UDK [УДК] 656.34
DOI 10.17816/transsyst20195247-59

Rubric 2: SCIENTIFIC AND PRACTICAL DEVELOPMENTS
Field "Electrical Engineering"

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DECREASING OF PROFILE AIR DRAG TO THE TRAIN MOVEMENT INSIDE THE TUBE TRANSPORT

Background: The movement of the train in an insulated space with the natural atmospheric pressure is accompanied by energy losses for unproductive work to overcome the profile air drag from the front and rear surfaces of the vehicle. At the same time, there is also a considerable increase of energy costs for overcoming the growing force of oncoming air drag. In order to exclude these energy losses, it is proposed to organize synchronous and volume-balanced pumping of air from the front part of the tube transport and injection of the air into the back part of the tube transport.

Aim: To develop a method of organising air exchange inside the tube transport, which will ensure the reduction of air resistance to the movement of the train.

Methods: The proposed developments are based on well-known national and foreign designs of high-speed tube transport systems, the results of a comparative analysis of tube transport with varying degrees of air pumping (backing vacuum and hard vacuum), taking into account the experience of redistributing the residual air volume in the "Hyperloop" and "TransPod" tube transport systems. The operating parameters of the compressor units that pump air into the internal cavity of the tube when the train is in motion is regulated on the basis of process models of gas dynamics.

Results: A new method and device has been developed for reducing the air drag to the movement of the train by forced air exchange, which provides for the redistribution of air from the front to the rear of the transport tube relative to the vehicle travel direction. For the air redistribution, the external air exchange unit, consisting of air ducts, compressor units, gate valves, and air collectors is used. The process of external air exchange takes place only when the vehicle is in motion, for the movement of the vehicle no prior air exhaust is required. The air redistribution is controlled taking into account the speed of the train, its location in the tube, the design features of the tunnel and vehicle. The speed of the train for each segment of the speed section is normalised depending on the actual performance of the components of the air exchange system. Modes of operation of the compressor units must ensure synchronous redistribution of air from the front to the rear of the tube. The movement of a vehicle along a tube with normal atmospheric pressure in the internal cavity provides conditions for the safe transportation of goods and passengers.

Conclusion: The developed method is designed to reduce the force of air resistance when the train is in motion inside the airtight tube without creating vacuum. The presented developments have good prospects for use in projects of high-speed transport systems of both underground and underwater designs.

Keywords: high-speed transportation systems, evacuated tube transport, profile air drag, air exchange, Hyperloop, TransPod.

Received: 27.06.2019 **Revised: 13.07.2019** **Accepted: 15.07.2019**
Поступила: 27.06.2019 **Одобрена: 13.07.2019** **Принята: 15.07.2019**

Рубрика 2. НАУЧНЫЕ И ПРАКТИЧЕСКИЕ РАЗРАБОТКИ
Направление «Электротехника»

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О СПОСОБЕ СНИЖЕНИЯ ПРОФИЛЬНЫХ СОПРОТИВЛЕНИЙ ВОЗДУХА ДВИЖЕНИЮ ТРАНСПОРТНОГО СРЕДСТВА ВНУТРИ ТРАНСПОРТОПРОВОДА

Обоснование: Движение поезда в изолированном пространстве с естественным атмосферным давлением воздушной среды сопровождается потерями энергии на непроизводительную работу по преодолению профильных сопротивлений со стороны фронтальной и тыльной поверхностей подвижного состава. При этом также отмечается значительное увеличение затрат энергии на преодоление растущей силы встречного сопротивления воздуха. Для исключения указанных потерь энергии предлагается организовать синхронное и сбалансированное по объёмам откачивание воздуха из передней части транспортопровода и нагнетание воздуха в заднюю часть транспортопровода.

Цель: Разработать способ организации воздухообмена внутри транспортопровода, который обеспечит снижение профильных сопротивлений воздуха движению поезда.

