Numerical Simulation of Snow Accumulation on a Bogie of a High-Speed Train

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ABSTRACT

The operation of high-speed trains in ice and snow weather results in a large amount of snow accumulation with ice on bogie, which will seriously damage the safety of high-speed trains. In this paper, the snow accumulation on the bogie has been investigated using numerical simulation method based on Realizable $k-\varepsilon$ turbulence model. The accuracy of mesh resolution and methodology of CFD were validated by combining with the experimental results of wind tunnel tests. The Discrete Phase Model (DPM) was used to investigate the process of snow accumulation on bogie. The results show that the high-concentration snow particles mainly flow under the bogie, and the heat-producing equipment is in high snow concentration while the top surfaces of bogie are in low one; when high-speed trains running in one way, the snow on the front motor and gear cover is more than the rear, while the snow accumulation on the rear brake calipers is more than the front, the accumulation quality of snow on the motors is far more than on brake calipers and gear covers.

Keywords: High-speed train, Bogie, Snow accumulation, Discrete phase model, Numerical simulation

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1 INTRODUCTION

When high-speed trains running in snowy weather, lots of snow particles are rolled up by the train induced wind, which result in the massive snow accumulation on the surface of bogie \(^1\). The heat radiated by some equipment, such as brake calipers, gear covers and motors, will melt snow into water, then it will come into being massive ice in cold winter, which will lead to the serious snow and ice on the bogie. Especially, the moving parts of brake calipers may be hindered because of ice, which result in extremely dangerous running environment of high-speed trains \(^2\).

To solve the issue, a large number studies have been undertaken. Some European railway institution have investigated the methods for removing snow and ice on the bogie, such as hot air in Scotland \(^3\), propylene glycol in Sweden \(^4\), hot water in Finland \(^5\) and the propylene aqueous solution in Russia \(^6\). Moreover, some other countries reduce snow accumulation on the railway line to alleviate the snow and icing problem of bogie. For instance, the spraying device were installed Tokaido Shinkansen \(^7\) and the snow fences were built along the Bergen Railway \(^8\). However, the positions of deicing and snow removal devices are changeless so as to only deal with the ice and snow problems at certain locations. But, China High-speed Railway has far distance in cold region, which results in a long-time operation of high-speed trains. The snow and ice problems of bogie can not to be solved in time, which lead to the potential to pose a safety threat of high-speed trains. Therefore, it is completely necessary to have an investigation on snow accumulation on the bogie to ensure the operation safety of high-speed train.

The high speed train induced airflow blows the snow particles on the track up \(^7\), then the phase transition of snow particles on the surface of bogie lead to the serious snow and ice problem. So the discrete phase model (DPM) was adopted in this paper to simulate the motion characteristic of snow particles (discrete phase) in the flow field of bogie region (continuous phase) \(^9\-\^14\). By analyzing the motion characteristics of snow particles to study the process of snow accumulating on bogie surface. This paper is organized as follows. In Section 2, the mathematic model, geometric model, computational grid, boundary conditions and related parameters setting of numerical simulation are presented together. The numerical results of continuous are compared with the wind tunnel tests results to validate the accuracy of the resolution of the mesh and methodology. In Section 3, the concentration distribution and snow accumulation are analyzed. Finally, conclusions are drawn in Section 4.

2 CFD NUMERICAL ANALYSIS

2.1 Mathematical model and geometry model

Based on Reynolds averaged motion equation, the Realizable \(k - \varepsilon\) turbulence model of the numerical simulation was selected to simulate the flow field of bogie region. The details of continuity equation, momentum equation, energy equation and
related parameters can be consulted in reference \[15\]. And the details of Realizable \( k-\varepsilon \) turbulence can be consulted in reference \[16\]. The movement parameter (velocity and displacement etc.) of snow particles can be obtained by integrating the differential equations that describe the forces acting on the snow particles. The differential equation describing the forces acting on the snow particles can be consult in reference \[17-20\].

Owing to the numerical simulation results needs to be compared with wind tunnel test results to validate the accuracy of the CFD method, the wind tunnel test were conducted in National Engineering Laboratory for High Speed Railway Construction. The aim of this paper is to study the phenomenon of snow accumulation on bogie through analyzing the flow characteristics of bogie region, so a 0.5 scaled experimental model can be used, as shown in Fig. 1. The vertical flat of carriage was simplified to inclined face with 30 degrees to avoid causing disturbance to the flow field of bogie region by the air flow at end flat of carriage. The geometry model of numerical simulation and the wind tunnel test are basically the same. The wheels, brake calipers, motors, gear covers and bogie frame were both preserved in the numerical simulation and wind tunnel tests, as shown in Fig. 1(b).

