Study on Snow and Ice of Bogie based on STAR-CCM+

Mingyang Liu, Guangjun Gao, Jiabin Wang, and Yan Zhang

ABSTRACT

When high-speed train running in cold region, large quantities of snow and ice gather on the surface of bogie, seriously threatening high-speed train traffic safety. In this paper, the Lagrange multiphase model implanted in commercial CFD software STAR-CCM+ was used to simulate the air-snow two-phase flow in the flow field of high-speed train bogie. The results show that the airflow mainly entered the bogie region through the bottom surface of train, and the snow particles accumulating on the roadbed are accelerated because of the driving effect of the aerodynamic force. The many complex air vortexes form and flow around the main heating-generating equipment since the complex structure of bogie and the snow particles rush against the main heat-generating components (motors, brake clamps, gearboxes, etc.) and resulting in serious snow and ice accumulation. Key words: bogie region, snow accumulation, STAR-CCM+, numerical simulation

1 INTRODUCTION

China's high-speed rail has a large span in cold region. When the high-speed train runs at high-speed in the snowy weather, the snow particles will be rolled up by strong air induced flow of train and flow into the bogie region. Owing to the

Key Laboratory of Traffic Safety on Track of Ministry of Education, School of Traffic & Transportation Engineering, Central South University, Changsha 410075, China
aerodynamic force, large qualities of snow particles flush to bogie surface, causing serious snow accumulation in the bogie region. Then the snow accumulation will melt into liquid water and formed ice again due to strong cold weather, leading to massive ice. Serious snow icing in bogie region of high-speed train not only affect the transport efficiency and the comfort of passengers \[1\], but threaten the running safety of high-speed trains \[2\].

Aim at this issue, a large number researches have been done at home and abroad. Masaya SHISHIDO et al. \[3\] found that the floor equipment and bogie were the main place of snow accumulation. The anti-snow performance of the baffles with different sizes were obtained by wind tunnel test. Meanwhile they suggested that the future direction of reducing snow will be to explore the shape of the baffle as well as the snow particle attachment point. Ding Sansan et al. \[4\] have compared the different deflector anti-snow effect by analyzing air intake volume, flow line, car-body aerodynamic force, flow velocity of the bogie region with different slant distances. Aiming at the problem of snow and ice adhered to bogies, LI Chaohui et al. \[5\] used the numerical simulation method to simulate the aerodynamic flow field of the bogie. It was concluded that the surrounding flow field of the bogie region was improved after adding the spoiler structure, and it was pointed out that the anti-snow effect of the spoiler structure was related to its shape.

However, the literatures above have not used the multiphase flow to simulate the process of snow accumulation and ice. In this paper, numerical simulation method has been used to simulate the air flow field in the bogie region of high-speed train, and the snow accumulation in the bogie region was analyzed using Lagrange multiphase flow model. Based on the numerical simulation results, the movement characteristics and mechanism of snow accumulation were also analyzed in order to provide the theoretical basis for the future optimization of anti-snow design of high-speed train bogie.

2 CFD analysis

2.1 Mathematical model

In this paper, the speed of the train is less than 0.3 Mach, and the fluid in the numerical calculation can be considered as incompressible viscous fluid, which means that the fluid density is constant \[6\]. Combined with the high-speed train model used in this paper and the train running speed of 250km / h, the Reynolds
number around the train was far more than the critical number, so the ambient air flow was turbulent \[7\]. The realistic k-\(\varepsilon\) turbulence model was used to describe the process of airflow in the bogie region, and the CFD software STAR-CCM + was used for numerical calculation.

Based on the STAR-CCM + CFD software, the Lagrange multiphase model was used to simulate air-snow two-phase flow \[8\]. The particle was set to the material particle and the Schiller-Naumann correlation was used to define the drag coefficient.

The calculation was set to unsteady state and the time step was 0.005S.

2.2 Geometry model and computational grids

For this article, a single section high-speed train was used as the computational model. The vehicle length is 17.1 m. The vehicle width is 3.3 m and the vehicle height is 3.7 m. The train model shown in Figure 1, the bogie model shown in Figure 2. This section mainly explored the snow particle accumulation in the bogie region, so the computational model eliminates the complicated details of the pantograph, door and window of the car body, leaving only the simplified basic outline shape.

In this paper, the grids type used in numerical simulation is hexahedral mesh. The CFD analysis software OpenFoam was used to disperse grids. The grids size of the train body was set to 7 level and the minimum grids length is 0.03m. The grids size of the bogie was set to 8 level and the minimum grids length is 0.015m. Both the train body and the bogie were set to 6 layers of evenly distributed boundary layer grids. The ground was set to 5 layers of evenly distributed boundary layer grids. The track was set to 4 layers of evenly distributed boundary layer grids. Figure 3 for the vehicle grids, Figure 4 for the bogie grids.

