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Particularities of the formation of the air masses structure in the tunnel during the train movement

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ABSTRACT The effect of aerodynamic factors on the rolling stock and railway infrastructure has been analysed. The formation of air mass structure in tunnel structures during the movement of high-speed rolling stock has been investigated. The processes of aeroelastic interaction of rolling stock with tunnel portal structures are analysed by means of numerical simulation. The description of mathematical models and the ways of their three-dimensional realization in the Solid Works Flow Simulation software complex are presented. Methods of finite elements and volumes for the solution of the set tasks are used. The results of the numerical research of velocity fields near the tunnel portal area obtained with the help of the developed mathematical models for the cases of entry and exit of the rolling-stock into the tunnel are given. The complex structure of air masses formation in the gap between the train body and tunnel lining which leads to increased resistance to the train movement in the tunnel is revealed. The patterns in the changes of pressure dynamics on the surface of the head fairing when the train enters the tunnel are found. The fact of negative effect of high and low pressure zones, as well as their abrupt difference, on the locomotive crew and passengers has been established.

KEYWORDS: aeroelastic interaction; rolling stock; boundary layer; turbulent regime; pressure; air mass velocity; and structure of disturbed air medium

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Научная статья

Особенности формирования структуры воздушных масс в тоннеле при движении поезда

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АННОТАЦИЯ Выполнен анализ влияния аэродинамических факторов на подвижной состав (ПС) и железнодорожную инфраструктуру. Проведено исследование формирования структуры воздушных масс в тоннельных сооружениях при движении высокоскоростного ПС. Проанализированы процессы аэроупругого взаимодействия ПС с портальными сооружениями тоннелей с помощью численного моделирования. Представлено описание математических моделей и способы их реализации в трехмерной постановке в программном комплексе SolidWorks Flow Simulation. Использованы методы конечных элементов и объемов для решения поставленных задач. Приведены результаты численных исследований полей скоростей вблизи портальной зоны тоннеля, полученные с помощью разработанных математических

моделей для случаев входа ПС в тоннель и выхода из него. Выявлена сложная структура образования воздушных масс в зазоре между корпусом поезда и обделкой тоннеля, которая приводит к повышенному сопротивлению движения поезда в тоннеле. Обнаружены закономерности в изменении динамики давления на поверхности головного обтекателя при въезде поезда в тоннель. Установлен факт негативного влияния зон повышенного и пониженного давления, а также их резкий перепад на локомотивную бригаду и пассажиров.

КЛЮЧЕВЫЕ СЛОВА: аэроупругое взаимодействие; подвижной состав; пограничный слой; турбулентный режим; давление; скорость воздушных масс; структура возмущенной воздушной среды

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INTRODUCTION

The trend in rail transport is to increase the speed of the rolling stock. The speed of freight and passenger delivery plays the most important role in today's dynamic world. Increasing train speeds lead to a number of problems.

One such problem that engineers have to address is analysing the impact of aerodynamic processes on rolling stock and railway infrastructure. Complex aerodynamic processes and the movement of large volumes of air masses can have a major impact on the safety and efficiency of transport. This problem is particularly significant when high-speed rolling stock passes through tunnels.

The formation of air masses during the movement of a train in a tunnel is very complex. There are local zones of increased and decreased pressure in the front and tail parts of the train, accelerated air flows directed towards the train, and also local zones of compression and dilation in the portal part of the tunnel at the train's entrance [1, 2].

The physical processes accompanying aeroelastic interaction of moving rolling stock and tunnel structures can be considered in detail by numerical simulation.

MATERIALS AND METHODS

When trains move through a tunnel there is a significant air pressure drop in the front and tail section of the train. The pressure drop in the tunnel depends on many factors such as train speed, air viscosity kinematics, cross-sectional area, the shape of the front of the train and the shape features of the tail section [3, 4].

