E3S Web of Conferences 165, 04075 (2020) https://doi.org/10.1051/e3sconf/202016504075
CAES 2020

Characteristics of airflow in the platform with high-speed train passing through the underground railway station

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ABSTRACT: Underground high-speed railway station is becoming more and more popular in recent years, due to its advantage in relieving the tense situation of urban construction land. HVAC (Heating, Ventilation and Air Conditioning) system of underground railway station consumes large energy, therefore it is necessary to find a way to decrease the energy consumption in stations. Reasonable ventilation and air organization are the basis of energy-saving design of environment control system in stations. The energy consumption could be reduced greatly by utilizing the piston wind properly. In the present work, airflow characteristics in the station are investigated when high-speed train is passing through the underground railway station with CCM+ software. Results show that piston wind has different effects on airflow in the platform when the high-speed train is running. However, the air velocity in the platform is always lower than 5 m/s. In order to analyse the effect of piston wind on the airflow in the platform in more detail, the velocities and temperatures at waiting line are extracted. The air velocity near two ends of platform is larger and the similar results could also be observed for temperatures.

1 Introduction

More and more stringent regulations promotes the development of rail transit and the new energy technologies [1]. Rail transit has developed rapidly in the past 200 years, since the first railway was constructed in England. Due to its advantage, governments from all around the world tried their best to build the rail transit system, in order to improve the quality of living of their residents. For example, Chinese government plans to build eight vertical and eight horizontal high-speed railway network before 2030 recently [2]. Rail transit system, including metro and subway systems, are mainly composed of the station and tunnel. As a building, it is necessary to operate heating, ventilation and air-conditioning (HVAC) systems to create the indoor thermal and humidity environment in stations, in which the health of passengers could be safeguarded. Compared with the traditional citizen building construction, the building scale of rail transit stations and passenger flow are both larger. So the HVAC system of rail transit station will consume more energy. It has been revealed that environment control in stations has a great contribution to the energy consumption of rail transit [3, 4]. So it is necessary to find a way to decrease the energy consumption in stations.

Reasonable ventilation and air organization are the basis of energy-saving design of environment control in stations. Basically, There are mainly two types for the ventilation: natural and mechanical ventilations [5]. As a positive mean of ventilation, mechanical ventilations could control the temperature, humidity, air flow and air exchange process in the confined space effectively with assistance of air conditioning and ventilation equipment. Thus, it is used widely in the HVAC system to control air organization in the rail transit station and cause huge energy consumption problem. Natural ventilation could influence the airflow characteristics without the help of mechanical equipment. In the building, wind and thermal pressures could bring the airflow between the indoor and outdoor [6]. Natural ventilation avoids large electricity consumption but its effect is not obvious [7]. So, it has the potential to achieve high energy efficiency using the natural ventilation reasonably [8]. For Rail transit stations, piston wind could be generated due to piston effect when the metro vehicle in the tunnel is running around the subway station. In theory, piston wind could promote the air exchange among the tunnel, station and outside and this may reduce the energy consumption in HVAC system greatly. But it should be noted that piston wind may also lead to high temperature and poor air quality in the station [9]. So it is of great importance to conduct the research on the piston effect on the airflow and thermal environment in the station. In subway station, relative research have been conducted widely by researchers in previous published papers [10-13]. For example, Wang et al conducted the experimental study on particulate matter (PM) concentrations in Shanghai subway system and found that piston wind would influence the pollutant distribution in the station [11]. Liu et al focused on CO_2 concentration and thermal environment in subway system and analyzed the energy consumption when the piston wind is utilized fully [12]. Due to the potential of the

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https://doi.org/10.1051/e3sconf/202016504075

piston wind in energy saving, vented platform screen doors are investigated widely in recent years. The work by Ming et al showed that the piston wind could be made full use of by vented platform screen doors and reduce the energy consumption greatly [13].

