PROSPECTS FOR VACUUM MAGNETIC-LEVITATION TRANSPORT

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ABSTRACT

The authors propose a fundamentally new approach to solving the problem of overcoming two technological limits of speed growth existing for rail vehicles. The advantages of vacuum magnetic-levitation transport are assessed in comparison with traditional transport systems. The perspectives of the use of this type of transport as applied to the development strategy of the transport system of Russia are determined.

Keywords: vacuum magnetic-levitation transport, specific energy inputs, transit transport resource, magnetic suspension, vacuum pipeline.

Background. *To become a civilization center on the Eurasian continent, Russia needs to step up its participation in the implementation of geostrategic projects, the key role in which will be played by transport systems.*

For modern traditional transport technologies it is already obvious that the main limiting factors and the brake on progress have been insufficient vehicle speed limits, low transport efficiency, throughput and carrying capacity of the main lines. In particular, on the railways of Russia for the initially used technology of wheel-rail movement, problems have arisen when the transport reaches two technological limits of growth in the speed of transport vehicles (TV).

The first limit is related to limiting the dynamics of acceleration and deceleration of TV, depending on adhesion of the wheel to the rail and the reliability of the current collector on a constant and alternating current. The second limit is connected with limiting the possibility of a further increase in the speed of TV to about 500 km / h, due to the growth in the third degree of energy costs to overcome the growing aerodynamic resistance to its movement.

Objective. *The objective of the authors is to consider prospects for vacuum magnetic- levitation transport.*

Methods. *The authors use general scientific methods, comparative analysis, statistical method, economic evaluation.*

Results. *In the first case, the transition to contactless (maglev) or magnetic-levitation transport (MLT) principles of the organization of the movement of the TCP, which is actively developed including in our country, is seen as logical [1–4]. The advantages, disadvantages and unquestionable advantages of magnetic-levitation high-speed (about 500 km / h) technologies realized in natural «atmospheric» environmental conditions in comparison with traditional high-speed rail (HSR) technology have been examined in detail and substantiated in the works of domestic and foreign researchers [1–5].*

Magnetic-levitation (MLT) »atmospheric» transport is a promising first stage in the development of high- and ultra-high-speed land transport. In the strategic perspective, the implementation of this project and its advanced domestic development of «MagTransCiTi» [1–3] in combination with vacuum magnetic-levitation technology (VMLT) [6, 7] will allow, for example, the ultra-high-speed transport connection of the water areas of the Pacific and Atlantic Oceans through the Eurasian continent across Russia and will open new opportunities for creation of intercontinental transport highways, emergence of a number of new technological solutions in the field of energy, superconductivity, cryogenics, that can significantly change the ecological situation in the world. At the same time, Russia can realize a powerful export component in the form of a transit cargo flow, in particular, in the directions North–South, East–West between the countries of the Asia-Pacific region and Europe.

But even in the technology of «atmospheric» MLT, as the speed of motion increases, the aerodynamic resistance to the movement of TCP grows quadratically, and at the already achieved record speeds of more than 1000 km / h, the bulk of the power of the drive of TC is forced to overcome this resistance, determining the limits of applicability of this progressive technology.

We propose a fundamentally new approach to solving the problem of overcoming both the first and second limits of the increase in the speed of TCP on the basis of the obvious advantages of «vacuum pipeline transport technology» (BT3) [6–9].

The concept of VLMT for this technology is an example of the effective convergence of magnetic-levitation, superconducting and vacuum technologies for land transport, which allows it to reach a speed of about 6500 km / h and more, with a very high throughput capacity, an acceptable cost of moving passengers and cargo, as well as a record low energy costs. Thus, according to the data [8, 10], the transportation of 1800 passengers to a distance of 1 km requires an energy expenditure of between 1 kW•h and 0.004 kWh / ton•km for cargo delivery.

The basic principles of the symbiosis of two ideas – the concept of transport on a magnetic suspension and in an artificially created rarefied vacuum medium inside a sealed pipeline – were first formulated, developed and published by the Russian scientist–geophysicist B. P. Weinberg [11] and later developed and described in [6–10].

In this article, on the basis of the above-mentioned principle, a large-scale infrastructure project is being considered to create a new integrated transport system (TS) in the strategic perspective that will, in particular, solve the problem of transport accessibility in the countries of the Eurasian Union by combining the currently available traditional modes of transport and new zero-flight amphibious, screen planes, balloon and other innovative means of transport.

