Aerodynamic Load Analysis of Parts of Pantograph under Strong CrossWind

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Abstract. The pantograph-contact net model is established, and based on the N-S equation of the pressure correction procedure, the SIMPLE algorithm is used to solve the aerodynamic characteristics of different components of the pantograph under strong crosswind conditions. The effects of different crosswind speeds and different deflection angles on the aerodynamic load law of the pantograph components are discussed. Results show that among the various components of the pantograph, the aerodynamic drag and lift of the skateboard are the largest, and the lateral force of the lower arm and the bottom frame is also the largest. The pitching moment of the upper frame is the largest, and the overturning moment and the lateral moment of the sliding plate, the lower arm and the underframe are larger than before, which needs to be taken into consideration when we do calculations and optimizations. The research results can provide a basis for the operational safety and optimal design of high-speed pantograph under strong crosswind conditions.

1. Introduction
Under the condition of the strong crosswind, the aerodynamic loads of the various components about pantograph change significantly, and the flow field of the components of the crosswinds is very complicated. Therefore, it is necessary to analyze the methods about the distribution of the aerodynamic forces and moments of the pantograph under strong crosswind. Foreign scholars have done lots of research works by doing experiment and the numerical simulation[1-6], but there are few literatures on studying the aerodynamic characteristics of the components about the pantograph under strong crosswind. There is no systematic analysis of the variation of each component. According to the actual characteristics of the project, we can use the numerical simulation method and the pantograph-contact net model to analyze the aerodynamic characteristics of the pantograph under strong crosswind conditions, which is needed to increase the operation stability and optimization about the pantograph, and also improve the means of simulation and theoretical research.

2. Calculation models and conditions

2.1. Control equation
The flow process is governed by basic physical laws. The momentum equation and the continuity equation are solved simultaneously to solve the external flow field[6]; the boundary layer is solved by the equation \( k - \omega \) with low Reynolds number. The flow control equation is as follows:
\[
\frac{\partial (\rho \varphi)}{\partial t} + \text{div} (\rho \varphi \mathbf{U}) = \text{div} (\Gamma_\varphi \text{grad} \varphi) + S_\varphi
\]

In the formula: \( \rho \) is the density of the fluid; \( t \) is the time; \( \mathbf{U} \) is the velocity vector of the fluid; \( \varphi \) is the general variable (\( u, v, w, T, m \), etc.); \( S_\varphi \) is the generalized source term; \( \Gamma_\varphi \) is the generalized diffusion coefficient.

2.2. Boundary conditions
The pantograph moves in the +x direction along the calculation domain. According to the relative movement rules, the boundary conditions of the numerical simulation are set as follows: the boundary condition of the inlet is the velocity inlet, and the component of the velocity along the -x direction is 97.22 m/s. The component along the +z direction is the crosswind wind speed; the boundary condition of the outlet is the pressure outlet, the relative atmospheric pressure is 0; the gas boundary is the slip boundary. The floor has no slip boundary and sets the speed, which is -97.22 m/s.

2.3. Physical model
The model is simplified by the pantograph of an train-set. According to the prototype size ratio, the model is established and calculated. The aerodynamic performance is considered as six different components, and the components I, II, III, IV, V, VI are divided according to the current direction (I chassis, II push rod, III lower arm, IV upper frame, V bracket, VI slide board), as shown in Figure 1.

![Figure 1. the Geometric Model of Pantograph](image)

The computing domain is 70m long, 80m wide and 35m high, and the contact line is 6.0m from the ground and the sum of grids is 4 million. The thickness of the boundary layer is 6.8mm, and the boundary layer is divided into 4 layers in order to the distance about the mesh and the wall is within 2mm, ensuring the accuracy of calculation.

3. Pneumatic load of various components of the pantograph
The simplified model of the pantograph is divided into six parts, each of which can be regarded as a bluff body. At the same time, the currents are around the bluff body, forming a complex flow field. Experts and scholars at home and abroad have made some deep researches on the Ahmed bluff body to verify the accuracy of the calculation method[9-10]. According to the numerical analysis, the resistance coefficient of Ahmed bluff body is 0.290, the test value is 0.285 and the error-free value is 1.0\%, which meets the engineering and calculation requirements, so the calculation method is feasible. The calculated speed of the pantograph is 97.22 m/s and the crosswind speed is 5 m/s to 30 m/s. The deflection angle is 10° to 90°, and the variation law of aerodynamic forces and moments of the components of the pantograph is analyzed. The definition of the wind direction angle is shown in Figure 2. The \(-v_x\) is the mainstream direction, the \(v_w\) is the crosswind direction and the \(\theta\) is the angle between the mainstream and the crosswind direction.
Figure 2. the Angle of Crosswind Acting on the Pantograph

3.1. Pantograph pneumatic force

Figure 3 and Figure 4 are curves showing the aerodynamic drag of the components of the pantograph as a function of the deflection angle under the conditions of crosswind speeds of 15m/s, 30m/s. Among them, the resistance of the push rod is minimum and the resistance of the sliding plate is maximum. As the increase of deflection angle, the resistance of the components of the pantograph decreases steadily. It can be seen easily that the deflection angle has small effect on the aerodynamic drag, but the degree of declining of the total resistance is up to 25%.