Методы: Предложенные разработки основаны на общеизвестных отечественных и зарубежных конструкциях высокоскоростных транспортных систем трубного типа, использовались результаты сравнительного анализа транспортопроводов с различной степенью откачки воздуха (глубоким вакуумом и форвакуумом), учитывался опыт перераспределения остаточного объёма воздуха в транспортопроводе в системах “Hyperloop” и “TransPod”. Параметры работы компрессорных установок, перекачивающих воздух во внутренней полости транспортопровода при движении транспортного средства, регулируются на основе моделей процесса газодинамики.

Результаты: Разработаны новый способ и устройство снижения силы сопротивления воздуха движению поезда путём принудительного воздухообмена, который предусматривает перераспределение воздуха из передней части в заднюю часть транспортопровода относительно направления движения транспортного средства. Для перераспределения воздуха используется устройство внешнего воздухообмена, состоящее из воздуховодов, компрессорных установок, задвижек, воздухонакопителя. Процесс внешнего воздухообмена производятся только во время движения поезда, для движения транспортного средства предварительная откачка воздуха не требуется. Процесс перераспределения воздуха регулируется с учётом скорости движения транспортного средства, его местоположения в транспортопроводе, конструктивных особенностей тоннеля и подвижного состава. Скорость движения транспортного средства по каждому отрезку скоростного участка нормируется в зависимости от фактической производительности компонентов воздухообменной системы. Режимы работы компрессорных установок должны обеспечивать синхронное перераспределение воздуха из передней части в заднюю часть транспортопровода.

Received: 27.06.2019 Revised: 13.07.2019 Accepted: 15.07.2019
Поступила: 27.06.2019 Одобрена: 13.07.2019 Принята: 15.07.2019

Движение поезда по транспортопроводу с нормальным атмосферным давлением во внутренней полости обеспечивает условия для безопасной транспортировки грузов и пассажиров.

Заключение: Разработанный способ предназначен для снижения силы сопротивления воздуха при движении транспортного средства внутри герметичного транспортопровода без создания вакуума. Представленные разработки имеют перспективы использования в проектах высокоскоростных транспортных систем подземного и подводного исполнения.

Ключевые слова: высокоскоростные транспортные системы, вакуумный трубный транспорт, профильное сопротивление воздуха, воздухообмен, Гиперлуп, ТрансПод

INTRODUCTION

As of today, there are various conceptual options of high-speed tunnel and tube transport systems, which are being designed for passenger and cargo transportation at speeds of more than one thousand kilometres per hour. The most popular systems among the engineers are vacuum transport systems with sealed lines, from which the air which is the cause of air drag to the transport running in closed space, is pumped out by compressors. For safe transportation of passengers and cargo in vacuum transport systems, it is required to use specially designated vehicles with sealed casing, able to maintain atmospheric pressure inside the vehicle with significantly decreased outside pressure (i.e. transport line). Among the major competitive advantages of vacuum transport systems over other modes of transport, there are: high speed of transportation with low operational costs (as there is no energy spent to overcome counter-running airflow); independence of operation from weather conditions (wind, fog, rainfall); exclusion of vehicles collision.

The main sphere of application of vacuum transport systems is cargo and passenger transportation for long-distance between large metropolises. On such routes, the vacuum transport systems are capable of competing with even air transport, since planes spend time and energy to take off to the required altitude in a low-density atmosphere, in which it operates. In its turn, the vehicle while moving in a vacuum pipeline switches to the same operation mode (with low-density counter-running airflow) without additional time and energy losses. The biggest benefit from operation of vacuum transport systems can be gained through their integration with urban transit systems, in particular, with underground and suburban trains [1-4]. However, vacuum transport systems have a number of weaknesses: they require considerable capital costs for their construction; operational safety provision in low-pressure medium is required; and transport pipeline maintenance costs can outweigh the effect from transportation speed increase [5].

Received: 27.06.2019 **Revised: 13.07.2019** **Accepted: 15.07.2019**
Поступила: 27.06.2019 **Одобрена: 13.07.2019** **Принята: 15.07.2019**

METHODS

The main structural element of high-speed tunnel and tube transport systems is the evacuated line, which is composed of casing (round as a rule) and a track, used to carry the vehicle. The first prototypes of high-speed tube systems, using vacuum to reduce the air drag in sealed tube, emerged more than one hundred years ago. For instance, the Russian scientist Boris P. Weinberg and the American engineer Robert H. Goddard independently suggest a way to organise high-speed motion of transport vehicle in a tube that would have air pumped out of it [6-7].

