Research on foldable coupler device of modern tram

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Abstract: This article introduces the basic requirements of the coupler buffer device of modern tramcars, gives a detailed description of the new type of folding coupler type, structural parameters, and principle of action. At the same time, the compression and tensile strength analysis of the main stressed parts of the foldable coupler after the lightweight structure design transformation carried out through finite element, and the analysis results meet the design requirements.

1. Introduction

The current urbanization process is accelerating, especially the construction of urban rail transit in China, the demand trend of urban rail vehicles is very strong. As an important member of urban rail transit vehicles, modern tram has taken on important functions to meet the requirements of urban traffic. The new tram has the characteristics of fast-starting and quick-stopping, large passenger capacity, green environmental protection, and strong landscape and so on. It is suitable for the application of urban suburbs and scenic spots.

According to the different traffic volume of urban lines, modern trams are more flexible in marshalling form. Generally, the number of trams is between 2 and 8. Fig.1 shows the tram line 1 in New York City, consisting of 5 modules, 8 vehicles, two-drive and one-tow configuration. Different from the coupler types of subway vehicles (usually three basic models: automatic coupler, semi-automatic coupler and semi-permanent coupler), modern trams generally adopt articulated devices in the middle, and the rescue couplers are installed on the cab modules at both ends, both ends of modern trams are equipped with a set of rescue couplers.

In order not to affect the urban landscape, the coupler at both ends of the cab needs to be improved, that is, instead of adopting the automatic coupler type of the subway, it is replaced by a lightweight foldable coupler, which can meet the requirements of train impulse, strength and impact toughness. This paper introduces the structural parameters, action principle and coupler type test of the foldable coupler.
2. Components of manual foldable coupler

2.1 General composition

In general, the manual foldable coupler can be divided into three main components (Fig. 2), Coupler head, Coupling bar (front and rear coupling bar), and Bearing bracket (with vertical support).

2.1.1. Coupler head

The coupler head is the type of ‘Albert’, Albert coupler was designed by German engineering car Karl-Albert in 1921 and first used in German trams. It has a history of nearly 100 years and is still widely used in the world. The appearance of Albert coupler is to solve the safety problem of coupler coupling. The early coupler required two trains to approach each other during the coupling process, and workers stood in the middle to operate the coupler, so that there is a situation due to the vehicle out of control resulting in injuries to workers. The operation method of Albert coupler is as follows:

(A) The rescued vehicle is in the parking brake state, and the rescue vehicle is controlled by the driver to approach the rescued vehicle. When the distance between the two vehicles is within the length of the two couplers, the driver stops and gets off the vehicle to manually operate the two couplers.

(B) When connecting the coupler, the operator will first open the folding coupler from the end of the tram body, swing the folding coupler on both sides, until a connecting pin can be inserted, connecting the two couplings, and then you can operate one side of the modern tram back, straightening the coupler, and finally insert another connecting pin.

In this way, the coupling operation of the coupler is completed. The advantage of operation is that the two modern trams are in a static state during the manual coupling process of the coupler, and only one driver needs to operate the coupler. In the process of coupling, the distance between the workshop and the coupler is low, as long as the modern trams are close to the length range of the two couplings, the coupling can be completed.
2.1.2. Swing arm mechanism
The swing arm mechanism is the key mechanism of the folding coupler, and its main function is to realize the folding function and folding lock of the coupler (Fig.3). The swing arm mechanism includes a swing arm joint, a rotating shaft, a locking pin, two locking pin springs and an unlocking handle, etc.

![Figure 3. Folding state of the foldable coupler](image)

The folding coupler realizes the folding function of the coupler. When the coupler is in the straight state, the locking pin is inserted into the locking pin hole of the rear pull rod under the tension of the tension spring to realize the straightening and locking of the coupler. At this time, the coupler can be regarded as a straight coupler, which can realize the coupling function of the coupler and transfer the force between trains. When the coupler is used up, the operator can pull the unlocking handle to overcome the tension of the tension spring, pull the locking pin out of the locking pin hole of the rear pull rod, and the locking state is cancelled. At this time, the folding joint can rotate around the rotating shaft to realize the folding function.

2.1.3. Bearing bracket
Bearing bracket component consists of the bearing bracket, pivot shaft, securing block, and other parts. The securing block is used to prevent the shaft from rotating. The bearing bracket defines the interface with carbody using 4xM24 bolts according to the requirement. (Fig.4)

![Figure 4. Bearing bracket](image)

2.1.4. Locking device
The locking device is used to fix the folded coupler. A R-pin is used to ensure the locking pin, and a chain ensure the captive fastening. When the coupler is folded in place, the Albert coupler head enters into the tiger mouth of the fixing device, and then the fixing pin is penetrated into the coupling pin hole of the hook body.

