Numerical Simulation of the Snow Icy Phenomenon of the Bogie Motor

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ABSTRACT

In this paper, the turbulence model of SST $k-\omega$ is used to simulate the air flow field characteristics of the bogie motor, and the velocity field and pressure field of the bogie area are analyzed. The results show that the structure of the bogie is complicated, and the airflow with snow particles will impact the heating element in the bogie area. The positive pressure on the motor is larger and the entrained snow particles are rapidly melting and freezing. At the same time, there are a lot of low-speed vortexes above the motor, where the snow particles may be stationary and fall onto the surface of the motor. As the speed increases, the snow particles are increased, and the snow accumulation is more serious.

INTRODUCTION

The train running in the snow weather will cause strong wind along the track, and the snow near the track will be raised and fly in the bogie area by the wind. The bogie usually exposed to the air will be affected by the wind, in which area the snow followed the wind either directly impact on the bogie, or move to the
up-surface of some parts such as the motor and brake calipers where the airflow velocity is low and then fall onto the surface because of the gravity. The dynamic performance of the high-speed train will decline [1-2].

The Computation Fluid Dynamic (CFD) has been developed greatly in recent years, and the turbulence model of Shear-Stress Transport two-equation model has been widely used in various fields. The SST k-ω two-equation model is proposed by Menter FR, which takes the turbulence shear stress transport into account, and can be applied to turbulence models with low Reynolds coefficients, without additional complex viscous damping functions, and can be applied in areas away from the wall, such as outside the boundary layer [3].

In foreign countries, the study to solve the snow and ice problem in railway industry often stay on preventing or clearing the snow on the lines or bogies of the train, and it is rare to optimize the bottom structures of the train to reduce the quantities of the snow entering the bogie area, according to the features of the flow around the bogie. Leif [4] considered the Russia's low temperature conditions, and sprayed the mixture on the bogie to reduce icing problem. Kim [5] researched the feasibility of electrical snow-melting system installed on the bogie by numerical simulation. Azuma [6] used the air discharged from the air conditioning system to the bogie area to melt snow and ice.

In China, the related research based on studying the flow characteristics of bogie field has been carried out. Zheng’s [7] studies showed that the bogie area of the flow field structure is very complex, and both of the front and rear of the bogie will form lots of vortices. The regional flow field of the train bogie was tested by Han [8] to verify that the snow in the bogie area came from the bottom. In order to solve the problem of ice and snow accumulation in the area of the shroud of the equipment cabin, Li [9] proposed a structure of the shroud to improve effectively the surface of the air flow, and can alleviate the bogie region's ice and snow accumulation problem.

In this paper, through the simulation of trains running at different speeds, we compared the CFD simulation results of the flow directions, velocities and pressures of the bogie surfaces, and the possible causes and laws of the snow in the bogie area were summarized.
METHODOLOGY

Basic

Gordon [10] studied the size and density of snow particles to obtain the relevant physical properties of snow particles. Snow particles have a strong follow quality with airflow, and the trajectories in the air can be indirectly described by the flow of air.

The numerical simulation results using RNG k-ε and SST k-ω turbulence models are obtained by calculating the Ahmed bluff model at different tail angles, which showed that the SST k-ω turbulence model is superior to the RNG k-ε turbulence model in the calculation time and turbulence simulation, and is more suitable for the calculation of external complex flow field. Xia Chao [11] used different turbulence models to simulate and proved that the SST k-ω turbulence model has high accuracy.

Therefore, this paper used the steady-state calculation method, and used the RANS model of SST k-ω to simulate the air flow field characteristics of the bogie area. The corresponding turbulence equation is described in the literature [12].

Model

This paper mainly studies the snow on the parts of the bogie motor, and the existing train model needs to be simplified. Take the influence of the various parts of the bogie on its flow field into account and ensure the integrity of the bogie as far as possible, the complex brake lines were deleted, the bogie frame, wheels and other necessary structure were simplified: the simplified model of motor, gear cover, brake clamp and other heating elements were retained. Figure 1 (a) is a simplified model of the body and bogie, and Figure 1 (b) is a simplified bogie model.

Meshing and boundary conditions

The computational domain was set as the Figure 2, of which the length was 40m, the width was 28m and the height is 20m.

