Research of Installation Stress of EMU Aluminum Alloy Beam and its Connecting Structure

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Abstract. Bolt hanging is one of the common ways of rail vehicle hanging equipment. In this paper, the assembly structure of a type of EMU and converter is taken as the research object, and the load values at the four suspension points are calculated by theoretical calculations. A simulation model of a single hanger is established, and the simulation is determined by reference to the theoretical calculation under working conditions, the stress distribution at the hanging points under different loads was studied. The results show that under different loading conditions, the stress distribution of beam is basically the same. The maximum stress of the beam occurs at the point where it contacts the bolt head. Compared with other regions, the stress at the corner of the T-slot of the beam is also larger.

1. Introduction

For high-speed EMUs, subway vehicles, etc., most of the equipment under the car is directly suspended on the beam of the chassis of the car body by bolts, mainly including braking, electrical, and air conditioning equipment. The T-slot of the beam and the converter box are connected by special rectangular bolts and belong to the direct hanging type [1]. The bottom beam structure of high-speed EMUs uses A7N01S-T5 aluminum alloy extruded materials. Its strength is high, and can extrude thin-walled profiles with complex shapes, and its welding performance is good, but under the action of tensile stress, it is prone to stress corrosion failure behavior [2]. In order to prevent the occurrence of stress corrosion of the beam, it is particularly important to study the stress distribution of the beam assembly structure.

As for the research of the hanging structure, there are more studies in the two major fields of petrochemicals and nuclear power technology involving large equipment structures. In fact, in the field of high-speed EMU technology, hanging problems are also common, and the problem of hanging equipment directly related to train safety, so it is very important to the reliability of high-speed EMUs [3]. However, there are few studies on the installation stress of the car body under and the beam. Zhang Shucui proposed to convert the underconstrained problem into the static balance problem of a multibody system, and based on the principle of virtual work, calculated the balance equation for the hanging node force and its corresponding tangent stiffness matrix [4]. Li Tuo studied the optimal lifting ear position of the containment module, and used ANSYS software to make a detailed study and analysis of the stress at the lifting ear position of the three-stage lifting [5]. Based on the calculation of static equilibrium theory, this paper proposes a calculation method of eccentric load, which is applied to the calculation of the load at the suspension point of the beam. Based on this, the detailed stress distribution of the assembly structure is obtained through simulation research.
2. Introduction of Beam Hanging Structure

In this paper, the connection model of the beam and converter of a type of EMU is taken as the research object, and the specific stress distribution at the suspension point of the beam is studied. The static load of the beam is mainly transmitted to the beam by the gravity of the converter through the bolt. But because the converter is not homogeneous and its center of mass is not in the geometric center, it belongs to the problem of eccentric load distribution. The analysis of the stress distribution of each suspension point of the beam is of great significance for improving the safety and reliability of the beam and the EMU. This paper studies the assembly stress distribution of two beams through four suspension points to suspend the converter. The concrete structure of the T-slot of the beam and the bolt connection is shown in the figure:

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![Assembly structure of beam and bolt.](image)

Figure 1. Assembly structure of beam and bolt.

3. Load Calculation at the Suspension Point of the Beam

The geometric center of the hanging point does not coincide with the geometric center of the hanging weight, which belongs to eccentric hanging. Aiming at the above eccentric suspension structure, based on certain assumptions, the load distribution of the beam suspension points is analyzed by theoretical calculations. Assume that the hanging points of each beam are in the same plane, the position of the hanging points is as follows:

![Location of hanging points.](image)

Figure 2. Location of hanging points.

