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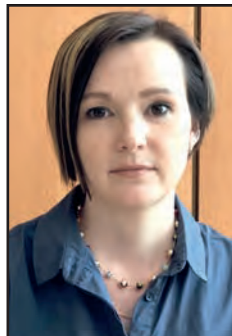
The Concept of Development and Implementation of High-Speed Transport



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ABSTRACT

The article discusses the issues of implementation and organization of high-speed transport. The objective of the article is to consider possible options for implementing high-speed (HS) motion systems using the principle of magnetic levitation, which will ensure high speeds for delivery of goods and carrying people over long distances. To achieve this objective, it is necessary to develop an engine and technical solutions for design of HS rolling stock, make decisions on energy supply infrastructure and the HS track, address safety issues and new control systems considering the state of the infrastructure and its design elements.

The article discusses several options for implementation of high-speed transport systems, differing in the power supply system, current collection and track based on the magnetic levitation approach. An original approach is proposed in implementation of magnetic levitation transport using the technology of electromagnetic guns designed to implement traction forces of a magnetic levitation vehicle. The advantage of this approach is that it opens the possibility of maneuvering for the vehicle while driving. This allows to abandon switch turnouts, now significantly limiting the use of magnetic levitation transport. A mathematical model describing interaction of an electromagnetic gun and supermagnets located on the track is considered. In constructing the model, methods of the theory of electromagnetic field and interaction of magnetic bodies were used, and when constructing a model of interaction of rolling stock with a magnetic track, methods of mathematical algebra and the Cauchy theorem were used.

The article discusses various principles of organization of movement using the magnetic levitation for urban, suburban, and intercity transport.

Keywords: *transport, magnetic levitation, electromagnetic gun, eddy currents, magnetic induction, high-speed train, diamagnets.*

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To date, several approaches have evolved in the field of urban and suburban traffic development. Many city administrations are gradually returning to recognition of public, especially rail, transport as an effective means of solving increasingly growing complex transport problems, most important ones being associated with overloading of streets with cars, leading to congestion and, consequently, to an increase in travel time, air pollution by exhaust gases. Initially, underground metro lines were built in the capitals and largest cities of different countries on an expanding scale. Then, comprising smaller cities, light metro networks began to be created, the lines of which partially run at ground level. And finally, lately, attention has been paid to the tram, the cost of infrastructure and rolling stock of which is significantly lower than that of the metro. The tram's advantages are obvious, these are high carrying capacity and high speed of coupled vehicles (when separate lanes are allocated), as well as environmental friendliness (when taking measures to reduce noise impact on the environment). Thus, conditions arose for the return of the tram to the cities.

The second equally important feature is implementation of the new concept of a universal «tram–train» vehicle. The transport administrations of many cities in Europe and America have recently begun to show interest in the concept of using rolling stock that can go along the tracks of both tram and main railways as public transport for transportation between the city center and the suburbs or between the centers of nearby cities. The concept of such combined transport systems was called «tram–train» [1, pp. 28–36].

Ten years ago, few people thought about it, even though for the most part the tracks of tram and railway networks are the same and technical compatibility problems can be normally overcome. Both rail transport systems have a track similar in design and are based on the general principle of using adhesion in a wheel–rail system. However, traditionally, they were completely separated from each other and operated in different ways. So, the question of their (at least partial) integration has never arisen. At the same time, in a number of cases, a different question arose and it concerned a possibility of passing tram trains on unused or under-used suburban railway lines, which would allow residents of the nearest suburbs to get to the city center without transfer. In the same way, suburban trains (respecting some conditions) could enter the city center along tram lines. Such a combination of two types of public rail transport with joint use of infrastructure would be especially useful for increasing the efficiency of public transport and creating additional amenities for passengers, provided, of course, solution of the associated problems.

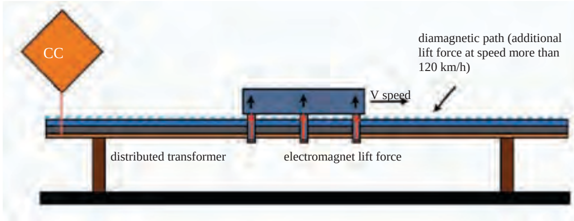
The increase in speed of passenger transit has recently become topical issue for urban, suburban, and intercity traffic. The development of high-speed transportation systems that helped creating high-speed trains had to bring new solutions. The high-speed railways while offering multiple advantages can not be integrated into urban and suburban transit systems, except for rare stopping points in cities neighboring megalopolises to receive part of passenger flows at most intensive directions, and to allow to travel to and from the downtown without stops.

