Research on Glass Fiber Reinforced Plastic Head Cover of High-Speed Train

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Abstract: The role of the high-speed train head cover was discussed in this paper. According to the actual situation of the train operation, comparing the theoretical calculation to experimental analysis, the calculation load of the high-speed train head cover was confirmed, strength and mode calculation on the glass fiber reinforced plastic head cover by using ANSYS software were performed, and the result was analyzed in order to provide some reference for future work.

1 INTRODUCTION

The high-speed train head cover is the part at the front of the train that covers the coupler, which is closed during normal operation constitutes a streamlined shape to ensure the aerodynamic performance of the train. In the case of a shunting operation, rescue, and double-linking, the head cover of the vehicle needs to be opened to expose the mounting and operating space for the lifting hooks and the lifting rods of the coupler.

At present, many kinds of high-speed trains produced in China have adopted streamlined car body. If the head cover adopts a fixed structure, disassembly and storage are inconvenient. China has already conducted research on the automatic opening and closing head cover and has applied it to production [1]. However, there are also imperfections. It is necessary to conduct in-depth research on the structural design of the head cover in order to achieve the desired results.

2 PROBLEM ANALYSIS

During train operation, the air resistance is proportional to the square of the speed. When the train speed reaches 200km/h, the air resistance accounts for more than 70% of the total running resistance. The aerodynamic load on the head cover at the front end of the train head is more complicated.

In order to ensure the aerodynamic performance of the train, the head cover and supporting mechanism of the head of the locomotive must meet the following requirements: (1)The head cover itself should have a certain strength and cannot be destroyed by steady state pressure or transient pressure wave impact; (2) Under the action of wind load, the head cover itself cannot produce large deformations that affect aerodynamic performance, nor can they cause unexpected opening and closing actions; (3) The support mechanisms of the head cover should have sufficient support/self-locking capability and resistance to wind pressure.

There are no specific standards and specifications as reference for the complex wind load that the train. To solve the above problems, it is necessary to rely on the combination of theoretical calculation and experimental analysis to determine the calculation load of the head cover. On this basis, the ANSYS was used to theoretically calculate the strength and natural frequency of the head cover under certain load conditions, and the basic structural form and size range of the head cover were determined based on the calculation results. Which will provide institutions for designing of opening and closing mechanism of the head cover.

3 LOAD SOURCE AND BASIS

In order to obtain good aerodynamic performance, the shape of the train head cover is a freeform surface. Its mathematical expression is:

$$F(x, y, z) = 0 \tag{1}$$

In the formula: x, y, and z are positional parameters.

During the operation of a high-speed train, the actual load on the head cover mainly comes from the surface pressure caused by air resistance, and the surface pressure changes with time. That is to say, during the running of the train, the actual load received at a certain point on the head cover needs to be expressed by a four-variable functional relationship:

$$P = P(x, y, z, t) \tag{2}$$

In the formula: t is the time parameter.

If the load in the calculation process according to its actual stress, the calculation process will be extremely tedious. While use the FLUENT to simulate the load of the high-speed train head flow field at speed 200km/h, compared with the dynamic real vehicle test, found that the error is small, the accuracy meets practical requirements, can be used as the calculated load[2]. Therefore, assuming that the surface pressure of the train does not change with time, this paper uses the aforementioned calculation results as the source of the load data, and converts it into a load with a running speed of 300 km/h using the Bernoulli equation [3]. The conversion formula is as follows:

$$C_P = \frac{P_{200}}{\frac{1}{2}\rho v_{200}^{2}} = \frac{P_{300}}{\frac{1}{2}\rho v_{300}^{2}} \qquad (3)$$

In the formula: C_P - pressure coefficient;

ρ - the density of air;

v_{200} , v_{300} — train speed, v_{200} = 200km/h, v_{300} = 300km/h;

P_{200} , P_{300} ,—surface pressure experienced at train speeds of 200km and 300km.

In order to simplify the calculation, in the actual analysis, the head cover is divided into 8 pieces along the horizontal plane and a certain section of the longitudinal section to load. In the place where the curvature changes smoothly, the blocks are sparse; in the places where the curvature is more severe, the blocks are dense. Take the pressure value at one point in each block as the surface pressure value of the entire block. And fully consider the fluctuation of the load caused by the speed change, the selection of all data complies with the principle of safety and conservation. Figure 1 shows the block diagram along the coordinates of the head cover.