In this paper, the grid was automatically generated by setting parameters in Open FOAM, the mesh size of the train body is 18.9 mm, and of the bogie is 9.45 mm. 10 boundary layers are arranged on the surface of the train body, and the
thickness of the first boundary layer is 1.89 mm; So it is with bogie and the thickness of the first boundary layer is 0.95 mm. Fig. 3 is the overall mesh and boundary layer mesh of the model. At the same time, the refining meshes are applied to near the wall of the train and bogie to catch the flow characteristics. The total number of grid units in the whole domain is 18532987.

![Figure 1. Model of computation: (a) train body and bogie ;(b) bogie.](image1)

![Figure 2. Computational domain.](image2)

![Figure 3. Meshes of flow field: (a) meshes of the domain; (b) meshes of the boundary layers.](image3)

The numerical simulation was performed in Fluent, and the boundary conditions were set as the table I.
TABLE I. BOUNDARY CONDITIONS.

| Faces of boundary | Boundary Conditions | Parameters                  |
|-------------------|---------------------|-----------------------------|
| ABCD              | velocity-inlet      | V=30m/s,40m/s,50m/s         |
| EFGH              | pressure outlet     | P=0 Pa                      |
| ABFE              | symmetry            | \                           |
| CGHD              | moving wall         | V=30m/s,40m/s,50m/s         |
| AEHD              | no-slip wall        | \                           |
| BFGC              | no-slip wall        | \                           |

RESULTS AND DISCUSS

Analysis of slices of velocity field of the bogie motor

Owing to the symmetry of the structure of the bogie, the flow characteristic in the bogie area should be symmetrical. So the slice is set on the middle of one motor. Figure 5 is the locations of the slices on the motor and figure 6 is the slices of streamlines.

![Figure 5. Location of the slice on the motor.](image)
Figure 6. Slices of streamlines of bogie area.

Study the characteristic of the airflow around the outline of the motor. Because of the narrow space between the motor and the axle, the airflow near the surface of the motor is accelerated. The range of the airflow in this area extends backward, which means more snow particles are taken up to the bogie area. Also there is a big vortex above the motor. The snow particles mentioned previously will decelerate along their motion tracks, and move to the big vortex and Although the flow speed above the bogie don’t change as the train’s speed increases, the big vortex moves upwards and backwards, which can be concluded that the snow particles move higher and away from the motor. Thus, as the running speed increases, the possibility of snow accumulating on the upper surface of the motor is reduced. But there are a lot of vortexes of low speed near the right side of the motor, where the space is too small and the slow snow particles tend to be more easily to adhere to the motor surface.

Study the characteristic of the airflow around the outline of the motor output shaft. It is clear that there are two distinct vortexes above and at the right side of the motor output shaft, while the airflows of the other two directions move along the motor output shaft surface at higher speeds and pass away. When the snow particles in the two vortexes move to the surface of the motor output shaft, the snow particles will melt due to the heat giving out by the motor where the process of converting electrical energy into mechanical energy is working all the time when the train is running, and then the flakes mixed with droplets formed by
melting fuse together and produce ice crystals on the surface of the motor output shaft. The following snow particles experience the same process, massively and quickly accumulating on the surfaces.

This is the analysis of the cause of the snow accumulation on the surface of motor by the streamlines of the velocity field, from which we can infer the cause of snow accumulation on other surfaces of the bogie.

**Analysis of pressure field of the bogie motor**

The pressure distributions of bogie at different speeds are shown as figure 7. The bottom surfaces of the bogie are directly impacted by the airflow where the surface pressure is positive pressure, and in the figure 7, the surfaces of the impact parts are obvious red.

![Pressure distributions of bogie](image)

Figure 7. Pressure distributions of bogie.

Most of the other surfaces of the bogie are under negative pressure, where the airflows move along the nearby surfaces and pass away. In the positive pressure areas, snows particles following the airflow impact on the surfaces of some heating parts such as the motor, melt and then quickly frozen due to the cold weather. The following snow particles experience the same process, massively and quickly accumulating on the surfaces.

In order to study further about the connection between the snow accumulation and the pressure of the impacted surfaces on the motor, the slice is set as the figure 5 and slices of pressure distributions of bogie area are displayed as figure 8.
As the running speed increases from 30m/s to 40m/s, the negative pressure is more and more serious in the whole bogie area, from which we can infer that the speed in bogie area also increases.