Let us compare the various transport systems for such an important quantitative indicator as the unit energy consumption per unit of cargo transportation per unit of distance (in kilojoules per ton km) in terms of the so-called «physical economy». The main energy criterion of transportation here is the criterion of specific energy costs for the transportation of a unit of cargo weight per unit of distance [12]. This criterion, designated Ure (specific energy expenditure), has the dimension kJ / ton. The value of Ure is given by the formula:

Таблица 1

Energy indicators of various transport systems

№	Transport system	Type of transport	Power, MW	Speed, m/sec	Weight of iseful cargo, t	Yr • e KJ /t • km
1	Boeing-747	Air	71	253	64	4380
2	Screen plane «Lun'»	Air	137	138	120	8333
3	Freight train	Rail	4,4	20,0	2000	110
4	HSR- main line TGV	Rail	8,8	83,3	50	2173
5	Autotrailer	Automobile	0,338	22,2	20	761
6	STU	String	0,040	3,3	4	120
7	Autoferry	Sea	17,6	10,8	3345	487
8	HFV «Vikhr'»	Sea	3,5	19,4	26	7009
9	VMLT	VMLT	0,5 (имп., 16 сек.)	180	0,4	14,05

Designations: HSR – high-speed main line; TGV – type of West European HSR; STU – string transport of Unitsky; HFW– hydrofoil vessel.

Table 2

Aggregate specific energy consumption and delivery time for various TS and modes of transportation of goods

N	Type of transit	U r e, (kJ/ t • km)	L, (km)	P, (kJ/t)	Cargo delivery time (days)
1	Railway (Russian transit) (China–Finland)	110	10000	$1.1 \cdot 10^6$	12 (7)
2	Sea (China–Finland)	54,3	21000	$1.14 \cdot 10^6$	28
3	Railway (Russian transit) (Korea–Western Europe)	110	11000	$1.2 \cdot 10^6$	14
4	Sea (Korea–Western Europe)	54,3	22000	$1.2 \cdot 10^6$	30
5	Railway (Russian transit) (China–Western Europe)	110	11000	$1.21 \cdot 10^6$	15
6	Sea (China–Western Europe) (Shanghai–Amsterdam)	54,3	23000	$1.25 \cdot 10^6$	27–46
7.	Russian transit (China–Western Europe) TS VMLT	14,05	11000	$1{,}54 \cdot 10^5$	0,1

Ure = N/M x V,
where N is the useful power of the traction machine (traction motor) of the transport system, in kilowatts (1 kW = kJ / s);

M is the mass of the goods carried, in tonnes;

V is the speed at which the cargo is transported by the transport system, km/sec.

With the help of specific energy consumption indicator Ure, it is possible to solve the problem of determining the prospective directions for the development of various modes of transport, including VMLTS. Table 1, based on the data of [13], shows the results of the comparison for the Ure indicator of traditional and prospective modes of transport, including ground, sea (water) and air, and below there is the estimate for VMLT.

As can be seen from Table 1, without taking into account VMLT, the best parameters of energy efficiency (but not always with a comparable speed of transportation) have a classical type of railway transport according to the chosen criterion, but it is inferior to VMLT in efficiency by almost an order of magnitude.

The energy indicator used in the assessment of transport systems can also be used to determine the transit transport resource of Russia.

As a criterion, it is advisable in this case to use the total energy input for moving a ton of cargo from the point of departure to the point of arrival (in kilojoules per tonne), i.e. P = Ure x L, where L is the distance. The results of comparison of two modes of shipping (sea and rail) for the Europe–Asia transit are shown in Table 2, based on the data of [13]. Here, there is also assessment of a similar Russian transit of China–Western Europe by means of the VMLT transport system.

And in Table 2, the advantage of VLMT based on ET3 on all compared parameters is quite obvious, and for the main, target parameter, P – total energy costs, they are less by almost an order of magnitude, i.e. almost 10 times better.

Of course, the use of only one generalized energy indicator of Ure (and the associated modified one – P) is not enough to describe and manage such a complex system as a transport complex. A one-dimensional model for any transport is not able to adequately reflect the complex multi-dimensional and dynamic processes and interrelationships of the system. It is necessary to develop a whole set of interrelated and physically measurable indicators when developing the physical economy for transport (as for other life support systems) [12].

Although, of course, the use, even in the first approximation, of only one so-called indicator of «transport efficiency» (C) [14], equal to the ratio of the speed of TV in m / s to its specific energy consumption in [J / kg · m], assessing the advantages of TV also with account of differences in their speed, can serve as a good guide for comparing different transport systems and their efficiency.

Table 3

Comparative characteristics of various modes of transport

N	Type of transport	Average speed, km/h	Average speed, m/s	Specific energy costs, J/kg • m (MJ/t • km)*	Transport efficiency**
1	Railway	60	17	0,15	100
2	Sea transport	40	11	0,08	125
3	Car	100	28	2,0	15
4	Aircraft	700	194	2,2	90
5	Inertial pipeline transport	500	139	0,009	16000
6	Promising airship	150	42	0,021	1900
7	VMLT	6500	1800	0,014	128500

* – in terms of primary energy sources; ** – transport efficiency – ratio of speed to specific energy consumption.

