Simulation study on the dynamic velocity field of the supplying jet coupled with the platform piston wind in non-screen door subway stations

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Abstract. The coupling airflows of platform piston wind and station air-conditioning supply air is the most typical airflow organization of non-screen door subway station platform. By establishing a CFD software model of the coupling process between piston wind and air-conditioning supply air in subway station platform, the velocity field of the coupled airflow in the platform under different vehicle conditions is numerically simulated. It has been found that: when the train enters the station, the maximal piston wind velocity can reach 8 m/s with the air-conditioning supply air near the approach end significantly affected by the piston wind than at other positions. The study can provide a theoretical basis for the optimization of the airflow organization and energy consumption in the non-screen door subway station platform.

1 Introduction

The coupling airflows of platform piston wind and station air-conditioning supply air is the most typical airflow organization of non-screen door subway station platform. Since it has a significant impact on the distribution law of cooling capacity in air-conditioning seasons, this study has important research significance.

In recent years, a number of scholars have studied the effect of piston wind on subway platforms and achieved certain results. Hui Yang and Li Jia[1] simulate the velocity field on a subway platform without mechanical air supply with CFD software, revealing that the airflow velocity near the track side of the platform exceeding 5 m/s during train operation and the temperature rising 2-3°C. Lihui Wang [2-3] studied the changes in the velocity field of the station under the entering and leaving conditions through field measurements, and found that the piston wind had a greater impact on the airflow organisation of the part near the train side in entering process and a greater impact on the airflow away from the train side in leaving process. The average wind velocity in the entering condition was about 51% higher than the other conditions. Lihui Wang and Wei Wang [4] obtained the theoretical models of the platform piston wind through mathematical modelling, revealing that the platform wind velocity increases first, remains constant and gradually decreases at the end as the train approaches the station. Lihui Wang [5] obtained a theoretical model of the dynamic coupling of piston wind and air-conditioned air through theoretical modelling, which shows that the trajectory of the coupled airflow gradually deflects to the right, remains unchanged and deflects to the left with the train operating. The above studies mainly focus on theoretical models and field measurements, but the dynamic coupling of platform piston wind and air-conditioning supply air is not fully demonstrated by numerical simulation.

Therefore, in this paper the velocity field of coupled airflow in different sections of the platform is further investigated by numerical simulation. This research work provides important references for optimizing the air distribution in the newly built subway station, improving passengers’ comfort while reducing energy consumption during air-conditioning seasons.

2 Method and methodology

2.1 Calculation method and mesh division

The calculation equations include continuity equation, momentum conservation equation, turbulent kinetic energy and its dissipation rate control equation, and energy equation. The pressure-velocity coupling algorithm is the SIMPLE algorithm. Considering the existence of body forces such as gravity and buoyancy, the pressure discrete difference format adopts the Body Force Weighted format, and other variables adopt the first-order upwind style discrete. The turbulence model adopts the Standard k-ε model, and the governing equation of the Standard model is as follows:

\[ \frac{\partial (\rho u_i)}{\partial t} + \text{div}(\rho u_i u_j) = \text{div}((\Gamma \text{grad} \phi) + S_i) \]  (1)

Where \( \rho \) is the density; \( \Gamma \) is the diffusion coefficient; \( S \) is the source term; \( u \) is the velocity vector; \( \phi \) is the general dependent variable.

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Considering the complexity of the model, an unstructured mesh is used for division, the division method is Robust (Octree), the mesh type is Tetra/Mixed, the number of meshes is 3.16 million, and the mesh quality is below 0.4, accounting for 0.1%. The parameter settings in the simulation regarding the dynamic grid calculation are shown in Table 1.

### Table 1. Dynamic grid parameter setting

| Smoothing                  | Remeshing                  |
|----------------------------|-----------------------------|
| Spring constant factor 1   | Minimum length scale(m) 0.25|
| Boundary node relaxation 1 | Maximum length scale(m) 1.5|
| Convergence tolerance 0.001| Maximum cell skewness 0.85  |
| Number of iterations 20    | Size remesh interval 5      |

#### 2.2 Station geometry model

The structural section of the station model created by software is shown in Figure 1 and the overall geometric model is shown in Figure 2.