With the increasement of the crosswind speed, the resistance of the pantograph and various components increases, not exceeding 10%. Figure 5 and Figure 6 are the curves of the aerodynamic lift of the components of the pantograph with the deflection angle under the conditions of crosswind speeds of 15m/s, 30m/s. With the increase of the deflection angle, the lift is increasing except the upper frame. As the crosswind speed increases, the total lift of the chassis, skateboard and pantograph changes obviously, but general trends remain unchanged. The pantograph is a complex rod system which contains a variable cross-section member such as a skateboard, an upper frame, and a lower arm.
The resistance and lift of the skateboard are the largest which should be considered into the optimization design, and the chassis shape should be optimized. The lateral force of each component varies with the deviation of the deflection angle and the crosswind speed. In the process of designing, the operation safety of the lower boom should be emphasized.

3.2. Distribution of aerodynamic moments of the components of the pantograph under different deflection angles

Figure 7 to Figure 10 are the curves showing the overturning moment force of the components of the pantograph as a function of the deflection angle under the conditions of the crosswind speeds of 15m/s, 20m/s, 25m/s, and 30m/s. It can be seen from the figure that the changes of the lower arm, the slide plate and the underframe are obvious with the deviation angle. The changes trend of the push rod, the upper frame and the bracket are gentle, and the maximum value of the pantograph overturning moment increases with the increase of the crosswind speed of 38%. When the crosswind speed reaches 30m/s, the overturning moment of the chassis, the lower arm and the skateboard appears bumps.

Figure. 11 shows the variation of the lateral moment of the components of the pantograph with the deflection angle when the speed of crosswind is 15m/s. It can be seen from the figure that the lateral moment of the underframe, the lower arm and the sliding plate increases with the increase of the deflection angle, however, the upper frame is opposite. When the deflection angle reaches 30°, the pantograph overturning moment increases sharply. Figure 12 is a graph showing the pitching moment of the components of the pantograph as a function of the deflection angle under the condition of the crosswind speed of 15m/s, and the pitching moment of each component decreases as the deflection angle increases, and the trend is gentle. In the calculation of the dynamic torque of the components of the pantograph, the focus should be placed on the lower arm, the slide, and the underframe.
3.3. Aerodynamic distribution of the components of the pantograph under different crosswind speeds

Table 1 shows the variation of the aerodynamic forces and moments of the pantograph at different crosswind speeds, with a deflection angle of 90°.

Table 1. Aerodynamic Force and Moment of Pantograph

| Crosswind Speed (m/s) | Resistance (N) | Lift (N) | Lateral Force (N) | Overturning moment (N·m) | Pitching Moment (N·m) | Lateral deviation moment (N·m) |
|-----------------------|----------------|----------|-------------------|-------------------------|----------------------|-------------------------------|
| 5m/s                  | 1164.65N       | 112.53N  | 16.66N            | 195.53N·m               | 2714.09N·m           | 138.04N·m                     |
| 10m/s                 | 1173.50N       | 122.22N  | 51.32N            | 430.16N·m               | 2669.33N·m           | 407.51N·m                     |
| 15m/s                 | 1181.66N       | 111.17N  | 101.20N           | 772.21N·m               | 2777.85N·m           | 783.23N·m                     |
| 20m/s                 | 1196.23N       | 105.34N  | 155.69N           | 1164.7N·m               | 2875.83N·m           | 1194.31N·m                    |
| 25m/s                 | 1207.40N       | 85.20N   | 207.47N           | 1522.75N·m              | 3096.57N·m           | 1583.90N·m                    |
| 30m/s                 | 1240.69N       | 77.87N   | 279.28N           | 2040.81N·m              | 3203.00N·m           | 2121.29N·m                    |

When the crosswind speed is 5m/s, the aerodynamic force and torque of the pantograph are small. As the lateral wind speed increases, the total resistance of the pantograph increases, the lift decreases, and the lateral force increases, and the lateral force changes significantly. It can be seen from Table 1, that the pantograph pitching moment changes little, the crosswind speed increases from 5m/s to 30m/s, the overturning moment increases by 10 times, and the lateral moment torque increases by 15 times.

4. Conclusion

1) Among the various components of the pantograph, the aerodynamic drag and lift of the skateboard are the largest, and the lateral force of the lower arm and the underframe is the largest. In the design of the calculation and the optimization, the aerodynamic force of the push rod and the bracket should be minimized. At the same time, with the increase of the deflection angle and crosswind speed, the aerodynamic distribution of each component is consistent.

2) The upper frame has the largest pitching moment, but the overturning moment and the lateral moment are smaller. The chassis, the push rod and the lower arm are less subjected to the pitching moment; the sliding plate, the lower arm and the bottom frame are subject to the overturning moment and the lateral moment torque is large.

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