c, there are two massive magnets of the same alloy, creat “magnetic force mirrors”.

During the experiment, the cryostat with HTSCs at room temperature was pre-installed on a non-magnetic stand, of height h above the track.Then

Received: 16.10.2018. Revised: 10.11.2018. Accepted: 17.11.2018.

Transportation Systems and Technology. 2018;4(3 suppl. 1):57-84
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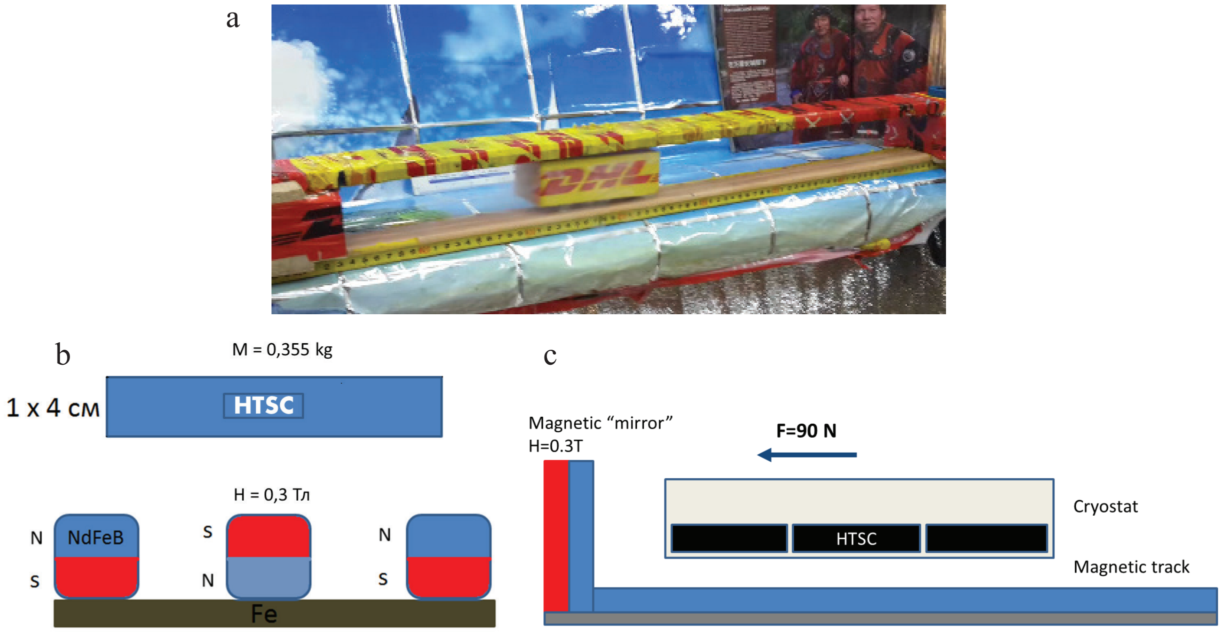

Fig. 3. Experimental miniature model of Maglev track based on PMG and HTSC ceramic. On the left and right ends of the route, there are «magnetic mirrors» strong permanent magnets. Reflecting from the «mirrors», the prototype can fly on the track more than 100 passes continuous movement before to stop. a – the general view of the model, b – cross section scheme of the experimental model of the HTSC Maglev route with a track of three lines PMG, levitating cryostat with HTSC ceramic, c – scheme of «magnetic mirror» at the ends of the track

HTSCs were cooled by pouring liquid nitrogen into cryostat. After pouring, the nonmagnetic stand was removed, and the cryostat with a HTSC of the 2nd order was in a state of levitation. At the same time, it is affected by magnetic forces, both vertical, holding from falling on the track, and horizontal, holding on the line of the track. Fig. 4 shows the levitation of the cryostat under external load and without it.

Qualitatively, the very preliminary results of the evaluation of the power characteristics of the model in dimentionless units N, are shown on the graphs in Fig. 5 a–d. These graphs reveal the dependence of the forces: F1 – the force required to break the cryostat from the track in the vertical direction – up, F2 – the lateral force required to break the cryostat from the track to the left or right, F3 – the vertical force directed downwards, necessary for the touch of the route from the height of the stand h, which was located on the cryostat over the track. Also presented is the graph of the dependence of a on h, where a is the height of levitation of the cryostat after being freed from the stand ($a < h$). The thickness of the bottom of the cryostat was about 3 mm. As can be seen from the graphs in Fig. 5, the height of levitation a increases with increasing h to 12 mm, and then decreases. F1, F2 decrease, and F3, on the contrary, increases with the growth of h. The dependences are in good qualitative agreement with the literature data.

