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Study on a control method of the wake of high-speed train with vortex generators

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SUMMARY:
As the speed of the high-speed train grows up, the aerodynamic performance plays an increasingly important role in the running process of the train. The chaotic wake of high-speed trains has a significant impact on its aerodynamic performance, especially a pair of high strength inward rotating vortices in the wake area. To weaken the untoward effects of the wake vortex, a control method with vortex generators was submitted. The results show that the wake vorticity of the train is weakened, the aerodynamic performances have been optimized. The aerodynamic performance of the head car and middle car changed little while the tail car changed more. The static pressure of the tail car increased. The drag of the tail car can be reduced by 5.11%, and the drag of the whole car reduced by 2.23%. The lift of the tail car has been reduced by 14.93%, while the whole car has been reduced by 72.66%.

Keywords: high-speed train, wake flow, vortex generators, aerodynamic drag

1. INTRODUCTION

Studies show that the wake control has been increasingly important on improving the aerodynamic performance of the high-speed train. With the optimization of the wake structure, the stability and safety during the operation of the train can be greatly improved. The wake of a high-speed train has been found to be a very complex three-dimensional flow. A pair of symmetrical vortices detaches from the rear of the train and alternately break apart as they move away from the train, increasing the pressure difference between the head and tail cars as well as the lift and side force of the tail car. As a flow control method, vortex generator (VG) has been playing an important role in the past decades and has been widely used in aerodynamics due to their superior cost advantages and outstanding aerodynamic performance. In this paper, vortex generators are combined with the high-speed train, which produced a pair of vortices in the opposite direction of rotation to the wake vortex of the high-speed train. The flow field structure of high-speed train under the control of vortex generators is studied and compared with which of the original train.

2. METHODS

The model used in this paper is the ICE3 train. To reduce the computation cost, the pantograph, and other features of the outer surface of the train are omitted, the main contour of the car body is simplified. At the same time, the car body is simplified into three trains. The train model was placed on the center of the computation domain with 235mm between the train model and the ground. The shape of the vortex generators and where they are located on the train are shown in Fig. 1. The vortex generators were originally built in the shape of a right-angled trapezoid, but their bottom edges were altered to fit the streamlined surface of the train. All parameters are based on the lower points A and B of the right-angled edges which are on the side near the tail nose. The height of the vortex generators h is 400mm while the length of the upper edges l_1 is 100mm. The trapezoidal base angle α is 36.87°. The thickness of the vortex generators is 10 mm. The vortex generators are symmetrically distributed. The distance *d* between point A and point B is 550mm and the distance *D* between these two points and tail nose in flow direction is 585mm. A pressure-outlet boundary condition was applied at the outlet of the computation domain. A uniform velocity of 80m/s was applied at the inlet. A moving no-slip wall with the same velocity as the inlet was employed at the lower face of the computation domain to produce relative movement between the train and the ground. The other surface of the computation domain was set at symmetry boundary conditions. All the surface of the train was treated as no-slip wall. In this paper, Fluent is used to simulate the flow field at the wake area of high-speed train. The study employs the k-ω SST turbulence model. Finite volume method and SIMPLEC algorithm are adopted to get the numerical simulation results.

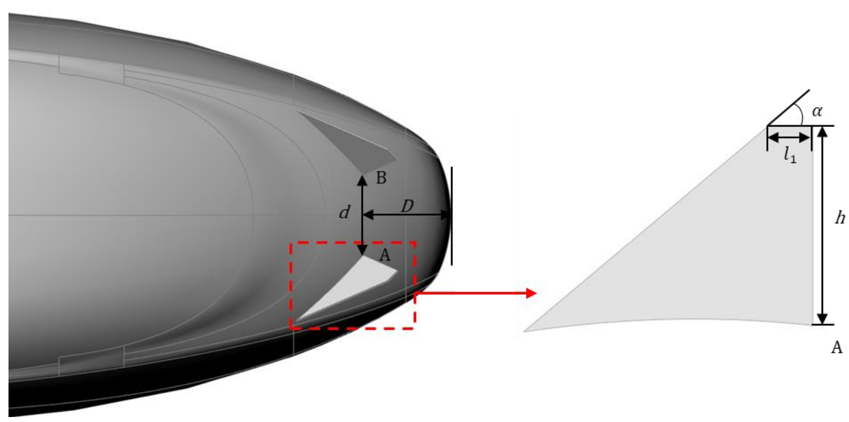

Figure 1. The shape and the location of the vortex generators.

3. RESULTS AND DISCUSSIONS

The results show that only when the angles between the vortex generators and the flow directions are greater than 90°, the vortex generators can create a pair of vortices moved along the reverse rotational direction of the wake vortices of the high-speed train. Other situations will have the opposite effect. In this paper, the angles between the vortex generators and the flow directions were set to be 135°. To compare the changes on the aerodynamic performances of the train before and after the arrangement of the vortex generators, a cross-section of the fluid region along the centre of the train and a horizontal plane at about half of the height of the train were made.