According to the static balance conditions of the beam, the moments of the OX axis and OY axis are obtained respectively:
\[ \sum P_i^* B_i = 0 \]  
\[ \sum P_i^* C_i = 0 \]  
Because the sum of the loads carried by each lifting point is equal to the gravity of the hanging weight, that is:
\[ \sum P_i = W \]

Assuming that the hanging points are in the same plane, and the hanging points a, b and hanging points c, d are arranged in a row, the deflection at the intersection of the hanging points a, d and hanging points b, c can only be a value [6], which is:
\[ \frac{\delta_a + \delta_d}{2} = \frac{\delta_b + \delta_c}{2} \]  
(4)

According to
\[ P_i = K_i \cdot \delta_i \]  
(5)
The stiffness values of the hanging points are basically equal, so:
\[ \frac{P_a + P_d}{2} = \frac{P_b + P_c}{2} \]  
(6)

Where: \( W \) is the gravity of the hanging weight, \( P_i (i = 1, 2, 3 \ldots n) \) is the load received by each hanging point, \( B_i \) is the lateral coordinate value of each hanging point, \( C_i \) is the longitudinal coordinate of each hanging point value.

According to the formulas (1)-(3) and (6), \( P_i (i = 1, 2, 3, 4) \) can be obtained.

The above calculation method is used for the load calculation of the hanging point studied in this paper. The total weight of the converter is 1800kg. The distribution points of the T-slot beams to suspend the converter are as follows. The numbers 1-4 indicate the number of the suspension points.

![Figure 3. Distribution of hanging points.](image)

In the case of four hanging points, according to the distribution of the hanging points, we can know \( B_1 = -1152 \), \( C_1 = 1420 \); \( B_2 = -1152 \), \( C_2 = -1740 \); \( B_3 = 1148 \), \( C_3 = 1420 \); \( B_4 = 1148 \), \( C_4 = -1740 \).
According to equations (1)-(3) and (6), let \( A = \begin{bmatrix} -1152 & -1152 & 1148 & 1148 \\ 1420 & -1740 & 1420 & -1740 \\ 1 & -1 & -1 & 1 \\ 1 & 1 & 1 & 1 \end{bmatrix} \), \( B = \begin{bmatrix} -4978 \\ -4037 \\ -4963 \\ -4052 \end{bmatrix} \), so \( P = A^{-1} \times B \), that is \( P = \begin{bmatrix} -4052 \\ -4963 \\ 4037 \\ 4978 \end{bmatrix} \), that is, the loads of the four hanging points are 4978N, 4037N, 4963N, 4052N.

4. Simulation of Single Hanging Point Assembly Structure

The distributed load of each hanging point is obtained through theoretical calculation in the second section. The maximum hanging point force is close to 5000N. In order to further analyze the stress distribution of the hanging assembly structure, a single hanging point assembly model of the beam, bolt, and hanger was established, and the stress response under different external loads was obtained.

4.1. Simulation Method of Contact Relationship and Preload

Bolt connection structure is a typical nonlinear contact behavior, when two separate surfaces contact each other and tangency, they are said to be in contact. The nonlinearity of the contact is caused by the nonlinearity of the state conditions. In order to simulate the assembly between the connected part and the bolt, we need to use contact elements in ANSYS. The first is to prevent the contact surfaces from penetrating each other, which is called contact coordination; the second is to transfer normal pressure and friction between the contact surfaces, and the other is to track the change of the relative position of the contact surfaces [7-8].

In order to simulate the pretension force of bolts, a pretension force element needs to be established in ANSYS. Generally, PRETS179 element is used. This element has only one degree of freedom and can only apply tension load, bending moment or torque load will be ignored. When creating the element, it is required that the fasteners be a whole, and the fasteners are cut into two parts at the selected pre-tension position, a pre-tension section is generated using a pre-tension element, and then pretension force is applied on the pre-tension section [9-10].

4.2. Related Parameters

The T-slot cross beam is made of A7N01S-T5 aluminum alloy thin-walled profile, and its mechanical properties are as follows:

| material    | Elastic Modulus (MPa) | Poisson's ratio | Yield limit (MPa) |
|-------------|-----------------------|-----------------|-------------------|
| A7N01-T5    | 7000                  | 0.3             | 245               |

The faster adopts special T-bolt and HARD-LOCK strong lock nut, and the material is steel. The T-bolt adopts M20, class 8.8. According to the actual assembly experience, the pre-tightening torque is selected in the range of 156.9-200N·m. The preload force is selected according to \( F = \frac{T}{0.2d} \) [11], where \( F \) is the preload force of the bolt, \( d \) is the nominal diameter of the thread, and \( T \) is the tightening torque.
4.3. Establishment of Simulation Model

