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Research on the anti-snow performance of the diversion-slot structure in the bogie regions of alpine EMU

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SUMMARY:
In order to address the issue of snow accumulation in the bogie regions of alpine EMUs (Electric Multiple Units), this study investigates the effectiveness of a diversion-slot anti-snow structure using unsteady Reynolds-Averaged Navier-Stokes simulations (URANS) coupled with the Realizable k-ε turbulence model and Discrete Phase Model (DPM). The results demonstrate that the implementation of diversion slots facilitates the early separation of shear layers, reducing the fluctuation amplitude of vertical velocity in the wind-snow flow beneath the bogies and mitigating snow accumulation issues. Compared to the case with 5.14° guide slots, the use of 10° diversion slots significantly optimizes the wind-snow flow direction at the bogie entrance and narrows the vertical distribution range of the wind-snow flow within the bogie region. This effectively alleviates the intense impingement of high-speed airflow and high-concentration snow on the windward surfaces of vital heat-producing components. Compared to the original Alpine EMU configuration, the 5.14° and 10° diversion-slot anti-snow structures reduce the total snow mass accumulating on all bogies by 19.6% and 28.3%, respectively.

Keywords: alpine EMU, bogie region, anti-snow structure

1. GENERAL INSTRUCTIONS

By the end of December 2021, the total mileage of railway operation in China has exceeded 150000 km, and the length can circle the earth. Among them, the high-speed railway has reached 40000 kilometres, ranking first in the world. However, there are a variety of meteorological natural disasters that will directly affect the safety of railway operation, such as snow disasters, hurricanes, mud rock flows, etc., of which snow disasters are particularly harmful to the safety of railway operation (ZHANG Lichen, 2011 Jain, 1997; Scanlan et al., 1974; Simiu and Scanlan, 1996; Vickery and Basu, 1983). Now, with the opening of many cold railways in China, such as Harbin Dalian High speed Railway and Beijing Zhangjiakou High speed Railway, more and more high-speed trains need to operate for a long time under the conditions of cold wind and snow(ZHANG Hongtao et al., 2019), resulting in the problem of snow and ice in the bogie area, of which one example is shown in Fig.1.

In order to solve the problem of severe snow and ice in the bogie area of high-speed trains in alpine regions, railway experts and scholars at home and abroad have carried out a lot of research(Allain E et al., 2014； Paradot N et al., 2014； HAN Yundong et al., 2015； Liu M Y et al., 2019). Snow particles are light particles with small volume, so the movement track of snow particles is closely

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related to the flow field in the area. Therefore, the effect of preventing snow accumulation can be achieved by designing relevant diversion structures, optimizing the shear flow in the bogie area of alpine high-speed trains, reducing the distribution and accumulation of snow particles. Based on the flow control principle, this paper proposes a trough type drainage structure to prevent snow accumulation. Through the numerical simulation technology, the anti snow effect of the trough type drainage structure is compared and explored. The research results can provide the relevant basis for the design of the anti snow structure in the bogie area.

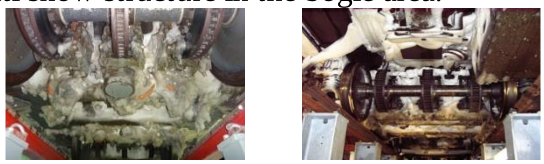

Figure 1. Snow and ice accumulation on the bogies of high-speed trains.

2 Numerical set-up

Aiming at the serious snow and ice problem in the bogie area when the alpine high-speed railway runs in the wind and snow environment for a long time, the method based on Realizable k- ε Unsteady Reynolds time average method (URANS) and discrete phase model (DPM) methods of turbulence model were used to study the anti-snow performance of the diversion-slot structure of alpine EMUs based on the three car train model, The train model consists of head, middle and tail cars. The model includes windshield and bogie structure. Because this paper mainly considers the characteristics of wind and snow movement at the bottom of the train and in the bogie area, while the influence of the pantograph, air conditioner and other roof structures on the characteristics of wind and snow movement at the bottom of the train can be ignored, and the subtle structure of the pantograph and air conditioner outlet will lead to a significant increase in the number of calculation grids and simulation cost consumption, the train model in this paper ignores the pantograph, air conditioner and other top structures. As shown in Figure 2.