3.1. Contrast of Static Pressure

Fig. 2 shows the static pressure on the surface of the tail car and Fig. 3 shows the changes of the pressure coefficient along centre of the upper surface of the train. With the control of the vortex generators, the pressure of the tail car increased, which reduced the pressure differential resistance.

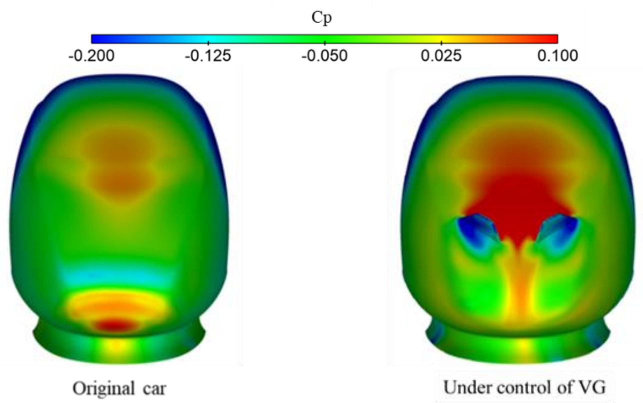

Figure 2. Surface pressure of the tail car.

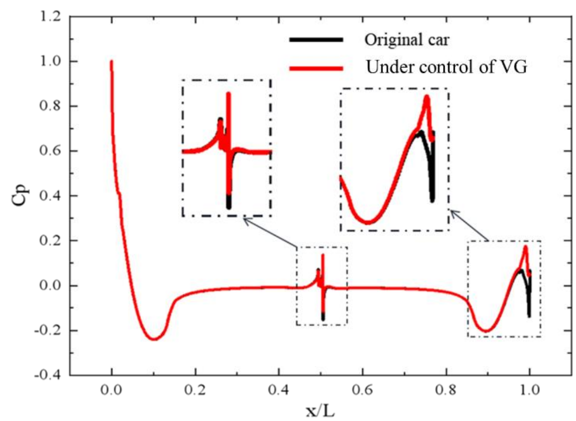

Figure 3. Surface pressure along centre of the upper surface of the train.

3.2. Contrast of Wake Vorticity

The wake vorticity of the high-speed train was shown in Fig. 4. In general, the intensity of the wake vortices was weakened under the control of the vortex generators. At the same time, the distance between the wake vortices has been shortened.

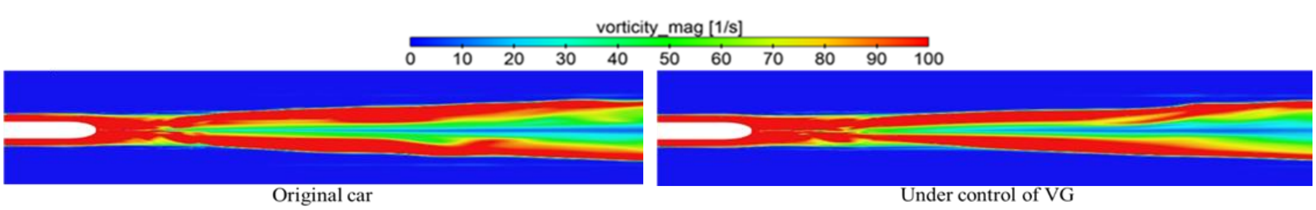

Figure 4. Wake vorticity of the wake area.

3.3. Contrast of Aerodynamic Drag

The aerodynamic drag of the tail car was reduced by 5.11%, which resulted in a drag reduction of 2.23% for the whole car, while the drag of the head car and the middle car had little change. Same as the drag coefficient, the lift coefficient of the head car and the middle car changed little, while the lift of the tail car was reduced by 14.93%, and the whole car was reduced by 72.66% under control of the vortex generators.

Table 1. Drag coefficient reduction under control of vortex generators.

	Original car	Under control of VG	Drag coefficient reduction
Head car	0.1259	0.1260	-0.09%
Middle car	0.0976	0.0976	-0.01%
Tail car	0.1765	0.1675	5.11%
Total	0.3999	0.3910	2.23%

Table 2. Lift coefficient reduction under control of vortex generators.

	Original car	Under control of VG	Lift coefficient reduction
Head car	-0.0921	-0.0922	-0.10%
Middle car	0.0088	0.0093	-4.90%
Tail car	0.1042	0.0887	14.93%
Total	0.0209	0.0057	72.66%

4. CONCLUSIONS

The control effect of the vortex generators to the wake vortices of the high-speed train is remarkable. The static pressure of the tail car increased, and the vorticity of the wake vortices decreased, which are the main reasons of the drag reduction of the tail car. The decrease of the aerodynamic forces is beneficial for the aerodynamic performance of the high-speed train. In this preliminary study, the drag of the tail car can be reduced by 5.11%, and the drag of the whole car reduced by 2.23%. The lift of the tail car has been reduced by 14.93%, while the whole car has been reduced by 72.66%. Further optimization and adjustment of the shape parameters and the position parameters of the vortex generators should be promoted to improve the aerodynamic performance of the high-speed train.

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