Conclusion could be made that the piston wind has been utilized in HVAC system in subway stations. For high-speed railway station, it should be noted that underground high-speed railway station is becoming more and more popular in recent years, due its advantage in relieving the tense situation of urban construction land. For example, HSR Taoyuan Station in Taiwan, Badaling Railway Station in Beijing and Futian Station in Shenzhen are buried in the earth. The structure of underground high-speed railway station is similar with that of the subway station, so it could be suspected the energy consumption could also be reduced greatly by utilizing the piston wind properly. However, there are still some difference in vehicle speed, station size and layout between the subway and underground high-speed railway stations. Thus, it is necessary to study the effect of piston wind on the ventilation in the underground high-speed railway station.

The object of the study is to investigate the effect of piston wind on the airflow in the underground high-speed railway station when the high-speed train passes through the station. An existing underground high-speed railway station in Beijing is simulated at various vehicle speeds with STAR CCM+ software. Then piston wind speed in the tunnel and airflow distribution in the station are recorded and analyzed.

2 Numerical methods

In the present work, STAR CCM+ software is used to simulate the airflow in the tunnel and station. It uses the finite volume method to solve N-S equation and its accuracy has been validated in the calculation of flow dynamic in HVAC system or fire in the rail transit system [14, 15]. The model is established and modified slightly according to the actual size of Badaling underground high-speed railway station, as shown in Fig.1. There are three tunnels between two parts of the platform. The high-speed train stops and departs in the tunnel next to the platform, for the passengers. If the train does not stop, it will run in tunnel 2. There are no platform screen or doors between the tunnel and the station. In the simulation, the vehicle speed is 250 km/h, which is a typical value for the high-speed train. It is assumed that the station operates in summer and we choose the outdoor temperature as 303 K, according to local climate conditions. As shown in Fig.1, one end of the tunnel is employed as the velocity inlet. The air from inlet is the piston wind and the value of velocity and temperature could be obtained with SES (subway environmental simulation) program. Then the equation of inlet velocity will be extracted from piston wind velocity curve with polynomial fitting and is set as the boundary. The other side of the tunnel, entrance and exit of the station are considered as the pressure boundary. The computational domain is defined as the fluid domain and consist of 2,449,792 hexahedral mesh cells. In order to choose proper mesh size, we solved the computational domain with several mesh cells, as shown in Fig.2. Results indicate that the computational domain with 2,449,792 mesh cells are accurate enough.

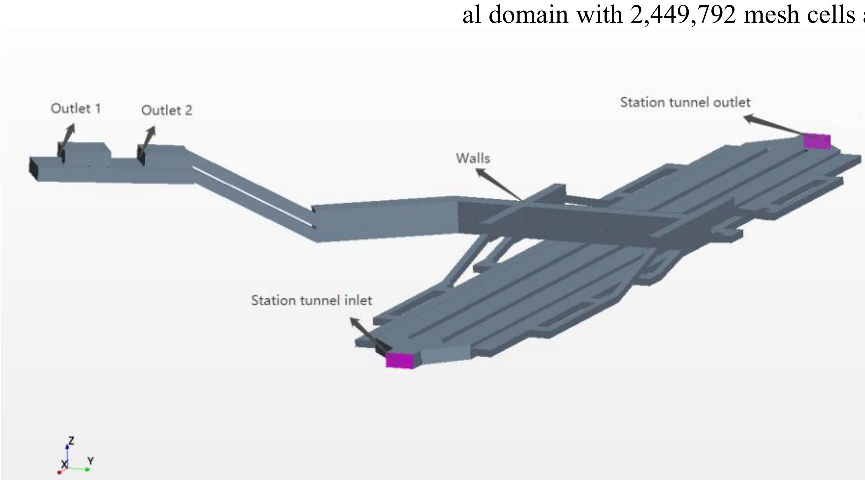


Figure 1 Physical model of the underground high-speed railway station.