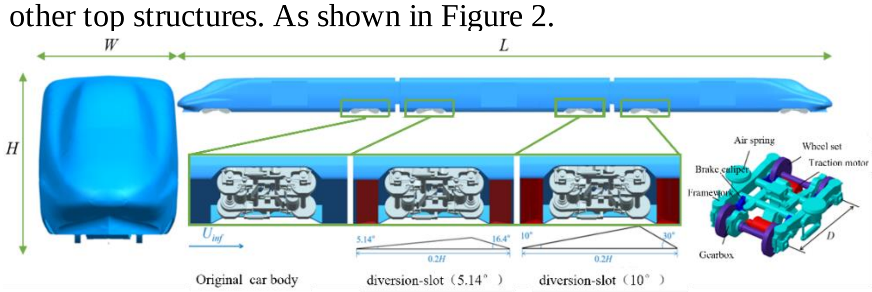

Figure 2. The geometric shape and installation position of diversion-slot anti-snow structure

This article primarily investigates the impact of slot-shaped drainage anti-snow structures on the wind and snow characteristics in the bogie area of high-speed trains. To facilitate the entry of more snow particles into the bogie area, the roadbed, track, and train surface are designated as reflection boundary conditions. Other boundaries of the computational domain are defined as escape conditions. Essential components on the equipment compartment end plate and bogie, such as brake clamps, gearbox, and frame, are set as snow particle capture conditions.

For the numerical simulation of two-phase flow, a Cartesian mixed grid predominantly composed of hexahedra is employed. To accurately capture the airflow characteristics within the boundary layer, fifteen layers of prismatic layer grids are introduced on the surface and the bogie area beneath the high-speed train. A smooth transition with the hexahedral mesh is ensured by setting the normal growth rate to 1.2. The surface grid of the train model object is dimensionless, with a normal thickness of n+=45, a dimensionless size of Δ l+=450 in the flow direction grid, and a dimensionless size of Δ s+=450 in the spanwise grid.

Previous studies conducted by Wang et al. have indicated that increasing the resolution of this grid has minimal impact on enhancing the accuracy of simulating wind and snow motion patterns. Considering the trade-off between computational accuracy and resources, this grid resolution setting can be deemed suitable for simulating the two-phase flow of wind and snow on the underside of high-speed trains.

3 Results and discussion

Figure 3(a) shows the influence of the guide groove structure on the air flow structure in the bogie 2 area. Although the structure of the diversion channel does not change the occurrence height of the shear layer at the upstream of the bogie, it promotes the occurrence of the shear layer in advance, making the shear layer in the diversion channel condition have a longer development distance. In addition, the flow separation structure in the diversion channel will push the shear layer downward, and the larger the diversion angle, the larger the separation structure scale in the diversion channel, and the lower the height of the shear layer at the bogie inlet. Therefore, the 10 ° guide groove structure significantly improves the direction of air flow at the entrance of the bogie, effectively reduces the vertical distribution range of high-speed air flow under the bogie, and effectively avoids the impact of high-speed air flow on the main heating parts of the bogie. At the same time, the anti-snow structure of the 10 ° guide groove also significantly inhibits the upward climbing movement of the air flow in the middle area and the rear end plate of the bogie, which has a significant effect on reducing the number of suspended snow particles in the area above the bogie. Moreover, the 10 ° guide groove structure also enhances the smoothness of air flow in the area above the bogie, greatly reduces the number of low-speed air vortex structures above the bogie in the original working condition, and helps the suspended snow particles above the bogie flow out of the bogie cavity area.

