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Air flow and differential pressure characteristics in the vacuum tube transportation system based on pressure recycle ducts

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A B S T R A C T

Based on the $k-\omega$ *SST* two-equation turbulence model, 2D physical models of the Vacuum Tube Transportation system with pressure recycle ducts were established. Numerical simulation was carried out in the different supersonic state. The air flow characteristics of the VTT with PRD and the influence of the interval length and opening width of PRD on the differential pressure were studied. The results show that the differential pressure is proportional to the square of the train speed and it increases with the increase of the blockage ratio when the system pressure is constant. The existence of PRD can effectively reduce the differential pressure between the train head and tail and it can be reduced by up to 30% when the system pressure is 10 kPa and the blockage ratio is 0.30 and the velocity of train is 1.18Ma. The greater the system blocking ratio is, the more effective the decompression effect of PRD is in VTT. The greater the opening width and the shorter interval length are, the more obviously the influence on the differential pressure in the VTT with PRD. 3E triangle model for evaluating VTT was proposed in this paper, which lays the foundation for the construction of VTT in the future.

1. Introduction

With the implementation of "The Belt and Road" strategy, the flow of personnel are taking on the tendency of long and high frequency, which puts forward higher requirements for the carrying capacity and speed of vehicles. In the available transportations, airplanes and trains are the appropriate ones for long-distance travel, but the former is weak in transportation capacity and high in delay rate, and the latter has to cost much more time on the journal. Therefore, a new type of transportation is urgently needed to adapt people's more frequent *trans*-regional communication, so as to promote cultural exchanges and economic prosperity between countries. The development of the Vacuum Tube Transportation system (VTT) emerges as the time requires. In simple terms, VTT is a kind of high-speed maglev train running in a vacuum tube. According to its design concept, VTT not only has velocity which could be comparable with the aircraft, but also possesses the carrying capacity of the train, moreover, the security of the operation can be enormously guaranteed for its limited influence imposed by the weather. Furthermore, benefit from its trackless and airless design, the running frictional resistances generated by the track and air are greatly reduced, consequently, operating speed of VTT can be enhanced maximized with low energy consumption and low operating cost.

The Electrical Experimenter introduced the ETT/VTT concept and work of Boris Weinberg in March 1917. Boris Weinberg published his paper on ETT/VTT which the velocity is five hundred miles an hour in Popular Science Monthly in 1919 [1]. However, the substantive research on the VTT had not been delved deeper in the past 100 years. Switzerland's Swissmetro and the VTT in the United States were internationally recognized as the blueprint of the VTT [2]. In 2005, Vacuum Tube Transportation Research Institute was set up in Southwest Jiaotong University which marked the research and development work of VTT officially launched in China. It provided an important platform for the basic research of VTT. A complete VTT test system officially passed the acceptance of the Ministry of Education expert group in 2011. This VTT test bench can reach 0.012 standard atmospheric pressure, which indicates that China's VTT research has entered the experimental research stage [3]. In 2016, Hyperloop One, one of the companies which developed super-high-speed rail, measured in the desert near Las Vegas and laid the foundation for the early realization of the VTT.

Up to now, although the study of the VTT has been gradually

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Nomenclature

β	blockage ratio
v	velocity in y axe
P	density
T	time
E	total energy
I	internal energy
K	the thermal conductivity
P	pressure
μ	coefficient of viscosity
Ma	Mach number
$\tau_{xx}\tau_{xy}\tau_{xz}$	the components of the viscous stress
F_1	the blending function
ω	turbulent frequency
ε	turbulent kinetic energy dissipation rate
K	kinetic energy
P	potential energy
U	velocity in x axe
W	velocity in z axe
T	temperature
c_p	specific heat capacity
S_T	the viscous dissipation
T	viscous force
λ	second viscosity coefficient
$S_uS_vS_w$	generalized source terms
$F_xF_yF_z$	physical forces on infinitesimal bodies
Φ_1	the basic $k-\omega$ turbulence model
Φ_2	the $k-\varepsilon$ turbulence model after deformation

started, the work is still limited to a single study of the blockage ratio and train speed and system pressure on the VTT. It rarely involved the influence of the specific structure of the vacuum pipeline on the aerodynamic problems of the VTT. The piston effect is obvious and the differential pressure between the train head and tail is also obviously increased when the train is running at high speed in the long vacuum pipe. Meanwhile, the aerodynamic heat also increases significantly. It not only affects the operation and energy consumption of the train, but also increases the damage of the train and the vacuum pipe. Therefore, it is necessary to study and optimize the structure of vacuum pipeline for long vacuum pipes.