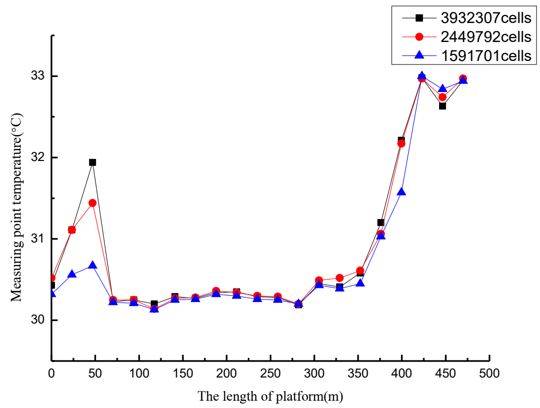


Figure 2 Verification of grid independence.

3 Results and Discussions

There are three tunnels between two parts of the platform. The high-speed train stops and departs in arrival-departure track, for the passengers. If the train does not stop, it will run in tunnel 2. In present work, the train will run in the main line and we study the effect of over-taken train on the airflow in the station, Fig.3 presents the velocity distributions in the tunnel and platform for V=155 mph when the train is on the left side of the station. Although the train is far away the station, the piston wind has affected the environment in the tunnel and station greatly. The high-speed train, as a block, moves towards the station. At this moment, the air in the tunnel was squeezed and the velocity in the tunnel moves toward from the left to the right. In tunnel 2, it could be observed that the air will flow in one direction in tunnel 2. In the tunnel close to the station, the airflow is more complex and its speed is higher. A small part of air moves into the tunnel from the entrance node. There are air path between the tunnel and the station and so the air in the tunnel close to the station will not run in one direction. The air will also enter into the station, as shown in Fig.3. So it is obvious that the velocity in main line is larger than that in tunnels close to the station. In addition, air from the entrance of the station and heat source will also affect the airflow in the tunnel. In Fig.3, the air is inhaled into from the outside, goes through the hall, exit/entrance and enters into the platform. The location of the maximum velocity is around the exit/entrance and could reach up to around 5 m/s. In the platform, the velocity will become larger when the airflow reaches near the exit/entrance. The maximum velocity is about 3m/s, with the influence of piston wind. This illustrates that the strong effect of piston effect although the high-speed train does still not reach the station.

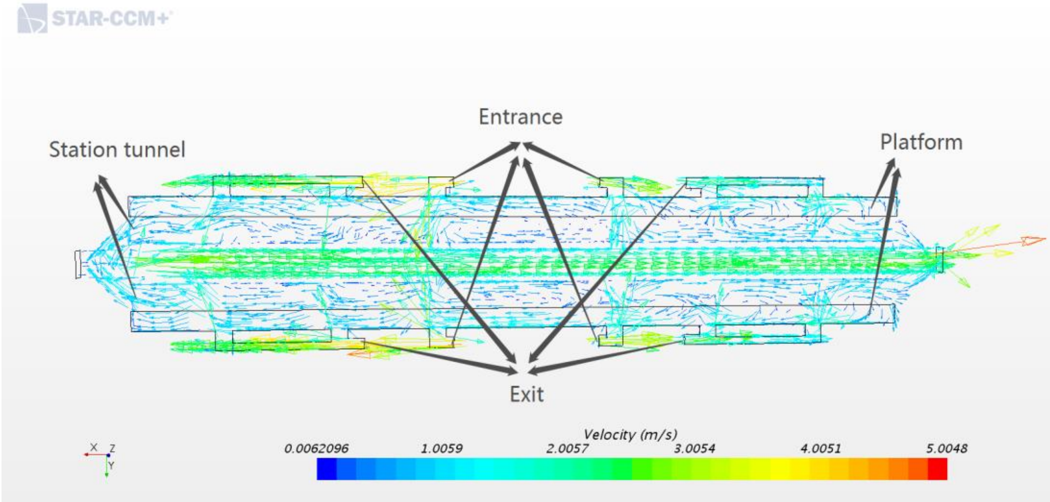
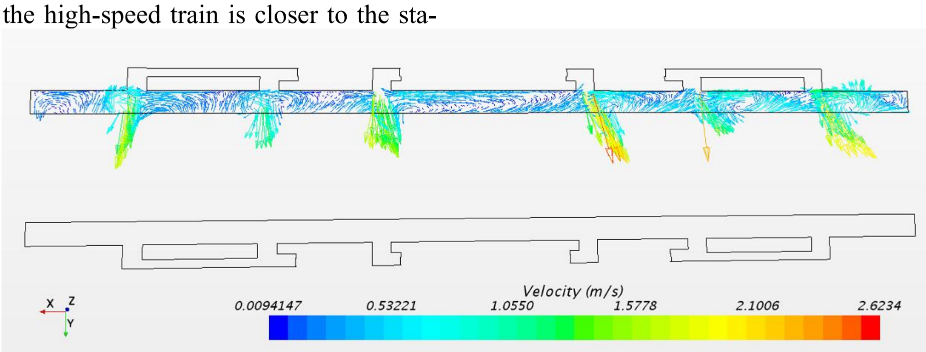
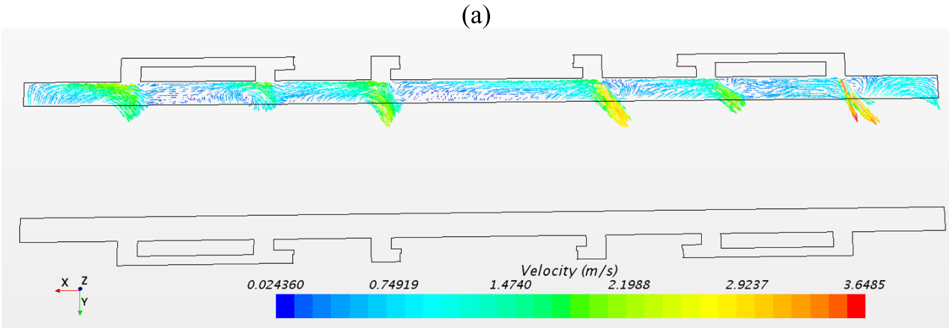