During the course of XX century, the conceptual approaches to design of vacuum transport systems were developed. Various modifications of the tube design were suggested and innovative power units for the vehicle drives were adapted. For instance, the American inventor Daryl Oster patented a combined structure of several vacuum tubes, which were supposed to carry vehicles in counter-directions [8-9].

Today's models of tube transport systems the idea of which is to use vacuum to reduce air drag to motion, are divided into two basic design types, depending on degree of reduction of atmospheric pressure in the tube: first, these are hard vacuum systems with pressure reduced to less than 1 Mpa, and secondly, backing vacuum systems with pressure reduced to less than 100 Mpa. As to many experts, the most promising are the backing vacuum systems, as the costs associated with their construction are considerably lower as compared to capital investments into hard vacuum systems, whereas the technical and operational differences between the two types of transport systems are insignificant. The greatest potential, however, is attributed to backing vacuum transport systems that use maglev technology for motion. Such designs are capable of excelling all existing alternative transportation systems [10].

However, speed characteristics and economic efficiency of backing vacuum systems are limited to fundamental factors, that are known in gas dynamics theory as "Kantrowitz limit" [11-13]. These factors manifest themselves when vehicle moves with supersonic speed in isolated medium and are characterised by air ceasing to seep from the front part of the inner cavity of the tube (located before the head part of the moving vehicle) to the rear part, located at the tail of the vehicle, through the interwall space, which is formed by the casing of the tube and body of the transport. The residual (that did not seep) air creates excessive pressure in front of the vehicle and enhances the air drag.

In order to ensure free air flow through the interwall space in backing vacuum systems, special forms of vehicles are used and the diameter of the tube is increased to such a size that the entire volume of residual air, regardless of the speed of the vehicle, will freely pass from the front to the rear of the tube and fill the discharged space behind the vehicle. However, these methods are not devoid of disadvantages either. In particular, the construction and operation of vacuum

Received: 27.06.2019 Revised: 13.07.2019 Accepted: 15.07.2019
Поступила: 27.06.2019 Одобрена: 13.07.2019 Принята: 15.07.2019

transport systems with large diameter of the tube leads to increased costs and has a negative impact on the return of investment in such projects.

Therefore, the task of reducing the counter-air flow resistance to the vehicle movement by means of forced redistribution of air from the front to the rear of the tube is also relevant for backing vacuum transport systems. In the context of the present study, the set of actions, which redistribute or which cause the redistribution of air from the front to the rear part of the tube, will be called the air exchange process.

In backing vacuum transport systems such as Hyperloop and TransPod the air exchange process suggested to be provided within the limits of the inner cavity of the tube, through equipment that is part of the vehicle structure. This method will be called "internal air exchange" in our study. The main structural element used for internal air exchange in vacuum transport systems, is the compressor unit, which is placed at the head part of the vehicle. In Hyperloop the compressor unit redistributes the counter-flow under the bottom of the vehicle to create an air cushion, that eases the motion of the vehicle [13]. In TransPod the compressor unit pumps the air through ducts in the body of the vehicle and exhausts it through the outlet nozzle to the rear part of the vehicle, thus creating additional propulsion for the vehicle acceleration [14].

However, organisation of internal air exchange as in Hyperloop and TransPod reduces throughput capabilities and operational efficiency of such transport systems, as placing of the additional equipment on the vehicle (i.e. compressor units, air blowers, etc.) will lead to reduction of passenger and load-carrying capacities of the vehicle. Furthermore, the designs of Hyperloop and TransPod have a number of other weaknesses, which are characteristic for all models of backing vacuum and hard vacuum transport systems. In particular, the reduction of air drag force through creation of vacuum in transport tube poses risks for passengers or cargo in case of the decompression of the vehicle. Besides, construction of vacuum transport systems will require skyrocketing investment, since the structure of vehicles and tubes designed to operate under large pressure differentials, must be of increased durability, and the operation of these systems will be accompanied by additional operational costs for elimination of possible air leakages in the walls of the tube casing. The elimination of these leakages will require suspension of all traffic. Therefore, the application of high-speed vacuumless tube transport systems with normal atmospheric pressure, which will use external air exchange between the front and the rear parts of the inner cavities of transport carrying structure, is seen as more promising.