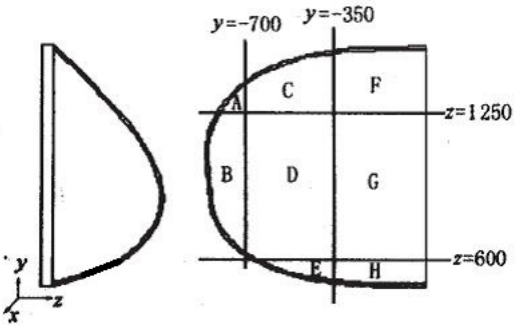

Fig.1 Block of head cover and its surface load.

Table 1 Block Loading Data Table.

area	A	B	C	D	E	F	G	H
Load/ MPa	3294	3918	3821	4164	3040	3821	4165	3040

The loads in this calculation are the distributed loads applied to the surface of the head cover. All the loads are added to the finite element model (nodes and units). The head cover and the opening and closing mechanism are connected by four supporting seats (as shown in Fig. 2), and each of the six degrees of freedom of each support base is restrained.

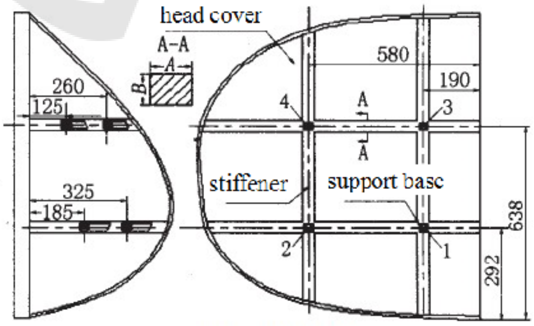

Figure 2. Head Cover Structure.

3 HEAD COVER INTRODUCTION

3.1 Selection of Head Cover Material

The material of the head cover must ensure that it has sufficient strength and rigidity; the free curved surface is difficult to process using conventional methods, so the material used to manufacture the head cover must have excellent processing properties. Glass fiber reinforced plastic, commonly known as fiberglass, it has so many advantages ensure that the free-form-shaped head cover can be manufactured at a lower cost. Therefore, FRP is used as the material of the head cover in this calculation.

The different types of glass fiber reinforced plastic and its fiber winding methods have a great influence on the physical properties of FRP materials. Considering the particularity of the working environment of the vehicle head cover, this calculation proposes the physical properties that should be possessed by the head cover and the parameters used in the calculation [4]:

Density/kg•m-3	1.8×103
Tensile strength/MPa	≥80
Quasi-static compression modulus	≥ 10
Dynamic compression modulus/GPa	≥15
Elastic Modulus/GPa	10
Poisson's ratio	0.4

3.2 Head Cover Structure

In this calculation, the thickness of the head cover shell is 10 mm, and the four Q235 steel stiffeners are connected to the head cover via the opening and closing mechanism support bases fixedly (see Figure 2). The role of stiffeners is to increase the stiffness of the head cover.

4 CALCULATION MODEL

The calculation model includes two parts: head cover and stiffeners. The model is built using solid modeling. The head cover is plate shell elements (Shell 63) and the stiffeners are beam elements (Beam 188). The grid is divided into free meshes. The discrete data of the finite element model are as follows: Shell63 and Beam188 have 543 and 96 cells, and the total number of cells is 639.The total number of nodes is 679.

5 CALCULATION CONTENTS AND RESULTS

In this calculation, the head cover was subjected to strength analysis and modal analysis.
The corresponding calculation results are shown in Table 2, Table 3 and Table 4.

Table 2 Calculation results of counterforce and counter-torque.

Support base	F_x /N	F_y /N	F_z /N	M_x /N •m	M_y /N •m	M_z /N •m
1	337.74	-3275.2	1432.8	5.5773	-117.43	-81.297
2	339.10	-2002.9	-1568.9	-5.6825	106.69	-61.571
3	-701.8	1588.8	-47.973	-2.8814	52.926	56.029
4	-1949.8	2406.5	213.40	0.49311	23.177	68.698
Sum	-2974.7	-1282.8	29.399	-2.4936	18.410	-18.140

Note: Fx, Fy, and Fz represent the counterforce along the x-axis, y-axis, and z-axis respectively; Mx, My, and Mz represent the counter-torque around the x-axis, y-axis, and z-axis respectively.