Table 3 compares this criterion for some traditional modes of transport, as well as an assessment of the operating modes of one of the promising designs of airships of innovative type and ultra-high-speed, which simultaneously combines both the advantage of ultra-high speed of cargo movement and low energy costs, or the advantages of very high energy efficiency in combination with rapid transportation of goods.

From this comparison, it is obvious that the transport efficiency of the TS VMLT is several orders of magnitude higher than the transport efficiency of all other traditional modes of transport compared here, and several times higher than the most efficient of inertial pipeline transport compared in Table 3, but still hypothetical [14].

Thus, according to the level of energy and transport efficiency, VMLT has no equal among other modes of transport. It quite rightly claims the role of the main or central, backbone TS in a number of components of the integrated system and in a strategic perspective – among the innovative transport systems proposed for creation.

Vacuum-pipeline transport technology is ideally suited to the needs of XXI century. It is tolerant to the majority of existing transport, including any type of maglev-technology [1–4].

In general, its main conceptual principles are described in [6–11] and are formulated, for example, in the following way: in a permitted environment of a double vacuumed main magnetic-levitation viaduct, located as an overpass over a flat part of the ground, in a tunnel under ground or even under a water obstacle, lightweight, compact and airtight capsules with dimensions optimized for the transport of both people and goods move at speeds up to 6500 km / h or more based on the principles of non-contact magnetic levitation.

Compared with trains of the high-speed rail system, the material capacity of VMLT in terms of one passenger is less than 1/20 of the material capacity of the HSR, and according to the specific energy consumption, VMLT has no equal. The cost of creating and maintaining a vacuum is also not so great and already with the efficiency of vacuum pumps in the region of 0,5 the costs for the initial pumping will be not more than 500 rub./km for an optimum overpass with a diameter of 1500 mm.

The throughput (carrying capacity) of VMLT depends on the speed of the capsule. So, for one pipe of an evacuated overpass at a speed of 650 km / h, it can reach 260 000 passengers or 17 000 tons of cargo per hour, if there are about 300 gateways, which is attractive enough for the main long-distance communication of megacities.

At the same time, Hyperloop technology widely advertised now and just similar to it is much more limited than the competing VLMT technology, for the maximum possible distance to the first necessary «technical» stop (about 600 km), is substantially limited in terms of marginal, economically justified (no more than 1500 km) range of travel, since the Hyperloop capsule «levitates» on the «air cushion» in the vacuum environment of the pipeline with a pressure of about 100 Pa, which is much less efficient than magnetic levitation [9].

It is becoming increasingly clear that today, in fact, the only economically and technically acceptable solution to the problem of energy-efficient speeding up of environmentally friendly land transport is to replace the wheel-rail system with a magnetic suspension system and replace the conventional environment with an artificially created one, in which the aerodynamic resistance will be relatively small. And here VMLT has practically no competitors.

At the same time, the VMLT system can provide 50 times more traffic per 1 kWh of electric power than the most efficient electric cars or trains, and the VMLT overpass can be built for money equivalent to 1/10 of the cost of a high-speed railroad or 1/4 of the cost of a comparable high-speed motorway, with the capacity of only one pair of evacuated overpasses, as in the 32 lanes of the main high-speed motorway [6, 10].

And as already noted in [7–9], domestic developers have long proposed new cost-effective and energy-saving principles for designing the elements of engineering structures [15], various types of power superconducting cables for power supply of VLMT network equipment complexes, and also experimentally tested effective methods of noise-immune control and monitoring of the state of equipment networks based on long-distance fiber optic diagnostics and cryogenic fiber sensors [16, 17], which are stable and reliable operating in the rigid conditions of the combined impact of vacuum, low (cryogenic) temperatures, strong influence of permanent and alternating electric and magnetic fields of the equipment of VMLT along the entire length of the overpass route.

Conclusions.

1. The technologies and the options for further development of high-speed and ultra-high-speed vehicles, considered in the article, are technically feasible, economically viable for Russia and possess high-tech solutions in the field of magnetic-levitation, vacuum-cryogenic, fiber-optic and superconducting technology.

2. The main constraint for the widespread introduction of such a transport system remains the lack of a realized representative and commercially *attractive pilot project, the development and implementation of which has now become the most urgent task.*

3. It is necessary that the government of the Russian Federation recognize the importance of the project at the state level and include work on the creation and development of MLT and VMLT in the Transport Development Strategy for the period until 2030.

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Article received 23.12.2016, accepted 28.02.2017.