![Fig. 1. Sectional view of the subway station structure](image1)

![Fig. 2. Schematic diagram of the subway station](image2)

#### 2.3 Boundary conditions

1) Wall boundary condition
   The solid wall is a no-slip boundary condition. The interval tunnel, surrounding walls and ceiling are given by the first type of boundary conditions which temperature is 27°C.

2) Load boundary condition
   The air-conditioning load of the platform is mainly composed of equipment load, lighting and billboard load, and personnel load. See Table 2 for specific data and parameter settings.

### Table 2. Load boundary condition setting values

| Name              | Escalator | Light | Billboard | Person | Floor |
|-------------------|-----------|-------|-----------|--------|-------|
| Heat flux (w/m²)  | 44        | 15    | 15        | 108    | 9.5   |

3) Tuyere boundary condition
   The supply air outlet is set as the velocity inlet boundary, the total supply air volume is 984000 m³/h, the supply air outlet is a double-layer louver tuyere with size of 600 mm×400 mm. The return air volume is 0.83 of the supply air volume, the outlet is a single-layer louver tuyere with size of 600 mm×400 mm. The supply outlets are arranged on one side of the platform while the return outlets on the other side, 24 on each side, as shown in Figure 3. The bottom heat exhaust system is 200 mm from the bottom of the platform. The size of the tuyere is 800 mm×320 mm with 96 on each side, 192 in total. The size of the tuyere in the top heat exhaust system is 1000 mm×500 mm with 80 on each side, 160 in total. The undefined tunnel exits are all pressure outlets, and the velocity boundary conditions are set as shown in Table 3.

### Table 3. Tuyere boundary condition setting values

| Name                      | Boundary condition                          |
|---------------------------|---------------------------------------------|
| Inbound port tunnel       | Using custom boundary conditions, the velocity decreases from 7 m/s to 0 m/s with the train operating, turbulence intensity is 10%, hydraulic diameter is 5.2m, temperature is 30°C          |
| Outbound port tunnel      | Using custom boundary conditions, the velocity increases from 0 m/s to 8 m/s with the train operating, turbulence intensity is 10%, hydraulic diameter is 5.2m, temperature is 30°C          |
| Air-conditioning supply air outlets | The velocity is 4 m/s, the temperature is 25°C                                |
| Tuyeres of heat exhaust system | The velocity is 3 m/s                          |
| Air-conditioning return air outlets | The velocity is 5 m/s                          |
| Stairway entrance         | Pressure Boundary Outlet                     |

#### 3 Results and discussion

As shown in Figure 2 above, the width, height and length of the subway platform are assumed to be the X, Y, and Z directions of this study. The whole simulation time is divided into four stages, including 0-28 s with the train entering the station at a constant speed, 28-52 s with the train decelerating and entering the station, 52-84 s with the train stopping at the station, and 84-112 s with the train accelerating and leaving the station. The Z1 section (z=20.3 m) near the train's approach end, the Z2 section (z=96.8 m) in the middle of the platform, and the Z3 section (z=165.7 m) near the train's departure end were selected as typical sections for this study.

### 3.1 Velocity field of vertical section below the outlets

In order to study the dynamic change law of the coupled airflow under the outlets with the train operating, three outlets in typical sections (Z1=20.3 m, Z2=96.8 m, and Z3=165.7 m) were selected as the analysis objects, and their location distributions are shown in Figure 3.
Figure 4 shows the velocity field varied with time in the vertical section below the outlets. Firstly, it can be seen from Figure 4(a) that at the time of 12 s, the jet at Z1 has been affected by the piston wind with the axial velocity attenuating to 0.8 m/s at 2 m above the ground, owing to the jet continuously entraining the surrounding air under the action of the piston wind. The supplying jet at Z2 and Z3 is hardly affected at this time. Secondly, Figures 4(b) and 4(c) show that with the train operating, the supplying jet at Z1 section is gradually dominated by the piston wind, and the airflow section expands rapidly. The maximal wind velocity in the local waiting area can reach 2 m/s, leading to a strong blowing feeling. Furthermore, the velocity field of the entire section has obvious upper and lower layers with an average velocity of 1.4 m/s. The supplying jets at Z2 and Z3 are shifted to a certain angle influenced by the piston wind. However, the coupled airflow still maintains the characteristics of the air-conditioning supply air. It can be concluded that during the train’s whole entering process, the supplying jet at the train’s approach end will be more strongly affected by the piston wind. And 24 s is the moment when the platform piston wind has the greatest influence on the air-conditioning supply air. The maximal wind velocity is 5 m/s taken below the outlet and the average velocity is 1.5 m/s, which can have a blowing sensation affecting comfort.