Table 3 Displacement and stress change with the cross section of the stiffeners.

cross section size of the stiffeners A×B /mm×mm	Maximum translational displacement vector sum /mm	Maximum rotation angle vector sum (°)	Maximum synthetic stress /MPa
—	11.483	3.017	54.722
40×8	6.7189	1.2571	24．811
40×10	3.325	0.9371	21.776
40×12	3.014	0.8089	19.518
40×14	2.776	0.8603	17.751
40×16	2.563	0.9089	16.321
40×20	2.274	0.97603	14.128
20×20	6.517	0.9614	25.08

Table 4 Modal calculation results when the cross section of the stiffeners is 40mm ×12mm (sixth-order natural frequency).

	1	2	3	4	5	6
f/Hz	52.595	55.145	89.111	98.198	162.88	182.28

When the cross section size of the stiffeners is changed, the results of the modal calculations varies very small, so only the modal calculation results of 40mm×12mm are calculated here.

6 CALCULATION RESULTS ANALYSIS

From Table 2, it can be seen that during the operation of the train, the head cover is subjected to a force of 2974.7N in the direction of the wind, so the head cover itself should have sufficient strength. The torque in the height direction of the support base 1 reaches 117.43N·m, which requires that the influence of this factor on the operation of the head cover should be fully taken into consideration when designing the support mechanism, the movement mechanism and the locking mechanism of the head cover.

As long as the value of the surface load and the position of the restraint do not change, the bearing reaction force will not change; but the change in the cross section size of the stiffeners has little effect on the modal calculation results, so this is mainly based on the results of the displacement and stress，the cross section size of the stiffeners was determined. This is also the reason why only the stiffeners cross section size of 40mm×12mm was calculated in the modal analysis. From the calculation results, it can be seen that the first-order natural frequency of the head cover is 52.595 Hz, and the natural frequency of the general high-speed motor car body is not bigger than 20 Hz[5], so the head cover does not generate resonance with the car body.

In view of the current literature on the calculation of FRP materials, from the perspective of safety, the safety factor of 4 is used in this calculation, that is, the allowable stress [σ] = 20MPa for FRP materials. From Table 3, it can be seen that the maximum stress reaches 54.722MPa, which greatly exceeds the allowable stress of FRP materials and is very unsafe. Therefore, it must be reinforced. When the cross section thickness was changed from 8 mm to 10 mm, the maximum translational displacement vector and the maximum stress were all reduced significantly. When the thickness was changed from 10 mm to 12 mm or more, the change was not significant. When the cross-sectional area is equal, the greater the height of the stiffeners, the more significant the effect of reducing the stress concentration. Based on the above results and taking into account the weight of the head cover, it is more appropriate for this type of head cover to use a cross section size of 40 mm×12 mm. If you want to better ensure the safety of train operations, the cross section size of the stiffeners can be 40mm × 14mm, 40mm × 16mm or even 40mm × 20mm.

With regard to the aging problem of glass fiber reinforced plastics, various countries are conducting research, but no obvious results have yet been obtained. Therefore, the question of the service life of glass fiber reinforced plastic head cover needs further study. For different shapes of the head cover, the distribution of the head flow field is not the same and the loads are not the same. Therefore, the shape and distribution of the stiffeners are also different. The requirements for the support structure of the head cover are also different. These need to be given specific analysis during the design process.

REFERENCES

1. Nie Yonghong. Design of Automatic Opening and Closing Mechanism for the Head Cover of Streamlined Vehicle Head., 2002. *Electric Transmission for Locomotives*, 2002 (4): 22-24.
2. Central South University., 2003. *Train Aerodynamic Vehicle Test Study and Assessment Report*. Changsha: Central South University
3. Anderso,J.D., 2010. *Fundamentals of Aerodynamics*, Aviation Industry Press. Beijing
4. Dong Junguo., 2000. *Practical Materials Handbook,* Mechanical Industry Press, Beijing
5. Wang Yali., 2001. *Analysis of response of random track irregularity to high-speed motor car*. Changsha: Central South University.