Numerical simulation of the train movement process in a tunnel confirms the wave nature of air mass movement [5]. On road sections where tunnels are encountered on the track, the moving train causes accelerated compression of the air medium, which leads to the formation of a compression zone in front of the train's fairing. Due to the viscosity of the air, there is a rarefaction zone immediately outside this compression zone around the train. This rarefaction zone is formed in the space between the train and the tunnel. Such phenomena have an impact on train safety and therefore must be taken into account in the design and operation of railway lines, tunnel design, and in the design of ventilation and air conditioning systems inside tunnels. The results are presented as calculation diagrams made in SolidWorks Flow Simulation software package using finite element and volume methods [6].

RESULTS OF THE STUDIES

Stable high-density vortex formations create the main mechanical resistance to train movement. The structure of the air medium in the train-tunnel gap is a system of multidirectional, interacting air medium flows with layer-by-layer distribution. The thickness of air medium layers depends on the surface profile of the train body, flow velocity, viscosity of the fluid medium. At high density sections the trajectories of air masses moved by the train take spiral shape [7].

Air flow distributions when a train moves in a tunnel at a speed of 200 km/h are shown in the *Fig. 1*.

The cross-sectional diagram in red shows the velocity flows of differently directed air masses, with them in the immediate vicinity of the train, and in the upper part and troughs in the opposite direction (see *Fig. 2, 3*).

Particular attention must be paid to the boundary layer. In the boundary layer there is a transition from laminar to turbulent air masses. The transition point is at some distance from the surface edge, with the higher the velocity, the closer to the leading edge this point is [8].

The frictional force of the flow on the hull surface in turbulent mode is several times greater than in laminar mode and is proportional to the velocity gradient of the viscous medium [9].

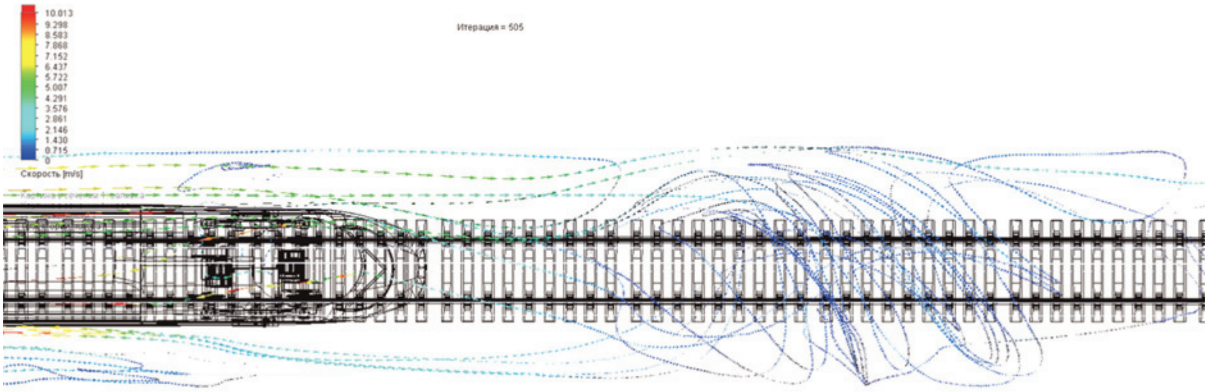

Fig. 1. The trajectory of the movement of air masses in the process of formation of the piston effect (the tunnel is not shown for clarity)