A current agenda can include the point on a basic possibility to create a transportation system that would meet two fundamental criteria: it should have high speed features, and should be general-purpose one, as to serve routes of different range (from long distances to intraurban ones).

Thus, we can declare that the concept of high-speed transportation system should be focused on development of a generally purposed vehicles, capable to provide travelling within the city, as well as to its suburbs [2, pp. 3–10].

It is also necessary to meet other conditions. The transition to high-speed transportation systems should be focused on minimizing operation costs of maintaining transport infrastructure. However, external factors are significant (weather, freezing temperatures), and will affect the options for implementing HS transport, particularly in Russia. The transition to high-speed systems should consider the human factor as well [3, pp. 21–32; 4, pp. 12–26].

The *objective* of this article is to suggest approaches to development of high-speed (HS) transportation systems based on the use of low-maintenance technologies, energy-efficient technologies using renewable energy sources, and systems of inductive energy transfer to mobile vehicles using the principle of magnetic levitation. This will ensure high



Pic. 1. Centralized power supply system. Authors' drawing.

speeds for delivery of goods and transporting of people over long distances and will make the Russian railway complex competitive [2, pp. 1–5; 5, pp. 35–65].

To attain this objective, it is necessary to solve the following tasks [6, pp. 61–63; 7, pp. 128–142]:

• development of an engine and technical solutions for design of HS rolling stock,

• development of power supply for HS;

• HS track infrastructure development;

• ensuring safety and new control systems, taking into account the state of infrastructure devices and structural elements.

One of the tasks consists in development of a new type of a track, operated in difficult climatic conditions, and that task requires consideration of non-standard options, since normal operation of HS transport is possible only if the access of unauthorized persons is completely limited, as well as prevention of rainfall and foreign objects getting on the track is provided.

POWER SUPPLY SYSTEM

One of the determining parameters in implementation of the high-speed transport project is organization of the power supply system. The infrastructure of the track, the design of the train, and the choice of control system are most dependent on the choice of the power supply system. There are two approaches to implementation of HS transport power system.

Let us consider the first that is a *centralized one*. A centralized system requires laying a power cable for a moving vehicle along the entire length of the train. On board the mobile vehicle, the mobile part of the linear motor (LM) is installed. The speed and braking of the LM is controlled by changing the frequency from the center, which makes it impossible to process more than one train along the track between stations. At the same time, this approach requires laying of large quantities of copper wires along the track. It is proposed to transfer energy to HS vehicle by transferring energy to LM using the induction effect, which tightly connects rolling stock and the track, since the gap between the elements of LM and the distributed energy source for efficient energy transfer should not exceed a certain amount. This requires that the design of high-speed train provides for special measures of considering the location of the distributed source transformer. In this case, the track becomes active with many infrastructure elements that provide energy transfer to LM of rolling stock. It should be noted, in view of the large extent of the traffic areas, that infrastructure costs are significant, including those related to maintenance. In this case, it is necessary to build many control and power supply systems (along the entire length of the route) that determine and control vehicle's movement. However, this method reduces the overall dimensions of vehicles, and that is a significant positive factor, since most of the control is outside the rolling stock. It is also necessary to note large energy losses due to the length of the hauls.

The second option for organizing power supply is *decentralized* one [5, pp. 5–8; 6, pp. 61–63]. In fact, this is a current collector using a pantograph (of any design), which reduces the load on the track infrastructure and allows it to be passive, but at the same time, train maneuverability is significantly limited, and losses during high-speed movement increase due to poor contact between the pantograph and the contact wire.

The use of a current collector with a pantograph makes the vehicle active, that is, the engine control system is located on the vehicle. This is an analogue of the existing traction system, with the only difference being that there is no wheel, and movement is carried out due to the forces of electromagnetic adhesion of LM. This method increases overall dimensions of vehicles, and that is a negative factor.