RESULTS

The main purpose of the proposed vacuumless way to reduce air drag to the vehicle is about increasing efficiency and safety of cargo and passenger

Received: 27.06.2019 Revised: 13.07.2019 Accepted: 15.07.2019
Поступила: 27.06.2019 Одобрена: 13.07.2019 Принята: 15.07.2019

transportation by sealed transport tubes through organisation of external air exchange between the front and the rear parts of the transport tube.

The motion of vehicle in an insulated space with natural atmospheric pressure is accompanied by energy losses associated with overcoming profile resistance of the front and rear surfaces of the vehicle, explained by undesirable changes of pressure in the transport tube: in the front part, the injection of pressure and compaction of air take place, in the rear part, the decrease of pressure and density of air is noted. The characteristic changes of the air parameters caused by transport mode travelling is called the piston effect [15].

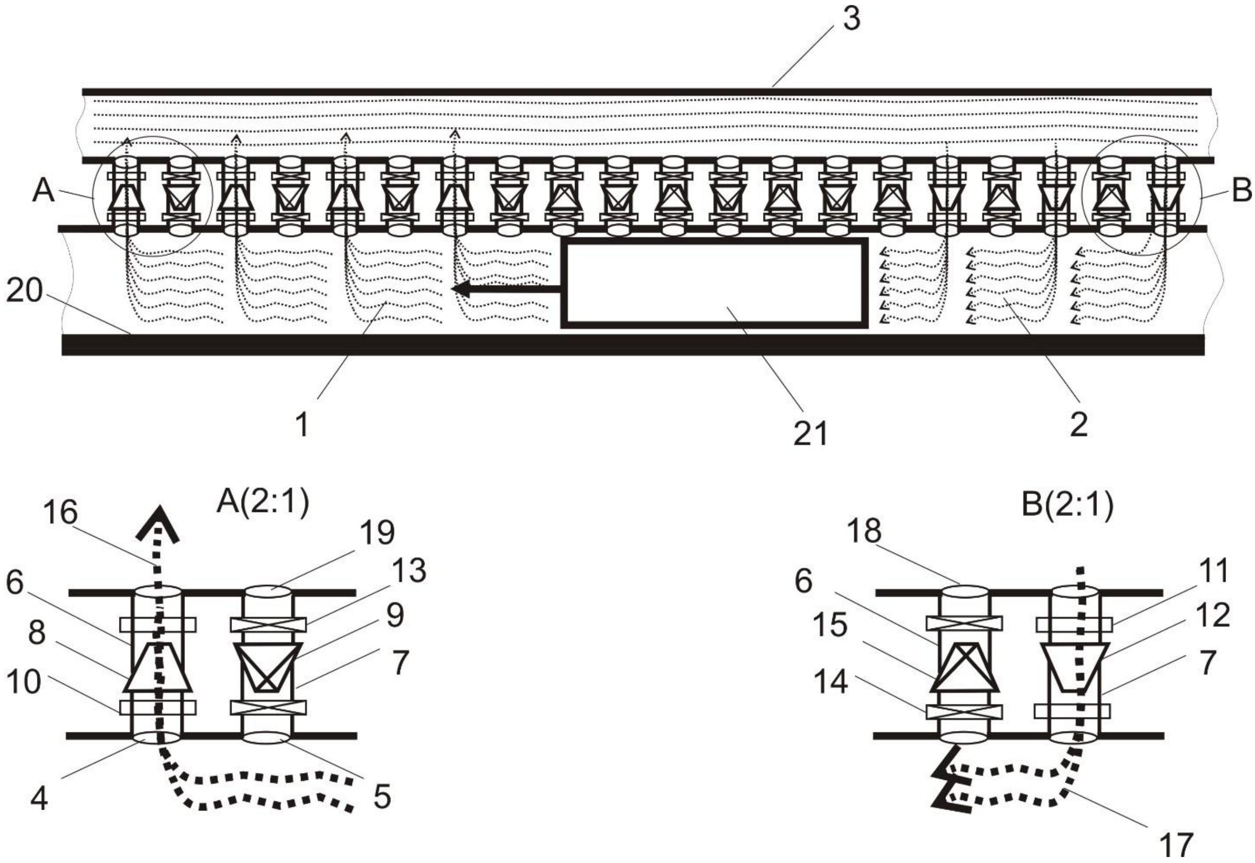

Fig. The general structure and principle of operation of the external air exchange with separate air ducts:
1 – front part of the tube (increased air pressure area); 2 – rear part of the transport tube (low air pressure area); 3 – air collector; 4 – through hole in the casing of the transport tube to pump out air; 5 – through hole in the casing of the transport tube to inject air; 6 – separated exhaust air duct; 7 – separated inlet air duct; 8 – exhaust compressor units switched on; 9 – inlet compressor units switched off; 10 – open gate valve of exhaust air duct; 11 – open gate valve of inlet air duct; 12 – inlet compressor units switched on; 13 – closed gate valve of inlet air duct; 14 – closed gate valve of exhaust air duct; 15 – exhaust compressor units switched off; 16 – direction of air movement from transport tube to air collector; 17 – direction of air movement from air collector to transport tube; 18 – through hole in the air collector casing used to pump out air; 19 – through hole in the air collector casing used to inject air; 20 – transport tube; 21 – vehicle.

Received: 27.06.2019 Revised: 13.07.2019 Accepted: 15.07.2019
Поступила: 27.06.2019 Одобрена: 13.07.2019 Принята: 15.07.2019

With piston effect, the significant increase of energy losses is indicated that is needed to overcome the growing force of counter-air resistance, the value of which is proportional to the square of the vehicle speed [16]. To exclude the energy losses above, it is suggested to organise synchronous and well-balanced (in terms of volume) pumping of the air from the front part of the tube to the rear part. The general principle of the external air exchange and structural elements of the equipment, used in this process, are shown in Fig.