Figure 3 Velocity vectors in the tunnel and platform (V=155 mph, L= -8800 m).

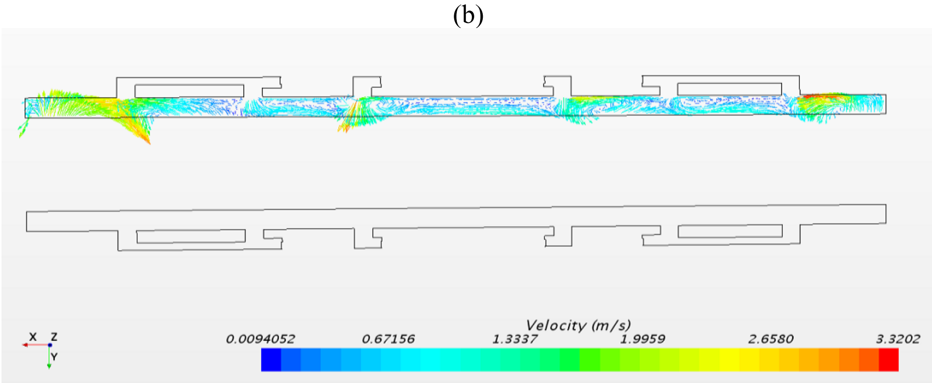
Fig.4 presents velocity vectors in the platform for the train at various locations. The heights of these data are all obtained from 1.7 m on the ground. The data from 1.2 m on the ground are also extracted but the results are similar with each other. It could be observed that the piston wind will affect the airflow in the platform all the time, whether the high-speed train reaches the station or not. Similar results could be concluded that the air will get into/leave the platform from/to the tunnel and the upstairs all the time. At the same time, the vortex could also be seen in the platform due to the strong effects of different airflow from the tunnel and the upstairs. These will affect the comfort of passengers in the platform greatly. However, there are still some differences when the high-speed train is running at various locations. As shown in Fig.4 a, the distribution of velocity in the platform is more even, when the high-speed train does not reach and is far away from the train. The location of the maximum velocity is still around the exit/entrance of the platform. When the high-speed train is closer to the station, the maximum velocity in the platform increases a little. Although the effect of high-speed train and piston wind on the airflow in the station will be influenced by the locations of the running train, the maximum velocity in the platform will not change greatly.