A significant reason that reduces the effectiveness of these approaches, both centralized and decentralized, is track infrastructure, namely requirement for switch turnouts or exits. When using this method, it is necessary to create heavy (several tons) switch turnouts (point setting is up to 2 min), which will not allow in the future to switch to small vehicles, which will allow organizing an efficient packet mode of movement of high-speed vehicles.

Another important factor determining implementation of the above approaches is the requirement to implement a gap between the track structure and the vehicle. This is achieved by using a structure that covers the track, with installation of electromagnets that attract the train and ensure the rise and levitation of HS structure over the track. To ensure higher reliability, diamagnetic elements (aluminum) are placed on the track to obtain an additional effect of raising the train at speeds exceeding 120 km/h. This provides a gap of up to 50–100 mm when driving at speeds above 250 km/h, and also prevents the vehicle from colliding with the track when the power is suddenly disconnected in the system of attractive electromagnets. At the same time, this does not allow abandoning the wheels for landing of the train in case of emergency power off for a long time.

Let us consider a variant of the power supply system and rolling stock when using high-temperature superconductors (HTSC). In this embodiment, the main safety element in the vehicle is HTSC. The track is a set of super magnets stacked on the track with induction (B > 1,6 T). HTSC provides the vehicle levitation height (clearance) above the track structure. Maintaining the HTSC operating conditions should consume most of the energy generated or accumulated in a mobile vehicle.

The use of HTSC allows to create a design of vehicles operating on the principles of point replenishment of energy in specialized service points. To date, time to maintain the working state of HTSC is within ten days (when using materials with a low coefficient of thermal conductivity). This allows to plan the technological mode of service at certain points (in large cities located at a distance of at least 500–600 km). The energy for moving a vehicle using LM on rolling stock should be partially replenished using solar panels, by recharging batteries (storage cells) at stops. The energy of the storage cells with recharging is used for operation of LM and should ensure movement of the vehicle at a distance of up to 8000 km.

To implement the power system of a high-speed vehicle, solar panels with increased efficiency should be used.

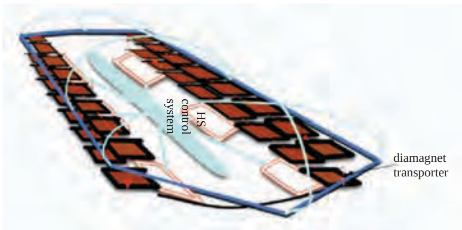
The movement of the vehicle at night can be carried out with a large number of stops to recharge the batteries (storage capacitors) of the vehicle.

One of possible ways to increase the effectiveness of this approach in implementation of HS transport may be to use a vehicle energy supply system using a non-contact pumping system or transferring energy to rolling stock using laser and electromagnetic technologies. Another possible option for replenishing energy can be wind energy, which is generated in large quantities during high-speed movement (the use of wind generators).

Let us consider implementation of the engine using the technology of diamagnetic elements. It is known that when the magnetic flux changes, counter forces arise due to appearance of eddy currents in diamagnetic conductive materials. The magnitude of the force depends on speed of movement and the electrical properties of the material of electrical conductivity of copper or aluminum (most commonly used). The rapid movement of the diamagnetic material into the magnetic field causes appearance of a current directed in the opposite direction from the force that moved the diamagnet into this magnetic field. Since the movable transport unit is in levitation mode, the whole structure begins to move. If the diamagnetic material moves in the opposite direction of the moving then the braking process begins. Various types of diamagnet rotation systems are possible: wheel, screw, conveyor and other types of trajectory.

Acceleration and deceleration are accomplished due to formation of eddy currents arising between diamagnetic elements and supermagnets in the track. The stabilization of the vehicle must be carried out using transverse «diamagnetic devices». And turning of vehicles is carried out due to difference in rotation speeds of «diamagnetic wheels».

A significant advantage of this approach in implementation of rolling stock is that



Pic. 2. Diamagnet motor. Authors' drawing.

the use of switch turnouts is not required. The turning of the vehicle is carried out due to the speed difference between the left and right parts of the engine. This vehicle model allows to build a track using ramps and multi-level interchanges. On straight sections of the track, where exit ramps are not intended, it is necessary to apply such a track geometry that would ensure stable movement for speeds close to 1000 km/h. The stability of the vehicle at speeds equal to or close to zero must be ensured by synchronous-counter-rotation of the «diamagnetic wheels».