(a)Train model                        (b)Bogie model

Figure 1. Geometry model for CFD.
2.3 COMPUTATIONAL DOMAIN

The boundary condition is affected by the boundary condition, especially the flow field around the train. In order to make the flow field of the computational domain fully develop, the length of the computational domain is 120m, the width of the Y direction is 60m, and the height of the Z direction is 40m. The computational domain was shown in Fig. 5.

2.4 BOUNDARY CONDITIONS

The net wind field boundary conditions: The wind speed of Velocity-inlet was constant wind speed 69.3m / s. The pressure outlet take static pressure to zero. In addition to inlet, outlet and ground, the others of the computational domain were set to symmetry plane. The train body and other wall were set to wall and no slip. The ground and the track were set to the same slip speed as the inlet speed.

The coupling boundary conditions for snow particles and continuous: the boundary condition of the train body was set to rebound. The bogie wall boundary condition was set to stick. The boundary condition of the track and the ground was
set to escape. The particle diameter was set to $2 \times 10^{-4}$ m, the particle density is 100 kg/m$^3$, the particle injection rate is 0 m/s, the particle injection frequency is 100 times/s, and the injection time was randomized. The remaining boundary conditions were the same as the condition of net wind field.

3 RESULTS AND DISCUSSION

3.1 Numerical results of flow field in bogie region

In this section, the spatial streamline distribution in the bogie the snow parts of the bogie and the reasons of snow will be analyzed and discussed.

![Streamline distribution in different regions](image)

Figure 6.

The motors streamline distribution is shown in Fig. 6 (a) and Fig. 6 (b), it is concluded that the front and rear motor is closer to the ground than the bottom of train, so that the airflow reaching the bogie region through the bottom of train directly acts on the motor, this causes the windward of front and rear motor to snow easily.

The left brake clamps streamline distribution is similar to the right as shown in
Fig. 6 (c) and Fig. 6 (d), it is believed that there is only a small amount of airflow passing through the gap between the front wheel and brake clamp, and the brake clamp at the rear wheel is directly affected by the airflow. Resulting in the front brake clamp is not easy to snow and the rear brake clamp is easy to snow.

Observations were conducted from Fig. 6 (e) to Fig. 6 (f), it was observed that the airflow reaching the bogie through the bottom of train directly acted on the windward of the front and rear gearbox, causing the windward of front gearbox to accumulate snow easily. For the vortex of the front end-plate where the airflow was moving downward relative to the front end-plate, it was not easy to snow. For the rear end-plate where the airflow was moving upward relative to the rear end-plate, so it was more snow.

3.2 Analysis of motion of snow particle in bogie region

The results obtained by using the Lagrange multiphase model described above. This provided insight into the flow field characteristics of the bogie and the movement trend of snow particles.

Figure 7. The movement of snow particles in the bogie.
The movement of snow particles around bogie obtained the by observation as shown in fig.7 and the volume fraction of snow particles is shown in fig.8. It is confirmed that the windward of front and rear motors, rear end-plate had a high volume fraction of snow particles, so the snow in this region was more serious. The front brake clamps had a low volume fraction of snow particles, and then the windward of rear brake clamps had a high volume fraction of snow particles, which showed the front brake clamp was not snow serious parts, and then the rear brake clamp was a serious snow parts. The windward of front and rear gearboxes had a high volume fraction of snow particles, indicating that the windward of front and rear gearboxes were severe snow regions. And there was a tendency for some high concentrations of snow particles to rise in the rear region of the bogie and a large amount of particles entered the upper region of the bogie. The velocity of snow particles entered the upper region was very low and thus accumulated in the upper region of the bogie. Finally, there was a serious accumulation phenomenon.

4 CONCLUSION

(1) Most of the airflow enters the bogie from the bottom of train under the no cross-wind condition. The snow particles which accumulate on the track bed are rolled up by airflow, and aerodynamic drive them to accelerate to the airflow speed. Airflow enter the bogie region and then many complicated vortices occur in the bogie region, this is because the bogie region is made up of complex geometrical structures. These complex flow phenomena lead to a large amount of snow in the bogie region.

(2) When the airflow bypasses some of the heating parts (brake clamp, motor,
gearboxes, etc.) in the bogie region, snow particles impact these parts under the action of inertial force as the snow particles have a strong follow-up. With snow melted and iced, snow continue to accumulate, it will create more serious snow and ice on these components.

ACKNOWLEDGEMENTS

The authors acknowledge the computing resources provided by the High-speed Train Research Center of Central South University, China.

This work was accomplished by the supports of the National Key Research and Development Program of China [Grant No. 2016YFB1200404], the Project of Innovation-driven Plan in Central South University [Grant No. 2015CX003], the National Science Foundation of China [Grant Nos. 51605044 and U1534210] and the Science Foundation of Hunan Province [Grant No. 2016jj3005].

REFERENCES