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a b

Fig. 4. Demonstration of vehicle model levitation, in which cryostat with HTSC blocks is used, maintained at a temperature of liquid nitrogen. a – free levitation of the model, b – levitation of the model under external load

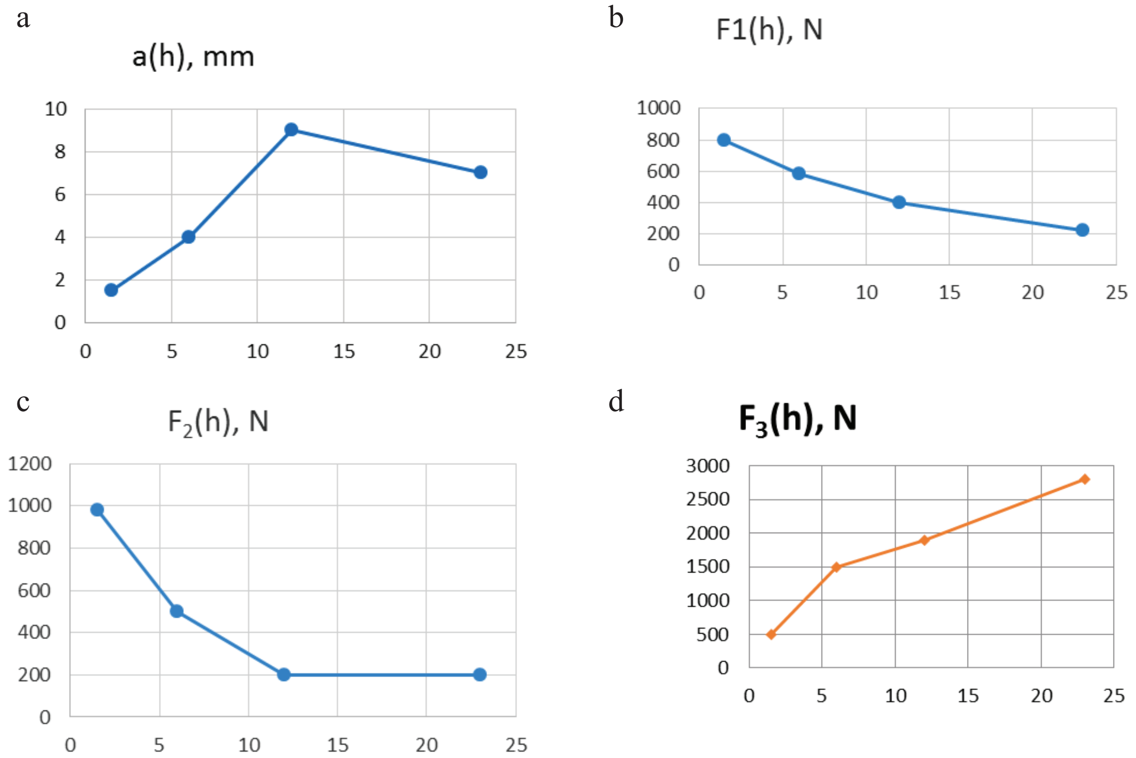

Fig. 5. Results of measurement of force characteristics of the experimental model of the HTSD AMLT vehicle and PMG, depending on *h*, mm
a – dependence of the height of levitation *a*(*h*); b – dependence of the separation force F1(*h*); c – dependence of the lateral stabilizing force F2(*h*); d – dependence of the maximum load force F3 (*h*)

Experiments on the study of force characteristics in the interaction of a levitating cryostat with "magnetic force mirrors" are of interest. It turned out that the force required to overcome the repulsion and touch the "magnetic force mirror" is about 900 N. As a result of the application of such significant forces, an effect of "magnetic plasticity" was observed. That is, after the mechanical force have

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acted near the "magnetic force mirrors", HTSC elements in the cryostat probably changed their magnetic state and acquired a new, weakly expressed position of the equilibrium along the alignment line near the "mirror". The effects of energy losses and magnetic state change of HTSC at extremal forces, depending on the speed of mutual movement of the superconductor of the 2nd order and the magnetic track, should be studied in details to justify the quality and reliability of the design of the VMLT vehicle.