Let us consider an approach based on the use of magnetic suspension and an engine with a large magnetic flux. This option provides suspension of the train due to interaction of supermagnets with magnetic induction B > 1,6 T, located in the lower part of rolling stock and on the track. This ensures high safety, since the repulsive force always exists. The engine is implemented on electromagnetic coils with a core material with high magnetic permeability μ. The engine is a distributed electromagnetic gun located on the left and right sides in the lower part of the train. This allows to realize turning of the vehicle, acceleration and braking. There is no need for switch turnouts, which greatly simplifies track design. Power is supplied either through storage capacitors or through a pantograph.

When solving the task of realizing an engine based on a large magnetic flux, one of the tasks is to position the engine relative to the track and select the geometry of the magnets located on the track.

The magnetic interaction of the coil with current and magnets on the track system is determined (in accordance with the provisions of the theory of electromagnetic fields and interaction of magnetic bodies) as:

$$F = (3 \bullet \mu \bullet \mu_0 \bullet p_m \bullet p_k) \bullet cos(\alpha)/4\pi\delta^4, \qquad (1)$$

where δ is distance between the coil and magnets on the track;

$p_m = J_m \bullet V_m \bullet p_m$ – magnetic moment of the floor magnet system with a volume of $V_m = s_m \bullet h_m$ and homogeneous magnetization J_m, where s_m, h_m – area and height of the magnet;

$p_k = J_k \bullet V_k = J_k \bullet h_k . 2 \bullet \pi \bullet r^2$ – magnetic moment of the coil with a core of height h_k and radius r;

$\mu_0 = 4\pi \bullet 10^{-7}$ (H/A^2) – magnetic permeability in vacuum;

M – magnetic permeability of the core of the coil.

Formula (1) is valid for the case of coaxial arrangement of the magnetic coil and the magnet. This corresponds to the case of vertical repulsion of a coil with current from a magnet. The vehicle needs to move, for this it is necessary to tilt the coil with current, as a result of which there is a horizontal force moving the vehicle. It is logical to rotate the magnet together with the coil so that interaction planes are parallel and the alignment angle α is 90°. This would provide maximum acceleration and braking power. But in reality this cannot be done. In this case, it is necessary to give the magnet a cone shape with the alignment angle $\alpha = 90°$ to ensure repulsive force. A change in the shape of the magnet entails a change in magnetization of a system of magnets located on the track. The magnetization (by magnetization vector) of a substance is the ratio of the total magnetic moment of the selected part of the substance to the volume of this part:

$$\vec{J_m} = \left(\sum_k \vec{p}_{m_k}\right) / \left(h_m \bullet s_m \bullet k\right), \qquad (2)$$

where k – number of magnets in the allocated volume under the coil.

The value J_m changes with movement of the vehicle, since location of a part of the floor magnet system under the coil changes. We express J_m in terms of the power series:

$$F = \left(3 \bullet \mu \bullet \mu_0 \bullet p_k \bullet V_m \bullet \left(\sum_{i_\alpha=0}^{n_\alpha} \sum_{i_J=0}^{n_J} a_{i_\alpha}^{\alpha} \bullet a_{i_J}^{J} \bullet t^{i_J+i_\alpha}\right)\right) / 4\pi \bullet (\delta)^4,$$

under restriction $\vec{J^m}_{min} \le \vec{J^m} \le \vec{J^m}_{max}$.

During movement, a change in the distance δ between the motor coil and magnets on the track and the alignment angle α between the coil and floor magnets can occur. We express *cos* (α) in terms of a power series (*methods of mathematical algebra*):

$$cos(\alpha) = \sum_{i_\alpha=0}^{n_\alpha} a_{i_\alpha}^{\alpha} \bullet t^{i_\alpha},$$

under restrictions $\delta_{min} \le \delta \le \delta_{max}$, $\alpha_{min} \le \alpha \le \alpha_{max}$.

Pic. 3. Transparent dome with solar batteries above the flyover. Authors' drawing.