In order to analyze the distribution of the installation stress of the beam and the hanger, the following model of the connection between the single hanger and the beam was established, and the bolts and nuts were connected as a whole, ignoring the threads, and it was convenient to apply the pre-tensioning force to the bolts using the section method. By establishing surface-to-surface contact between the lower surface of the T-nut head and the upper surface of the T-corner inside the beam, the lower surface of the T-corner of the beam and the upper surface of the hanger, and the upper surface of the nut and the lower surface of the hanger, it can be more realistically to simulate the of assembly situation of beam, hanger and bolt. In order to improve the calculation accuracy, the three parts in the assembly model were divided into hexahedral meshes, and solid 185 elements were assigned for calculation. A vertical load is applied to the MASS element below the hanger, and the MASS element is connected to a row of nodes below the hanger through rigid elements. The finite element model of the node is as follows:

![Finite element model](image)

According to the load value calculated in the second section and the selection range of the pre-tightening torque, the following three simulation conditions have been established.

| Working condition number | Working condition description |
|--------------------------|-------------------------------|
| condition 1              | 45KN preload                  |
| condition 2              | 45KN preload. Apply a vertical load to the hanger as: -1500N |
| condition 3              | 45KN preload. Apply a vertical load to the hanger as: -5000N |

The stress nephogram under each working condition is as follows:
Figure 5. Stress nephogram of working condition 1.

Figure 6. Stress nephogram of working condition 2.
4.4. Results Analysis

From the above calculation results, it can be known that under different working conditions, the stress distribution of the beam and the hanger are basically the same, and the position of the maximum stress is also basically the same. The maximum stress of the beam occurs where it comes in contact with the bolt head. The maximum stress of the hanger occurs near the bolt hole. In addition to the position where the beam is in contact with the head of the bolt, the stress at the corner of the T-slot is also larger than the stress in other surrounding areas, which should be paid special attention. When only 45KN of preload is applied, the maximum stress of the beam is 151.4MPa, the maximum stress at the T-slot of the beam is 57.8MPa, and the maximum stress of the hanger is 110.1MPa; when a vertical load of 1500N is applied based on the preload, the maximum stress of the beam is 150.9MPa, the maximum stress at the T-slot of the beam is 57.5MPa, the maximum stress of the hanger is 113.6MPa; when a vertical load of 5000N is applied on the basis of the pretension force, the maximum stress of the beam is 146.1MPa, the maximum stress at the T-slot of the beam is 51.2MPa, and the maximum stress at the hanger is 148.4MPa. According to the above results, it can be known that with the application of vertical load, the maximum stress of the beam is slightly reduced, and the maximum stress of the hanger is significantly increased.

5. Conclusion

1. Based on the calculation of static balance theory, the load distribution of each hanging point of the hanging assembly structure is obtained. The maximum hanging point load is 4978N and the minimum hanging point load is 4037N. The difference between the two is about 900N.

2. By establishing the assembly model of single hanging point suspension, the stress nephogram of the beam and the hanger is obtained. It can be known from the results that due to the application of the bolt pre-tensioning force, the position of the maximum stress of the beam appears on the side in...
contact with the head of the T-bolt. Except for the contact portion, the stress value at the T-corner of
the beam is also larger than other areas.
3. The maximum stress of the hanger appears at the position in contact with the lower surface of
the beam, and as the vertical load increases, the maximum stress of the hanger also increases. When a
vertical load of 5000 N is applied, the maximum stress of the hanger is 148.4MPa.
4. In this paper, theoretical calculations and simulation methods are used to analyze in detail the
load distribution of the beam suspension points and the specific stress distribution of the assembly
structure when the four hanging points are suspended, which can provide relevant research on the
installation stress of the aluminum alloy beams of the EMU and its connection structure reference. In
actual engineering, in addition to four hanging points, there are other cases of hanging at multiple
points. At the same time, aluminum alloy beams often fail due to stress corrosion. Readers who are
interested about it can also study it further.

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