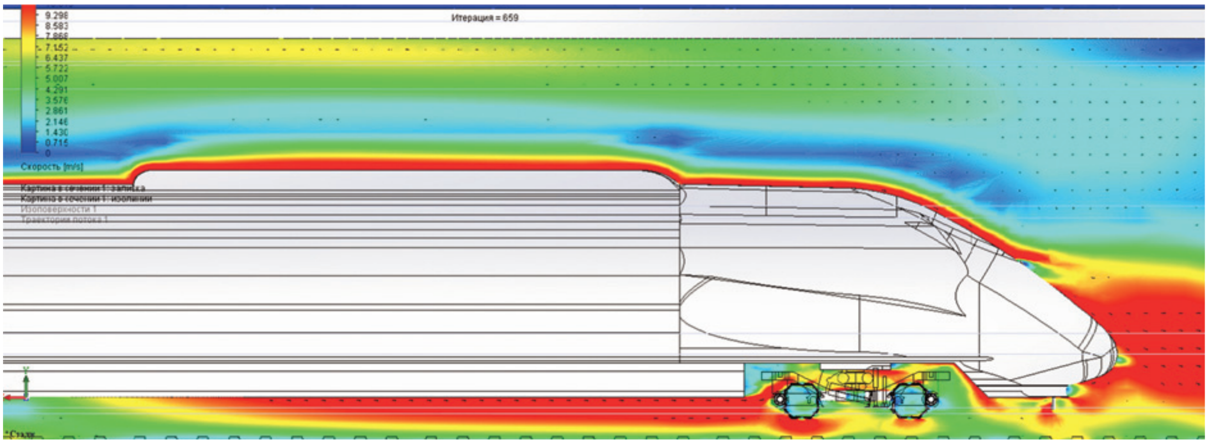

Fig. 2. Diagram of the distribution of air flow velocities near the mobile station moving in the tunnel

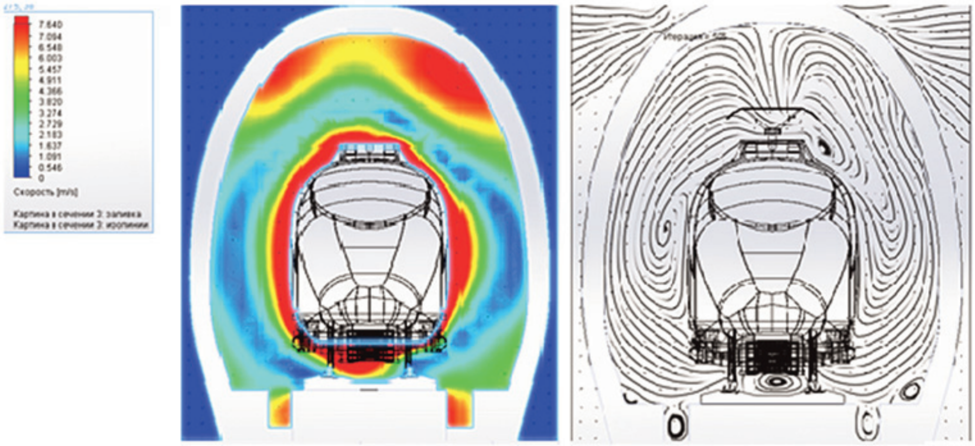

Fig. 3. Formation of the rotational movement of air masses located in the "train-tunnel" gap and the scheme for the formation of a vortex structure

The complex surface configuration of the rolling stock hull slows the airflow at certain points. This contributes to the detachment of the boundary layer and disruption of the flow, which contributes to the formation of a rotating vortex.

Disruptive vortices form periodically, with their centroids tending to gradually shift towards the tail of the train, followed by their collapse (see *Fig. 4*).

For the same reason, a stall vortex is formed at the tail end of the train, which creates destabilising