Substituting the latter formulas in (1) we obtain the series:

$$F = \left(3 \bullet \mu \bullet \mu_0 \bullet \left(\left(\sum_{i_J=0}^{n_J} a_{i_J}^{J_m} \bullet t^{i_J} \right) \bullet V_m \right) \bullet p_k \right) \bullet \left(\sum_{i_\alpha=0}^{n_\alpha} a_{i_\alpha}^{\alpha} \bullet t^{i_\alpha} \right) / 4\pi \bullet (\delta)^4.$$

We apply the formula of the Cauchy theorem for multiplication of the polynomials J_m and *cos* (α) (*theory and methods of mathematical algebra*):

$$\sum_{i_J=0}^{n_J} a_{i_J}^{J} \bullet t^{i_J} \bullet \sum_{i_\alpha=0}^{n_\alpha} a_{i_\alpha}^{\alpha} \bullet t^{i_\alpha} = \sum_{i_\alpha=0}^{n_\alpha} \sum_{i_J=0}^{n_J} a_{i_\alpha}^{\alpha} \bullet a_{i_J}^{J} \bullet t^{i_J+i_\alpha}. \quad (3)$$

Substituting (3) in (1) we get:

$$F = \left(3 \bullet \mu \bullet \mu_0 \bullet p_k \bullet V_m \bullet \left(\sum_{i_\alpha=0}^{n_\alpha} \sum_{i_J=0}^{n_J} a_{i_\alpha}^{\alpha} \bullet a_{i_J}^{J} \bullet t^{i_J+i_\alpha} \right) \right) / 4\pi \bullet (\delta)^4. \quad (4)$$

Solution (4) under the condition: $4\pi \bullet (\delta)^4 > (\delta)_{min}$. This means that the electromagnetic coil of the engine should not come closer to the track magnets for a distance shorter than the minimum gap. The strengthened solution is when the condition is fulfilled with a constant distance δ: $4\pi \bullet (\delta)^4 = 1$.

Thus, the presented model provides the ability to track the change in acceleration and braking forces of the engine using a coil with a core with high magnetic permeability μ.

Traffic organization and track infrastructure

The infrastructure of HS railway transport should be based on the flyover design of the track. This will allow us to integrate traffic with a new type of electric transport, providing that the lower part of the flyover road is equipped with the infrastructure for charging electric vehicles. This will create a secure track structure with multi-level interchange. Track infrastructure should provide year-round, weather-independent movement of HS railway transport. To achieve this goal, it is proposed to close the flyover with a transparent dome and place solar panels on the dome (Pic. 3).

The principles of construction, control and power supply, laid down in new vehicles, allow to organize multi-row traffic (two-way) and differentiated traffic along the tracks:

• speed up to 1000 km/h for freight and passenger transportation (Europe–Asia) in Russia;

• speed up to 650 km/h for intercity national transportation;

• speed up to 200 km/h for local urban and suburban transport in Russia.

Construction of track infrastructure should include ring flyovers in large cities and major settlements of Russia. There should be exits from the main highway to settlements to allow coverage of larger populated areas. It is advisable to envisage in large cities the construction of flyover railway transport of suburban traffic (for example, a large ring around the city) in order to cover remote residence areas.

Focus on designing of custom-made vehicles will significantly expand the range of mobile vehicles for individual use with the number of passengers up to four people, which will give an additional impetus to development of this type of transport and emergence of personal vehicles.

The construction of a flyover for movement of vehicles should include the following features of traffic organization:

• specialization of tracks in speed and distance of transportation: 200 km/h for suburban traffic, 650 km/h for inter-regional traffic, up to 1000 km/h for continental transportation;

• organization of exits between specialized tracks, providing interchange between vehicles at the same level (overtaking, parking, etc.);

• organization of exits to cities and towns, platforms for passengers embarkation and disembarkation.

Track infrastructure should include vehicle service points:

• points for charging power storage devices and liquid helium levitation systems for LM;

• vehicle traffic control centers;

• connection to a single power supply system.

Track infrastructure should provide the necessary places for installation of specialized equipment for traffic management, control and monitoring of vehicles, access of maintenance employees to structural elements of the track and the equipment installed on it. It is necessary to provide in case of an emergency the possibility of relocation of human forces and small-sized equipment.

Conclusion

The suggested proposals allow us to approach the development of the concept of high-speed transportation systems, based on the use of low-maintenance service technologies, energy-efficient technologies using renewable energy sources, and systems of inductive energy transfer to mobile vehicles using the principle of magnetic levitation. Further steps will require searching for solutions to numerous complex engineering problems, development of new technology.

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