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Study on Airflow Characteristics of Train Induced by Piston Effect in Subway Tunnel

Study on Airflow Characteristics of Train Induced by Piston Effect in Subway Tunnel

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Abstract. The piston effect caused by the subway train running in the tunnel will cause the air flow to move along the direction of the train to form piston wind. The piston wind generated by the train when braking, starting and through tunnels of different lengths has differences. Combined with these influencing factors, the airflow organization characteristics caused by the train piston effect are studied in a typical single hole single line subway tunnel. Through the test: When the train brakes, the wind speed at both ends of the platform will quickly decrease. When the train starts, the wind speed at the front of the platform will gradually increase, and there will be no obvious change in the wind speed at the end of the platform. Through tunnels of different lengths, the wind speed response time at tunnel exit varies with the distance of train piston wind propagation.

1. Introduction

The subway is different from the ground buildings, which is usually located in the deep underground. In the process of train operation, the power system of the train, the friction between wheel and track, and the lighting equipment will emit a lot of heat. If the heat is not discharged in time in this relatively narrow space, it will reduce the air quality and comfort in the subway [1]. Subway piston wind is very important for the ventilation of the tunnel and the environment of the station. The generation of piston wind does not require additional power. It is generated by the movement of the air stream driven by the train during its operation in the tunnel, which efficiently discharge heat from the tunnel and change the environment of the platform [2]. However, the piston wind produced by the train running in the tunnel is affected by many factors, and the comprehensive effect of various factors is very complicated. Therefore, it is of great significance to measure the piston wind in typical tunnels and study the air distribution characteristics caused by the piston effect in metro tunnels for improving the tunnel environment and reducing the energy consumption of subway tunnels.

2. The Piston Effect in the Tunnel

When the train is running in the tunnel, the air exhausted by the train is limited by the wall of the tunnel and cannot all flow around to the rear of the train. Some of the air will be pushed forward by the train to form longitudinal air flow along the direction of the train, and the negative pressure area behind the rear of the train will inevitably introduce the air at the entrance of the tunnel to the tunnel. Because this phenomenon is similar to that of cylinder piston compression gas, it is called piston effect of train, and the airflow generated by piston effect is called piston wind [3]. It consists of five different flow segments, as shown below.

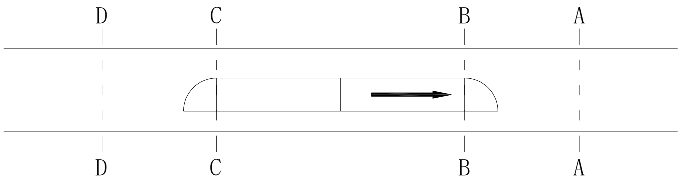

Figure 1. Schematic diagram of airflow organization of train piston effect in tunnel

The A-B flow segment is the flow segment formed by confined space flow. The basic characteristics of the flow section are unsteady and non-uniform. The B-C flow segment is an annular flow, the basic properties of which are constant and uniform. The C-D flow section is the flow section formed by the restricted space wake vortex, that is, the annular flow outlet section, which has the same flow characteristics as the inlet flow section. The two sections of the section A and D to the tunnel mouth are stable and uniform piston wind sections. The difference between the two segments is relatively variable flow length and Positive pressure and negative pressure respectively, but the flow characteristics are not affected [4]. In general, the piston wind varies with time, and the instability of this flow is manifested in the changes in the speed of the tunnel section as the train enters, leaves, accelerates and decelerates. When the train passes through an interval tunnel, the air flow in the tunnel is an unsteady flow process. Therefore, only take into account the changes in the airflow over time in the tunnel, can the unsteady flow process of the air flow can be accurately and truly depicted.

3. Test Methods

The high precision anemometer is used to collect the wind speed data of tunnel entrance and exit, and then combined with the speed of train passing through the tunnel, the variation of tunnel wind speed with train speed and time is obtained when the train brakes, starts and passes through tunnels of different lengths.