Secondly, combining Figure 4(b) and Figure 4(c), it can be concluded that the piston wind has little effect on the Z2 and Z3 sections at 24 s. Therefore, the original airflow organization form of the platform can be observed with the average wind velocity about 0.5 m/s, and the velocity field of the entire section uniformly distributed. It was also observed that some air-conditioning supply air would be directly discharged through the heat exhaust system, leading to additional energy consumption.

**3.2 Velocity field of platform transverse section**

It can be seen from the above that at 24 s the piston wind has the greatest impact on the air-conditioning supply air. The velocity field of typical transverse sections at this moment are shown in Figure 5.

Firstly, it can be concluded from Figure 5(a) that the platform piston air has a great impact on the entire Z1 section at 24 s. The airflow on the entire section has strong fluidity and the velocity field is unevenly distributed. The maximal wind velocity is 5 m/s taken below the outlet and the average velocity is 1.5 m/s, which can have a blowing sensation affecting comfort. Secondly, combining Figure 5(b) and Figure 5(c), it can be concluded that the piston wind has little effect on the Z2 and Z3 sections at 24 s. Therefore, the original airflow organization form of the platform can be observed with the average wind velocity about 0.5 m/s, and the velocity field of the entire section uniformly distributed. It was also observed that some air-conditioning supply air would be directly discharged through the heat exhaust system, leading to additional energy consumption.
In order to verify the reliability of the simulation results, field measurements were carried out on a subway platform of Shanghai Metro. The station is a double-column island structure with a size of 200 m×20.7 m×12 m, similar to the model built by the numerical simulation above. A typical tuyere in the middle of the platform is taken as the measurement object. 5 measuring points below the tuyere are selected as shown in Figure 6.

The measured and simulated velocity results of some measuring points are shown in Figure 7. It can be seen from the figure that the error value of the tests fluctuates in the range of -30% to 40% owing to the flow of people and the operation of trains. The difference between the setting model and the actual one and the error of the measurement equipments is another reason. However, most of the data errors are within an acceptable range, verifying the accuracy of the numerical simulation.

5 Conclusion

From this paper, we can come to the conclusion that: 1. During the train’s whole entering process, the supplying jet at the train's approach end will be more strongly affected by the piston wind. 24 s is the moment when the platform piston wind has the greatest influence on the supplying jet. On the contrary, the supplying jet at the departure end is greatly affected when the train leaves the station. 2. At 24 s, the platform piston wind not only has a great impact on the supplying jet at the train's approach end, but also has a great impact on the entire station section there. Other sections are less affected by the piston wind at 24 s, the velocity fields of the sections are uniformly distributed.

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References

1. H. Yang, L. Jia, P.L. Huang, Chinese Journal of Underground Space and Engineering, 6(02), 270 (2010)
2. L.H. Wang, X.P. Wu, Chinese Journal of Underground Space and Engineering, 161(2007)
3. L.H. Wang, Z.L. Li, X.M. Du, D.F. Tang, L. Shen, Journal of Chongqing University, 34(S1), 116(2011)
4. L.H. Wang, W. Wang, X.M. Du, Z.L. Li, Y.L. Sun, X. Jiang, Theoretical modeling and solution of the platform piston air jet attached to the wall[J], Journal of Refrigeration, 34(03), 96(2013)
5. L.H. Wang, X.M. Du, Y. Zheng, H. Tao, C. Huang, Theoretical analysis of velocity characteristics of coupled action between supply air jet and piston wind in subway platform[J], HVAC, 45(01), 82(2015)