Redistribution of the air flow between the front (1) and the rear (2) parts of the tube is provided by external air exchange through air collector (3) separated relatively to the tube, and which is a typical welded-structure reservoir for gas storage (cylindrical, as a rule) with increased requirements to materials of which it is manufactured.

To organise the external air exchange, in the casing of the transport tube at least one through hole (4) is made to pump out air, and at least one through hole (5) to let air in. The holes are usually round in cross section and are evenly distributed along the casing of the tube. Holes of different designation (for inlet and pumping out) are recommended to be placed in pairs near each other to the extent possible given the sizes of the transport tube structure.

The external air exchange unit comprises separated exhaust (6) and inlet (7) air ducts, through which, respectively, pumping out and injection of air is ensured in the transport tube; the air collector (3), receiving pumped out air from the front part of the transport tube, and it is from here that air is forced into the rear part of the transport tube; compressor units (8) and (9) which pump air; gate valves which are used to prevent air from flowing between the transport tube and the air collector when the compressor units are switched off. In Fig. 1, the gate valves (10) and (11) are shown as opened, when the exhaust (8) and inlet (12) compressors are switched on, and the gate valves (13) and (14) are shown as closed, when the inlet (9) and exhaust (15) compressors are switched off. At the given working condition of the air exchange unit elements, the air from the front part of the tube (1) moves to the air collector (16), and from the air collector (17) to the rear part of the tube (2). It is possible to organise the air exchange process without using the air collector unit directly through the atmosphere. This design can be used to reduce the cost of constructing a high-speed ground transport system.

The combination of exhaust ducts with the gate valves and compressor units forms the exhaust system. Similarly, a set of inlet ducts with the gate valves and compressor units form an inlet system. The ducts, gate valves and compressor units, as well as the connected inlet ducts, gate valves and compressor units, are structurally and functionally connected to form separate units of the corresponding air exhaust or inlet systems (hereinafter referred to as components of the air exchange system).