The Channel Tunnel between Britain and France has been completely constructed in 1994 and it consists of three 51 km long parallel tunnels. The highest speed of the train in the tunnel is 200 km/h. In order to reduce the differential pressure and piston effect caused by high-speed train passing through the single tunnel, the pressure recycle ducts (PRD) were set between two adjacent tunnels [4]. Each PRD is provided with a baffle that could be controlled. While the fast driving, the high pressure air formed in the front of the train flows through the PRD goes into the adjacent train running tunnel, then comes along the tunnel to the low pressure area behind the tail. Thus, the original differential pressure formed between front and rear, which impeding the moving of train, is balanced by the mixture of high pressure air and low pressure air themselves [5–9]. Meanwhile, aerodynamic friction resistance can be restrained effectively. But also could reduce the friction resistance between the train and the tunnel wall [10–21]. In VTT, due to the high blockage ratio and high cruising speed, aerodynamic problems, including the aerodynamic drag and aerodynamic heat are more prominent. It is necessary to reduce the damage caused by the pressure and temperature difference, so the structure of PRD is put forward into the VTT. The PRD connect the two vacuum pipes which the trains run and the schematic diagram of VTT with PRD is shown in Fig. 1. The existence of PRD not only realizes the large blockage ratio of VTT and reduce the construction cost, but also could ensure the safe operation of VTT.

2. Numerical simulation

2.1. Dynamic mesh method

In this paper, the dynamic mesh method is used to study the high-speed train running in VTT with PRD. For the case of low speed and incompressible, the way of moving wind and static train is adopted in the previous numerical simulation. Due to the movement of gas in the pipeline could cause the loss of resistance along the way, the flow field which we adopted the way of the static train and moving wind in simulation is far away from the real flow field. The application of dynamic mesh method makes the high-speed operation of the train in vacuum pipeline more close to the real environment. Using the dynamic mesh method, it is necessary to define the initial mesh and the boundary of the movement and also need to specify the moving area. Profile is used to realize the movement of high-speed train and boundary in this paper. The simulation is that the train runs at a supersonic speed in a straight line in VTT with PRD, so the layer method is adopted in dynamic mesh.

2.2. Physical model

The air flow and differential pressure characteristics are studied in VTT based on pressure recycle ducts. The running speed of the train is 0.29Ma, 0.59Ma, 0.88Ma, 1.18Ma. In order to save computational cost, the numerical simulation is based on the two-dimensional physical model, ignoring the running track of train and the connection of the train, and the vacuum pipeline with a certain distance is simulated in this paper.

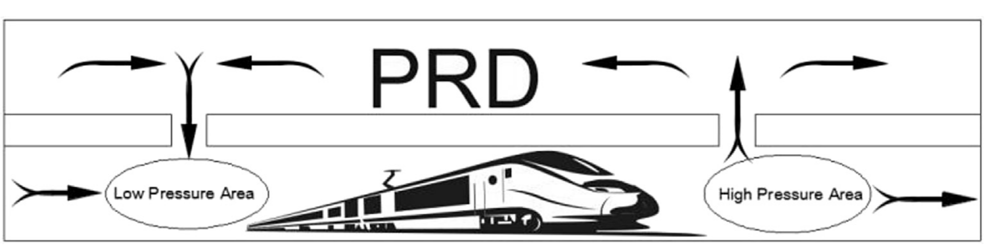

Fig. 1. The schematic diagram of VTT with the PRD.