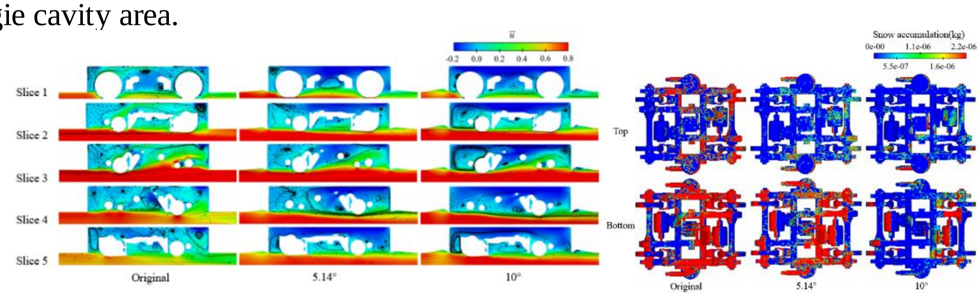

Figure 3. (a) Influence of diversion-slot anti-snow structure on air flow trend in bogie 2 area (b) Influence of diversion-slot anti-snow structure on snow distribution on bogie 2 surface area

Figure 3(b) shows the influence of the trough type drainage snow prevention structure on the snow distribution on the surface of bogie 2. Compared with the original working condition, the diversion trough structure guides the snow particles at the entrance of the bogie to the ground, effectively alleviating the violent scouring effect of the snow particles on the front structure of the bogie, and effectively reducing the snow distribution on the front traction motor, gear box and frame surface. In addition, the guide groove structure significantly reduces the vertical distribution range of high concentration snow particles, inhibits the upward movement of wind and snow flow in the middle area of the bogie, and alleviates the impact and adhesion of snow particles on the windward side of the rear bogie, thus effectively reducing the distribution of snow accumulated on the center pin, rear motor hanger and rear frame surface; In addition, the guide groove structure effectively reduces the number of snow particles entering the area above the bogie from the middle area and rear end plate of the bogie, thus significantly reducing the distribution range of snow on the upper surface of the bogie. The snow prevention performance of the guide groove increases with the increase of the diversion angle. Compared with the 5.14 ° guide groove structure, the snow particle concentration distribution characteristics in the 10 ° guide groove working condition are significantly better, and less snow distribution is caused on the bogie surface.

4 Conclusion

In this paper, the numerical simulation method of wind and snow two-phase flow is used to explore the influence of the diversion-slot type drainage structure at the bottom of alpine EMUs on the characteristics of wind and snow movement and the accumulation and distribution of ice and snow in the bogie area, and the the anti-snow performance of 5.14 ° and 10 ° diversion-slot type drainage structures in the bogie area is compared and analysed. The main conclusions are as follows:

1) The trough type drainage and snow prevention structure promotes the early appearance of the shear layer and has a longer development distance, reducing the number of low-speed air vortex structures inside the bogie cavity. The wind and snow flow control structure of the alpine high-speed train should focus on changing the spatial distribution characteristics of the shear layer under the vehicle.

2) The trough type drainage and snow protection structure significantly reduces the pressure peak and peak value at the bottom of the train, and the larger the diversion angle, the lower the pressure peak and peak value under the nose tip of the head car, which effectively alleviates the strong pressure fluctuation under the cowcatcher, and the snow particles deposited on the top surface of the ballast bed are drawn into the flow field at the bottom of the train.

3) The trough type drainage and snow protection structure mainly reduces the movement speed of the wind and snow flow direction between the vehicle bottom and the subgrade, inhibits the vertical velocity fluctuation amplitude of the wind and snow flow at the bottom of the train, alleviates the violent scouring effect of the wind and snow flow on the bogie structure, and reduces the number of suspended snow particles above the bogie.

4) Compared with the 5.14 ° groove drainage structure, the 10 ° groove drainage structure has better snow protection performance, which can reduce the total snow mass of the bogie of the three car high cold EMU by 28.3%, and reduce the snow mass of the surface areas of the bogies 2, 3, 4, 5 and 6 by 36.8%, 30.2%, 28.6%, 24.6% and 16.4% respectively.

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