3.1. Test Platform

The measuring tunnel is a single hole single line circular tunnel with a diameter of 3m, and the track bed is 4.82m from the top of the tunnel. The length A of the interval tunnel is 675m, the interval tunnel is B long 1435m, and there is no shaft in the tunnel. The platform A, B and C are all island platforms, the platform length is all 130m, and the platform is fully enclosed platform. The running trains are all type A Metro trains, with a length of 22 meters, a width of 3 meters and a height of 3.8 meters. A train has six carriages, including four power cars and two trailers.

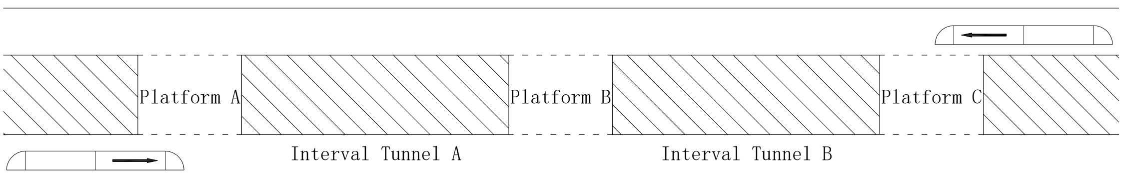

Figure 2. Test tunnel sketch map

3.2. Test Principle

The motion of any fluid is produced and developed in the three-dimensional space, but when only one direction is the main motion direction, the movement in the other two directions can be neglected, thus simplifying the one-dimensional motion [5]. Because the air flow in the subway tunnel is similar to the flow in the tube along the axis, it can be regarded as a one-dimensional motion along the axis. According to the basic principle of fluid mechanics, when the flow in the tube is $Re<2300$, the flow state of the fluid is laminar flow, and the velocity gradient on the cross section is obvious. When the flow in the tube is $Re>2300$, the flow state begins to change from laminar flow to turbulence. When the flow in the tube is $Re>>2300$, it can be considered that the flow of fluid is in a turbulent state, and the velocity distribution across the cross section is relatively uniform [6]. Therefore, the piston wind in a subway tunnel can be regarded as one dimensional longitudinal air flow along the direction of the tunnel, and the average wind speed of the whole cross section can be expressed by a point wind speed in the cross section.

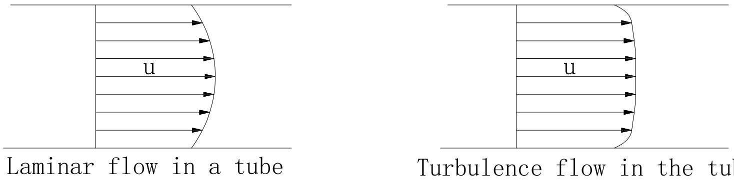

Figure 3. Diagram of velocity distribution in tube flow

3.3. Measuring Point Layout

During the operation period, metro tunnels are not allowed to enter, nor are lines allowed to be erected. Therefore, the piston wind in the tunnel can only be measured at the platform end door near the tunnel entrance. The measuring equipment is AS8166 hot wire anemometer produced by Smart Sensor Company. The measuring range of the anemometer is 0-30m/s, the accuracy is 1%, and the indexing value is 0.01m/s. Location of measurement points includes the front of platform A, the front of platform B, the end of platform B, and the end of platform C.

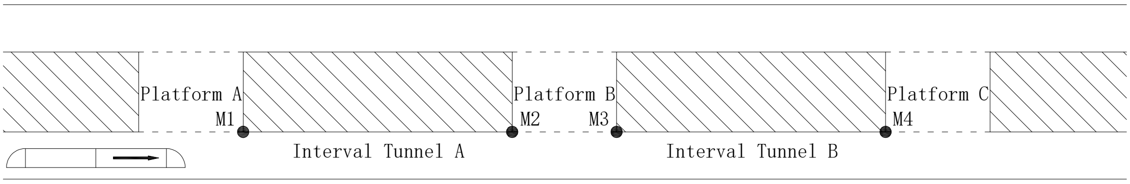

Figure 4. Layout of wind speed points

4. Test Results and Analysis

4.1. The Change of Wind Speed in the Station During Braking

After the train started to brake, the speed of the train is reduced from 50km/h to 0 in 21 seconds. In this process, the wind speed at the end (M2) of the platform is directly reduced from 6.3m/s to 1.8m/s in 10 seconds. But then the wind speed gradually increased, and keep it near 2.6m/s after the train stops. The wind speed at the front (M3) of the platform is reduced from 5.4m/s to 0.15m/s in 30 seconds, and stay around 0.15m/s. The wind speed changes of the platform during the train braking process are shown below.