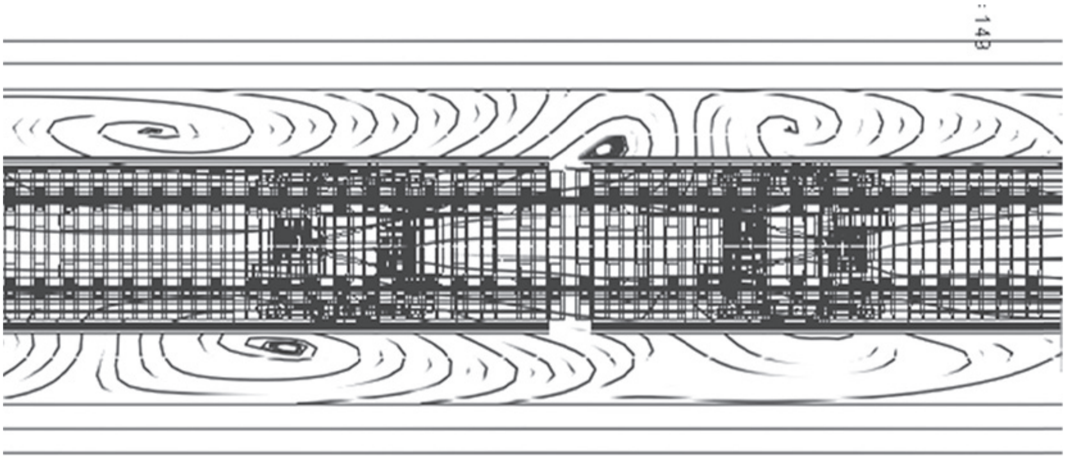

Fig. 4. Periodic formation of stall vortices on the side surfaces of the rolling stock

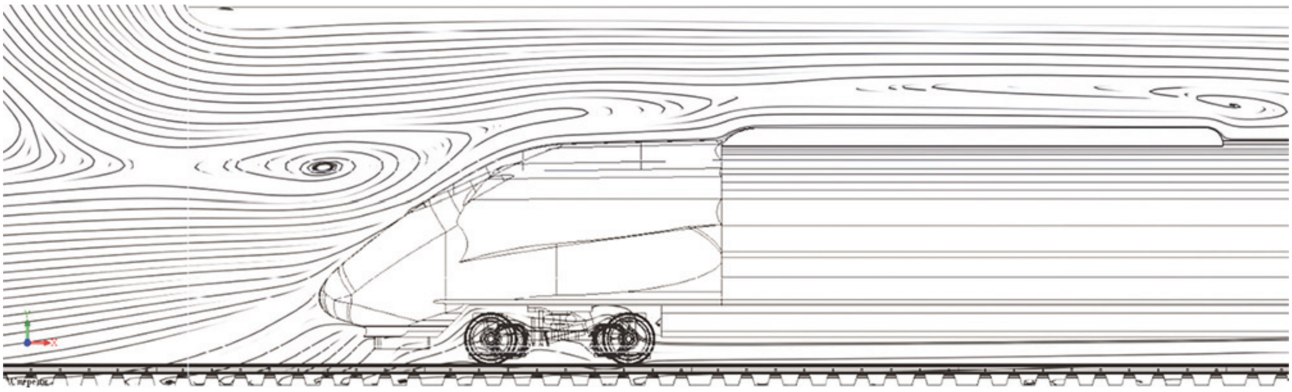

Fig. 5. Formation of a stall vortex in the tail section of the train

conditions for the train's movement (jolting, unstable behaviour). For rail transport, this problem only became relevant once certain speed regimes were reached, especially in tunnel traffic conditions (see *Fig. 5*) [10, 11].

It should also be noted that during the movement of a train in a tunnel, the nature of the structure of the disturbed air medium varies periodically depending on the position of the contours of the rolling stock surfaces and the tunnel lining. The most characteristic are combinations of decreasing cross section in the direction of movement (confusor), and increasing (diffusor).

In such sections, turbulent flow conditions are formed in the clearance between the train and the tunnel. Rotating eddies block the free flow of air masses in this gap and provide additional resistance to train movement, and therefore lead to an increase in traction energy costs for the train. This is particularly evident when the train exits the tunnel due to the interaction of air masses coming from the environment into the rarefaction zone behind the tail end of the rolling stock. This results in a powerful vortex flow towards the train, increasing the aerodynamic drag [12, 13].

CONCLUSION

Thus, the formation of both compacted and rarefied regions of air masses in the vicinity of train fairings creates conditions of increased resistance to train movement. The elastic interaction of the vortex structures discussed above increases the equivalent aerodynamic resistance to train movement in cramped tunnel conditions.

The phenomena described above have a negative impact on the traction energy consumption of the train as they significantly increase the drag and in addition cause significant discomfort to passengers.

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