Study the characteristic of the pressure distribution around the outline of the motor. Firstly, the negative pressure continues to increase as the speed increase, where it is profoundly obvious under the motor that the color is deepening and its scope is expanding. In this negative pressure area, the snow particles move along the bottom outline of the motor and pass away. Secondly, at the left upwind side, there exists a positive pressure in red and the scope is expanding with the speed increasing. This means the snow particles following the airflow impact on the motor and the heat around the motor makes the snow particles melt and then turn into the ice. The following snow particles experience the same process, and soon massively and quickly the snow particles accumulate on the surfaces.

Study the characteristic of the pressure distribution around the outline of the motor output shaft. The pressure distribution near the area of the output shaft looks like the pressure distribution near the area of the motor. On the one hand, the negative pressure rises where the area color is close to blue (though it is not easy to identify) is as the running speed increases. On the other hand, the upwind side’s positive isn’t obvious and we could estimate the snow particles don’t accumulate easily on the upwind surface of the shaft.

Figure 8. Slices of pressure distributions of bogie area.
CONCLUSIONS

When the high speed train is running, the snow particles flying with the train-induced wind enter the bogie area, where the airflow characteristic is so complex to describe. Through the analysis of the velocity field and the pressure distribution of the bogie area, especially the area closed to the motor and its output shaft, we can make some key points clear.

One point is that the speed of the bogie area increases, so it is with the negative pressure and its scope at the same time. The features of the airflow near the motor and the output shaft just look similar to each other.

Another point is that the snow particles move with the airflow, and because of the features of the airflow mentioned above, snow particles has three kinds of moving track. One is flying along the bottom surface of the motor or the output shaft, then flow away; one is flying up along the surface as the figure 6. These two kinds of moving track seem to be difficult to have snow accumulating on the surfaces nearby. The third one is flying in the vortexes formed at the leeward of the motor or the output shaft and the forth one is flying beating against the surfaces. In these two situations, the snow particles experience the process of phase transition, and then the snow is piled up on the surface of the bogie.

In this paper, we mainly discuss the airflow features of the motor. The cause of the other parts of the bogie will be studied in the following work.
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REFERENCES

1. Lennart Kloow. 2011. “High-speed train operation in winter climate;” KTH Railway Group and Tran sail.
2. Zhou Y, Qian W Q, Deng Y Q. 2010. “Introductory analysis of the influence of Mentor’s k-ω SST turbulence model’s parameters,” ACTA AERODYNAMICA SINICA, 28(2):213–217.
3. Menter F. R.1993. “Zonal two equation k-ω turbulence models for aerodynamic flows,” AIAA Paper: 2106-2203.
4. Leif Paulukuhn, Wu X. 2012. “The Low Temperatures Technology Concepts and Operational Experience in Russian High Speed Train Velaro RUS,” Foreign Rolling Stock,49(3):16-19.
5. Kim M S, Jang D U, Hong J S, et al. 2015. “Thermal modeling of railroad with installed snow melting system,” Cold Regions Science and Technology, (109): 18-27.
6. Azuma T, Horikawas, Fujino K. 2010. “Countermeasure against snow,” Jr East Technical Review,16: 31-34.
7. Zheng X H, Zhang J Y, Zhang W H.2011. “Numerical simulation of aerodynamic drag for high-speed train bogie,” Journal of Traffic and Transportation Engineering, 11(2):45-51.
8. Han Y D, Yao S, Chen D W. 2015. “Real vehicle test and numerical simulation of flow field in high-speed train bogie cabin,” Journal of Traffic and Transportation Engineering,15(6):51-60.
9. Li J M, Shan Y L, Lin P.2013. “Analysis on aerodynamic performance of anti-ice/snow dome of high speed motor train unit bogie,” Computer Aided Engineering,22(2):22-26.
10. Gordon M, Savelye M, Taylor P A. 2009. “Measurements of blowing snow, Part I: Particle shape, size distribution, velocity, and number flux at Churchill, Manitoba, Canada,” Centre for Research in Earth and Space Science, York University, (55):63-74.
11. Xia C, Shan X Z, Yang Z G, et al. 2014. “A comparative study of different turbulence models in computation of flow around simplified train,” Journal of Tongji University: Natural Science, 42(11): 1687-1693.

12. Wang F J. 2004. “Analysis Computational Fluid Dynamics: Theory and Application of CFD Software,” Beijing: Tsing hua University Press: 120-131.