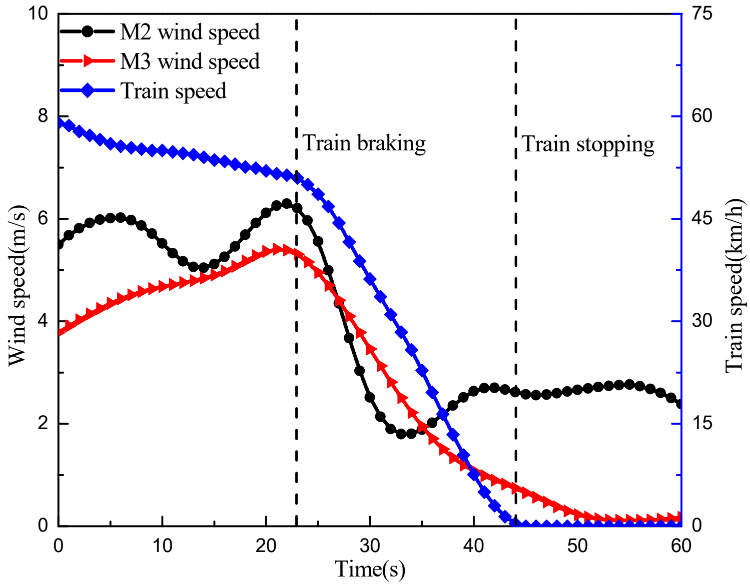

Figure 5. Wind speed change curve of platform during braking

Through the curve of the platform wind speed during train braking, it is concluded that the platform wind speed will drop sharply during braking, and the platform has certain air leakage effect. When the train starts to enter the platform, the blockage effect caused by the train will increase the wind speed at the end of the platform and will remain stable after the train stops. At the front of the platform, due to the blocking effect after the train entering the platform and the diversion effect after the platform screen door opening, the wind speed will be relatively small.

4.2. The Change of Wind Speed in the Station During Starting

After the start of the train, the running speed rises from 0 to 53 km/h in 19 seconds. At the end of the platform (M2), the wind speed is still decreasing within 5 seconds after the train starts. Thereafter, the wind speed increased from 1.7m/s to 2.5m/s in 14 seconds. After the train runs smoothly, the wind speed decreases slightly, and finally keeps near 2.2m/s. The wind speed at the front of the platform (M3) does not change significantly within 5 seconds after the train starts, and the wind speed will increase from 0.15m/s to 2m/s in 14 seconds after 5 seconds. After the train runs steadily, the wind speed decreases first and then rises, and finally stabilizes near 1.6m/s. The wind speed changes of the platform during the train starting process are shown below.