![Experimental setup and Computational model](image)

*Figure 1. Geometry model.*

### 2.2 Computational mesh and boundary condition

The Open FOAM mesh generator package was applied to build the hexahedral mesh around train and bogie, as shown in Fig. 2. The refining meshes are applied to near wall of the train and bogie. In addition, a uniform transition mode with a constant growth factor between the fine grid and the sparse grid is adopted. 10 prism layers in boundary layer are applied to the train and bogie surface in order to catch the flow characteristics in the boundary layer from the bogie surface. The thickness of the first boundary layer is 0.39mm to ensure the use of wall function in Realizable \( k-\varepsilon \) turbulence model \[21\]. There are approximately 22 000 000 volume meshes. The boundary layer configuration can be seen in Fig.2 (a).
The cross-sectional area of the wind tunnel is $3 \times 3 \, \text{m}^2$, the length of test section is 15m, so the computational domain are basically the same as the test section of wind tunnel, as shown in Fig. 3. In numerical simulation investigation of this paper, the velocity inlet of computational domain is given uniform wind speed of 35 m/s. The pressure outlet is given a static pressure of 0 Pa. The top, ground and side surfaces of the computational domain are set as no-slip stationary walls. The tracks and fixed board are set as moving walls with speed of 35 m/s. And the train and bogie surfaces are also treated as no-slip walls. For the DPM model, the tracks, fixed floor and train body are set as reflect condition, and all surfaces of computational domain are set as escape condition. To tally the number of snow particles accumulating on the bogie surfaces, the bogie surfaces are treated as trap condition. The snow particles are released at the vertical surface which is 1m far from the bogie entrance. The iteration time in the simulation of this paper was 2s, the particle time step size was 0.001s. In addition, the calculation was based on a pressure solver, and the pressure and velocity fields were coupled by the SIMPLEC algorithm.

### 2.3 Validation

To validate the accuracy of numerical simulation of air flow trend, the numerical results are compared with wind tunnel test. Fig. 4(a) presents the positions of pressure monitoring points. Fig. 4(b) shows numerical and experimental results of the pressure coefficients along the centerline of the front wheel. As it can be seen from Fig. 4(b) that the numerical simulation results are in good agreement wind tunnel test results, which means the mesh and methodology are sufficient to achieve accurate numerical results of flow field in the bogie region.
3 RESULTS AND DISCUSSION

3.1 Concentration analysis of snow particles

To investigate the process of snow accumulation on the surface of heat-producing equipment, the slices parallel to the axial direction were created at the positions of motors, gear covers and brake calipers, as shown in Fig. 5. Besides, 4 slices parallel to vertical direction were also created in Fig. 5. Since the slice 1 and slice 6 are in symmetrical position in bogie region, and the slice 2 and slice 5 are in antisymmetric position, and the slice 3 and slice 4 are also in antisymmetric position, so the concentration distribution of snow particles in the bogie region are only conducted on slice 1, slice 2, slice 3, slice 4 and slice 5. And the analysis of concentration distribution at slices with different height is conducted on slice 7, 8, 9 and 10.

It can be seen from Fig. 6 (a) that snow particles with high concentration mainly flow under the bogie, while the snow concentration of the upper space of bogie region is low. The heat-producing devices, such as brake calipers, motors and gear covers, are surrounded with high-concentration snow particles, which contribute to massive snow accumulation on their surface. Owing to the shielding
effect of the front wheels, the snow concentration around brake calipers is lower than it around other heat-producing equipment. Fig. 6 (b) presents the snow concentration on slices with different height. It shows the lower parts of motors and gear covers are in high concentration environment. With the height increasing, the snow concentration of bogie region becomes lower.

3.2 Snow accumulation analysis

Figure 6. Snow concentration on slices.

Figure 7. Snow accumulation on the bogie.
Fig. 7 presents the numerical results of snow accumulation on the bogie surface at the time of t=2.00s. It can be seen in Fig. 7 that the amount of snow accumulation on the bottom surface of bogie is much more than the top surface, and the snow accumulation at rear side of bogie is also far more than at the front side. To understand it clearly, the qualities of snow particles accumulating on the surface of gear covers, brake calipers and motors are counted in Fig 8. Owing to the larger exposure area in high concentration snow particles, the accumulation quality on motors is much more than it on brake calipers and gear covers.

4 CONCLUSION

In this study, the snow accumulation problem of bogie of high-speed trains were investigated using DPM model. The flow field numerical result was validated against experimental results. The reason for snow accumulation on bogie surface was analyzed, and the deflector was designed in this paper. Based on the results, the following conclusions can be drawn.

(1) The high-concentration snow particles flow under the bogie, and the concentration of the snow particles above the bogie region is really low. With the height increasing, the concentration of snow particles becomes lower and lower. The heat-producing devices (motors, brake calipers and gear covers) are in a high concentration snow particle flow field while the upper surface of bogie frame in the low one.

(2) When high-speed trains running in cold and snowy region, the quality of snow accumulation on the motors is much more than it on the brake calipers and gear covers. The snow accumulation on the heat-producing equipment will seriously affect the operation safety of high-speed trains.

REFERENCES