(a)



(b)



(c)

Figure 4 Velocity vectors in platform for the train at various locations (a) L= -8300 m; (b) L= 0 m; (b) L= 2300 m.

In order to get more information on the effect of piston wind on the airflow in the platform, the velocities and temperatures at waiting line are extracted, as shown in Fig.5 and 6. The heights of these measure points are 1.7 m from the ground, the standard height for the study of human comfort. When the passengers are waiting at the platform, it is necessary for passengers to keep behind the yellow waiting line. Thus, the airflow around the waiting line is very important for the safety and comfort. In fact, the velocities and temperatures at waiting line have been investigated widely in previous research work [10]. Basically, the velocities at the waiting line change little for different locations of the platform. Only at two ends of the platform, will the velocity increase greatly sometimes. This means that more air in the tunnel enters into the station by the end of the platform. The location of the high-speed train will affect the velocities at waiting line greatly. It could be found that the maximum velocities at two ends of the platform increase greatly when the high-speed train is around the station. However, the velocities at other parts of the platform is lower than those when the train is far away from the station. On the whole, the maximum velocity is lower than 4.5 m/s. There are similar results for the temperature at the waiting line. The maximum temperature will also occur at two ends of the platform. It is reasonable since more high-temperature air in the tunnel will get into the station from two ends of the platform, as discussed by Fig.5. From the discussion above, it could be concluded that the piston wind will also affect the airflow in the platform when the high-speed train is passing through the underground railway station, although the train does not stop at the station.

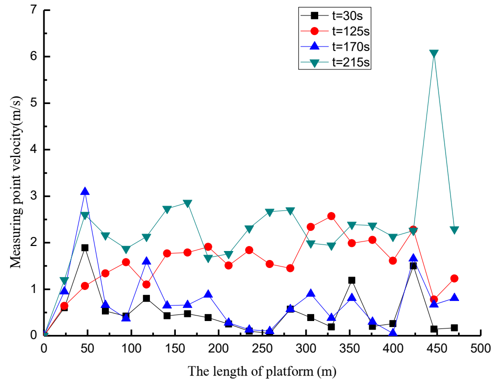


Figure 5 Velocities of the safety line in the station at various locations.

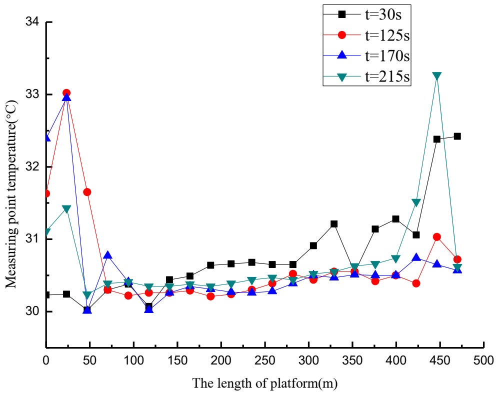


Figure 6 Temperatures of the safety line in the station at various locations.

4 Conclusions

High-speed railway construction has been increased greatly. As an important part of high-speed railway system, underground high-speed railway station is becoming more and more popular, due to its advantage in relieving the tense situation of urban construction land. However, HVAC system of underground railway station will also consume large energy. Research on the subway station shows that the energy consumption could be reduced greatly by utilizing the piston wind properly. Similar with subway station in structure, underground railway station could also achieve the goal of energy conservation by utilizing the piston wind properly. So, we simulate the airflow process in the existing underground railway station with CCM+ software and investigate the effect of piston wind when high-speed train is passing through the underground railway station. The result shows that piston wind has different effects on airflow in the platform when the high-speed train is running. The air velocity in the platform is always lower than 5 m/s. In order to analyse the effect of piston wind on the airflow in the platform in more detail, the velocities and temperatures at waiting line are extracted. The air velocity near two ends of platform is larger and the similar results could also be observed for temperatures.

Acknowledgements

This study is supported by National Key Research and Development Program of China (Grant No.2018YFC0705000)

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