![Figure 5. Locking device](image)

2.2 Detailed parameter of manual foldable coupler
Approx. weight ≤110kg
Distance from front of coupler level to mounting surface 1930mm
Coupling length (From coupling level to center rotating joint) 1800mm
2.3 Material parameters
The material and performance parameters of the coupler body, rotating arm, pull rod, bearing bracket and other components are shown in Table 1.

| Part name       | Yield strength /MPa | Tensile strength /MPa | Elastic modulus /GPa | Poisson's ratio |
|-----------------|---------------------|-----------------------|----------------------|-----------------|
| bearing bracket | 415                 | 620                   | 206                  | 0.3             |
| coupler body    | 415                 | 620                   | 206                  | 0.3             |
| pull rod        | 355                 | 680                   | 206                  | 0.3             |
| rotating arm    | 355                 | 680                   | 206                  | 0.3             |

3. Main experimental contents of coupler
The test contents of the folding coupler mainly include:

(1) Coupler connection and uncoupling test
(2) Curve passing capacity test of coupler
   It is required to provide a manual for the calculation of the curve passing capacity, and the actual curve passing capacity to be simulated by the experimental platform. Through test inspection, no parts are damaged or movement is restricted.
(3) Coupler load test
   Test whether the coupler meets the load capacity under the maximum design load.
(4) Weighing test
   After the production location changes, the type test should be re-conducted and the test report should be provided.

4. Calculation of coupler load limit
There are many factors that affect the extreme value of the coupler load, and the influence degree of each factor is difficult to determine accurately, so the kernel density estimation method is selected, and data analysis in the engineering field has been widely used in recent years.

Assuming that the density function of the random variable X is \( f(x) \), the distribution function \( F(x) \), \( f(x) \) can be expressed as:

\[
f(x) = \lim_{h \to 0} \frac{F(x+h) - F(x-h)}{2h} = \lim_{h \to 0} \frac{1}{2h} P(x-h < X < x+h)
\]

(1)

In the formula: H is the group distance.

According to the above formula, the density of \( f(x) \) is estimated as:

\[
\hat{f}(x) = \frac{1}{2hn} N(x-h < X < x+h)
\]

(2)

In the formula: N is the number in the interval.

In order to ensure that the selected bandwidth \( h \) is unrelated to the coupler load extreme sample, the optimal bandwidth is determined by the integral mean square error (mise) and the asymptotic integral mean square error (amise). Therefore, the formulas of Bias[ ] and Var[ ] can be obtained:

\[
\text{Bias}[\hat{f}(x)] = \frac{h^2}{2} f^2(x) \int K(u)du + o(h^2)
\]

(3)
The integral mean square error (MISE) can be obtained by the above formula:

$$\text{MISE}\left[\hat{f}(x)\right] = \frac{1}{nh} \int h^{2} \hat{f}(x) \int u^{2} K(u) du^{2} dx + o(h^{4}) + o\left(\frac{1}{nh}\right)$$

(5)

According to the integral mean square error (MISE), in order to make the asymptotic integral mean square error (AMISE) reach the minimum bandwidth, the following results are obtained:

$$\min AMISE\left[\hat{f}(x)\right] = \frac{1}{nh} \int h^{2} \hat{f}(x) \int u^{2} K(u) du^{2} dx$$

(6)

Take the derivative of the above-mentioned bandwidth $h$ and set the derivative to 0, the optimal bandwidth is:

$$\hat{h} = \left\{ \frac{1}{n} \int \left[ \frac{K(u)}{f'(x)} \int u^{2} K(u) du^{2} \right] dx \right\}^{\frac{1}{5}}$$

(7)

Based on the above theoretical knowledge, the extremum of tensile load and compression load of modern tram folding coupler can be calculated, which is 250kN.

5. Establishment of finite element model

Under tension and compression conditions, the main load application area of the bearing bracket is different from the restraint application area, as shown in Fig. 6. Use tetrahedral elements for meshing, establish a reference point at the cylindrical hole connecting the mounting seat and the pull ring. The coupling constraint between the reference point and the load loading area is established. Then the tensile and compressive loads are applied in the form of concentrated force on the reference point. The direction of the arrow in the figure is the loading direction of the load; a fixed constraint is applied to the constraint area. According to the force, the finite element models of the coupler body, rotating arm, pull rod and other parts are established respectively (Fig. 7).
6. Results of finite element analysis

Fig. 8 to Fig. 11 show the stress nephograms of components such as bearing bracket, coupler body, rotating arm and pull rod under 250kN tensile load and 250kN compression load.

7. Conclusion

Through the finite element analysis simulation results, we can see that:

The maximum stress of components such as bearing bracket, coupler body, rotating arm and pull rod under 250kN tensile load and 250kN compression load is shown in Table 2. It can be found that
the stress of component is less than the yield strength of the material under 250kN tensile and 250kN compression loading.

| Material       | Maximum stress under 250KN compression load /Mpa | Maximum stress under 250KN tensile load /Mpa | Material yield stress /Mpa |
|----------------|-----------------------------------------------|---------------------------------------------|---------------------------|
| bearing bracket| 145                                           | 358                                         | 415                       |
| pull rod       | 119                                           | 281                                         | 355                       |
| rotating arm   | 179                                           | 303                                         | 355                       |
| coupler body   | 141                                           | 317                                         | 415                       |

After the lightweight design of the folding coupler device, the maximum stress under the 250kN compression load meets the design requirements, and the weight is only 110kg, which is greatly reduced compared with 300kg-500kg of other types of couplers. It is well used in modern trams in China, and the technical scheme is also adopted in foreign countries such as Europe and the United States. The technical scheme fully meets the needs of the actual operation.

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