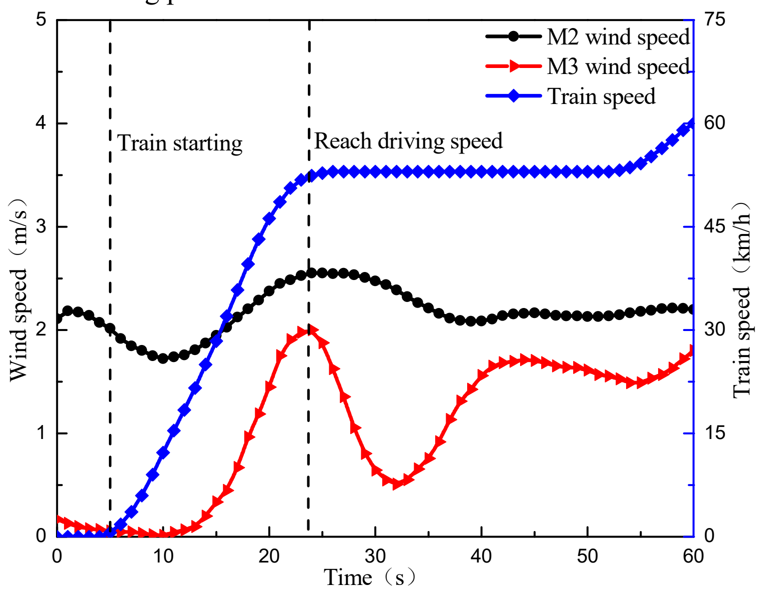

Figure 6. Wind speed change curve of platform during starting

Through the change curve of the station wind speed during the train starting process, it can be concluded that the platform wind speed will rise rapidly after a certain delay in the starting process. This is because the train did not completely exit the platform during the initial starting period, and the train still has a blocking effect near the platform. When the train leaves the platform, the wind speed at both ends of the platform rapidly increases. After the train runs steadily, the fluctuation of the wind speed at the front of the platform is caused by the arrival of the train on the other line. If the train of another line is not considered, the wind speed of the platform will also become stable after the train runs stably.

4.3. Changes in the Piston Wind at the Tunnel Entrance and Exit during a Train Running in a Tunnel

When the train stops at platform A, the wind speed at the exit of tunnel A is maintained near 1 m/s, while that at the entrance of the tunnel is basically 0. After 24 seconds of starting, the train reached a steady speed of 57 km/h. After 21 seconds of stable running, the train began to brake, and stopped at platform B after 21 seconds. In this process, the wind speed at the tunnel entrance (M1) increases from 0 to 3.2 m/s within 39 s after the train starts for 5 seconds, and then decreases from 3.2 m/s to 1.5 m/s within 30 seconds, and then stabilizes at about 1.5 m/s. The wind speed at the tunnel exit (M2) increases after 10 seconds of train start-up, increases from 0.9m/s to 5.7m/s after 18 seconds, and decreases after 15 seconds, from 5.7m/s to 1.9m/s within 15 seconds, and finally stabilizes near 2.2m/s. The curve of the wind speed at the entrance and exit of the tunnel when the train passes through tunnel A is shown in the figure below.

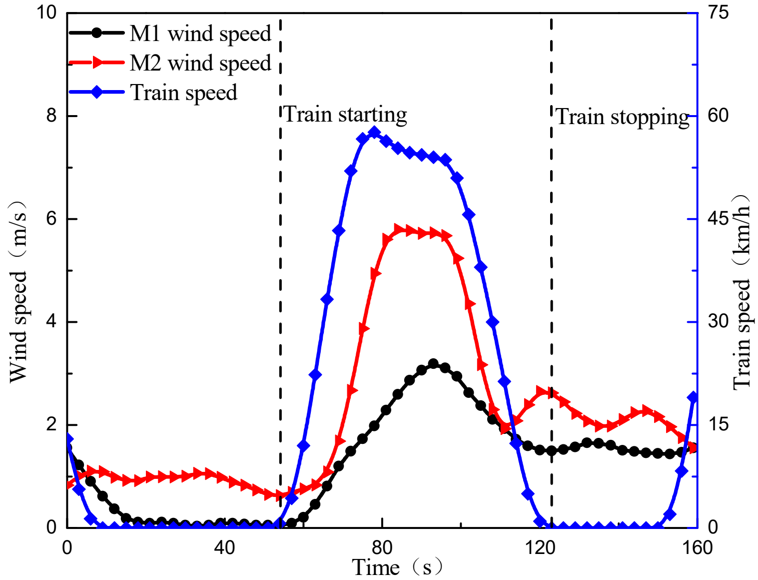

Figure 7. wind speed variation curve of tunnel entrance and exit during train passing through tunnel A