The exhaust (8) and inlet (9) air ducts are airtightly fastened (screwing, welding or other reliable methods) to the transport tube and air collector along

Received: 27.06.2019 Revised: 13.07.2019 Accepted: 15.07.2019
Поступила: 27.06.2019 Одобрена: 13.07.2019 Принята: 15.07.2019

the perimeter of the corresponding through holes (4) and (5). Similarly, the air ducts are fixed to the air collector (3) along the perimeter of the through holes (18) and (19) in its casing. The airtight connection of the transport tube with the air collector allows for construction of high-speed underground and underwater transport systems.

If required, the intensity of air exchange can be increased through additional pumping out and inlet air ducts. At this point, compaction of the air ducts (6) and (7) is possible by virtue of their connection to the transport tube or the air collector through combined through holes (4) and (5) or (18) and (19) respectively. This design solution also allows for reduction of sizes of the air collector.

The external air exchange systems provides for automatic control of the gate valves and compressor units using the actual vehicle location and speed data. To record the respective data, electronic sensors embedded into the transport tube track, casing or vehicle can be used [14, 17-20]. The speed of the vehicle at each section of the line is regulated depending on the actual performance of the air exchange system components. At the same time, the issues relating to regulation of the air exchange system components is a self-standing topic and is not covered in this study.

CONCLUSION

The developed method is suggested for reduction of the air drag in the airtight transport tube without creating vacuum. At the same time, the research results provided in the paper as well as the developments suggested do not intend to doubt prospects for developments and efficiency of application of vacuum transport systems. The authors seek to attract specialists' attention towards the necessity for further development of systems and structures, which will be able to reduce profile air drag of the vehicle operating at high speed within transport tubes and tunnels. It is the authors' opinion that such transport systems have prospects for widespread application. In recent times, various construction projects for such underground and underwater systems have been discussed. For instance, National Consultative Council of the United Arab Emirates have declared plans to construct the subsea tunnel to connect Fujairah (UAE) and Mumbai (India), which will be laid in the Indian Ocean. The airtight tunnel will be used to organise high-speed railway traffic, and lay down oil, gas and water pipelines. Additionally, the laying of separated backing vacuum railway transport tube is being discussed. The parameters of the undersea tunnel allow equipping it with the air exchange system proposed by the authors in this paper, thus simplifying the design of the tunnel and increasing the speed of trains. The method developed by the authors can also be used in organisation of tunnel railway connection between Helsinki and Tallinn, which is planned to be constructed on the bottom of the Baltic Sea in the near years.

Received: 27.06.2019 **Revised: 13.07.2019** **Accepted: 15.07.2019**
Поступила: 27.06.2019 **Одобрена: 13.07.2019** **Принята: 15.07.2019**

ACKNOWLEDGMENT

The authors would like to express their gratitude to the organisers and participants of the VII International Scientific Conference “Magnetic Levitation Transport Systems and Technologies” (MTST’19), during which the discussion of the above-presented developments took place, and essential comments and suggestions were made, that enabled the authors to improve the structure of the paper and the conclusions outlined in it.

The authors make it expressly clear that:

1. No conflict of interests has taken or may take place;
2. The present article does not contain any researches with people as the objects involved.

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Received: 27.06.2019 Revised: 13.07.2019 Accepted: 15.07.2019
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Received: 27.06.2019 **Revised: 13.07.2019** **Accepted: 15.07.2019**
Поступила: 27.06.2019 **Одобрена: 13.07.2019** **Принята: 15.07.2019**

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To cite this article:
Larin ON, Bokov AV. Decreasing of Profile Air Drag to the Train Movement Inside the Tube Transport. *Transportation Systems and Technology*. 2019;5(2):47-59. doi: 10.17816/transsyst20195247-59

Цитировать:
Ларин О.Н., Боков А.В. О способе снижения профильных сопротивлений воздуха движению транспортного средства внутри транспортопровода // Транспортные системы и технологии. – 2019. – Т. 5. – № 2. – С. 47–59. doi: 10.17816/transsyst20195247-59

Received: 27.06.2019 **Revised: 13.07.2019** **Accepted: 15.07.2019**
Поступила: 27.06.2019 **Одобрена: 13.07.2019** **Принята: 15.07.2019**