At present, on this experimental basis a series of calibration experiments, production and verification of various versions of AMLT protypes, based on HTSC, are carried out. The variants of routes of PMG NdFeB, different types of cryostats, assemblies of bulk elements of HTSC, maintained at the boiling point of liquid nitrogen, are studied. Different variants of configurations of the arrangement of PMG, relations of power characteristics with the magnetic field intensity near the track are experimentally investigated on the model.

As a result of the preliminary experiments one can conclude that the main tasks to be solved are: theoretical and experimental study of interaction forces between the permanent magnets of the stationary tracks and movable vehicle in different versions of their spatial orientation and with different combinations of permanent magnets and superconducting elements, at different temperatures of their superconducting properties stability, obtained with the help of cryocoolers in the range from 3 K up to 70 K, and with respective drain-free cryostats and cryogenic "cold accumulators". The stability of motion and dynamic modes such as acceleration, stationary motion and braking at a given point, the amount of energy, which is necessary for acceleration, motion and braking, energy recovery processes (the process of returning braking energy to the electric source, consumed for first accelerating of the vehicle in the atmosphere and then in vacuum) are supposed to be studied.

9. CONCLUSION

The main results and conclusions of this work are as follows:

1. When analyzing the efficiency of transport systems, the key aspect is the energy approach. The technologies and further development of high – and ultra-high-speed vehicles, combined into ITTS are, undoubtedly, relevant and cost-effective for Russia. The problem of creating an effective ITTS on the basis of traditional TSs is unsolvable. The analysis of existing and being developed transport systems from the points of view of maximum speed, productivity and energy efficiency indicates the need to search for new, breakthrough and innovative scientific and technical solutions.

Received: 16.10.2018. Revised: 10.11.2018. Accepted: 17.11.2018.
Transportation Systems and Technology. 2018;4(3 suppl. 1):57-84

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2. The implementation of high-speed transport routes of VMLT based on HTSC, which have, in principle, a record speed, energy and economical efficiency is particularly attractive.

3. The analysis of international and national experience, as well as preliminary experiments on small-scale models, shows that to justify pilot projects of VMLT based on HTSC, it is necessary to perform a large amount of fundamental and applied theoretical and experimental work. First of all, it is necessary to study the properties of promising superconducting and magnetic materials to prove the stability of their electromagnetic and electromechanical properties at high speeds and significant dynamic mechanical and magnetic loads.

4. The results of fundamental theoretical and experimental studies, as well as technological experiments carried out on miniature models, will allow to create a "medium scale" model of VMLT track based on HTSC , on which it would be possible to simulate the processes of acceleration, braking and energy recovery. Successfully tested, it will be possible to turn to the creation and testing a larger scale of VMLT based on HTSC, first to demonstrate the capabilities and then for practical use.

5. It is necessary to recognize at the State level – by the Russian Federation Government decision - to include the magnetic levitation transport (AMLT and VMLT) in the "Russian Federation Transport Development Strategy up to 2030".

ACKNOWLEDGMENT

The work is supported by RFBR grant 17-20-04236. www.cryomont.ru

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Received: 16.10.2018. Revised: 10.11.2018. Accepted: 17.11.2018.

doi: 10.17816/transsyst201843s157-84

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Received: 16.10.2018. Revised: 10.11.2018. Accepted: 17.11.2018.
Transportation Systems and Technology. 2018;4(3 suppl. 1):57-84

doi: 10.17816/transsyst201843s157-84

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To cite this article:
Terentyev YA, Filimonov VV, Malinetskiy GG, Smolin VS, et al. Russia integrated transit transport system (ITTS) basid on vacuum magnetic levitation transport (VMLT). *Transportaion Systems and Technology.* 2018;4(3 suppl. 1):57-84. doi: 10.17816/transsyst201843s157-84

Received: 16.10.2018. Revised: 10.11.2018. Accepted: 17.11.2018.