When the train stops at platform B, the wind speed at the exit of tunnel B remains about 1.5m/s and at the entrance is 0. After 18 seconds of starting, the train reached a steady speed of 53 km/h. After 78 seconds of stable running, the train began to brake, and stopped at platform B after 21 seconds. During this process, the wind speed at tunnel entrance (M3) increases from 0 to 1.7m/s within 15s after the train starts for 5s, and remains near 1.7m/s after a small fluctuation. When the train brakes, the wind speed decreases from 1.7m/s to 0.4m/s within 60s. The wind speed at the tunnel exit (M4) increases after 15 seconds of train start-up, increases from 1.6m/s to 4m/s after 27 seconds, and decreases after 48 seconds, from 4m/s to 1.7m/s within 15 seconds, and finally stabilizes near 1.8m/s. The curve of the wind speed at the entrance and exit of the tunnel when the train passes through tunnel B is shown in the figure below.

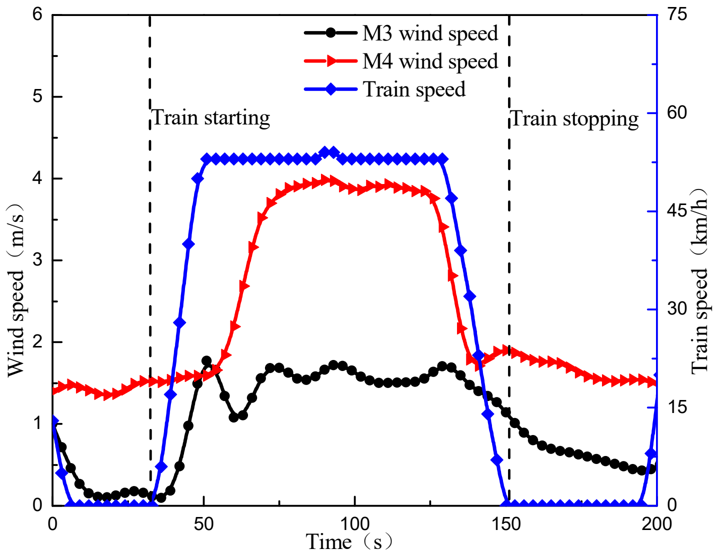

Figure 8. wind speed variation curve of tunnel entrance and exit during train passing through tunnel B

From the wind speed curve of the tunnel entrance and exit when the train passes through the tunnel of different lengths, it can be concluded that when the train passes through the shorter tunnel, the wind speed at the tunnel exit responds quickly and varies greatly. When the train passes through a long tunnel, the response of the wind speed at the exit of the tunnel is very slow and the change is small. After analysis, it is because the air flow generated by the piston effect of train travels in a longer tunnel and takes longer time to reach the tunnel entrance and exit. However, the wind speed at the exit of a longer tunnel is less than that at the exit of a shorter tunnel, which is not necessarily related to the length of the tunnel, which should be caused by other reasons. Because the train is running at a steady speed and approaching the exit of the tunnel, the wind speed at the exit of the tunnel does not increase with it.

5. Conclusion

Considering the braking process, starting process and the different length of tunnel, the piston wind will change. Therefore, the experimental study of the airflow organization characteristics in the actual subway tunnel is carried out. The following conclusions are drawn:

(1) After the train starts braking, the platform wind speed will drop rapidly. When the train starts to enter the platform, the blocking effect caused by the train will cause the wind speed at the end of the platform vehicle to rise. At the front of the platform, the wind speed will be 0 because of this blocking effect and shunting effect after the screen door is opened.

(2) After the train starts to start, because there is still a blocking effect due to not fully exiting the platform, the platform wind speed will remain basically unchanged. After the train completely exits the platform, the wind speed increases rapidly. After the train runs steadily, the wind speed at the platform will also stabilize.

(3) When the piston wind in the tunnel passes through the platform, even a fully closed platform still has a certain effect of air leakage, which will cause the wind speed at the front of the platform to be less than the wind speed at the end.

(4) When the train passes through tunnels of different lengths at basically the same speed, the wind speed response at the exit of shorter tunnels is faster, but the wind speed at the exit of tunnels is not determined by the length of tunnels.

On the other hand, it was also found in the experiment that the entry of another line train would have an impact on the wind speed of the line, and because of the opposite direction of the train running on the two lines, this effect is a weakening effect.

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