Forging Yoke Technology and its Application on Heavy Haul Wagon

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Summary: The yoke is an important component of railway vehicles. Along with the improvement of railway wagon load, the train traction tonnage and running speed, the separation of vehicle accidents caused by the crack and fracture failure of the yoke is gradually increased, becomes typical failure endangering the safety of railway heavy transportation. With the purpose to solve above-mentioned problems, QRRS has developed series of forging yoke, such as Type 17, Type 16, Type 13B etc., and which has been widely applied on the heavy haul rail wagons in China and Australia, and significantly reduces the risks of cracking of the yoke and fracture failure and increases the fatigue life and reliability of the yoke of heavy haul wagon. This paper explains several aspects involving the development background, product structure characteristics of the yoke, strength and fatigue life analysis and applications, etc.

Keywords: forging, yoke, heavy haul railway wagon, application

1. INTRODUCTION

The yoke of railway vehicle is one of the key components - especially the yoke for the wagon. For two decades recent, along with the development of China railway transportation, the cargo wagon formation on the universal line has been developed from 3000-5000t to 6000t to 10,000t, on Da-Qin line and other heavy haul lines, long and heavy haul wagons such as 10,000 tons and 20,000 tons wagons have been put into operation, and the vehicle speed is improved from 50-60km/h to 80-100km/h, and the vehicle axle load is improved from 21t to 23-25t, which causes sharp impulse inside the wagon along longitudinal direction increases rapidly. Yoke, as a key component of the traction forces bearing load of the wagon, the vehicle separation accidents caused by the crack fault and fracture are gradually increased along with the development of the heavy haul transport, and the fatigue life and reliability show an obvious decreasing trend, which has seriously affected the normal organization and the safe operation of the wagon. The countries with advanced heavy haul transportation are also facing with the inertia problems of cracks and fracture of the yoke.

With the purpose to ensure the safety of railway transportation, CNR QiQihar Railway Rolling Stock Co., Ltd. (hereinafter referred as: “QRRS”), has developed the railway wagon forging yokes for the railway wagon of Type 17, Type 16 Type 13B from 2004 to 2008, and the test result, simulation analysis and practical application show that the forging yoke technology has reached the world advanced level and becomes the upgraded products of coupler buffering technology of China heavy haul speedup wagon, now the technology has been widely applied to Chinese railway wagon.

2. FUNCTIONAL AND STRUCTURAL CHARACTERISTICS OF THE YOKE

The coupler buffering device system is an important part of the railway rolling stock. The three main functions of
the coupler buffering device system are coupling, traction, and buffering, and are mainly composed of the coupler, buffer, yoke, follower and yoke pin and other parts.

The yoke is one of important parts of the coupler buffering device and of the main force-bearing components, which plays an important and crucial role on the rolling stock. Firstly, it provides the installation space for the buffer, to facilitate the buffer to fully play its role; second, it connects with the coupler, provides installation space for the coupler, and transfers the longitudinal traction force and ensures that the buffer functions under traction conditions. The railway train is composed of railway vehicles by coupling through the couplers, and the coupler is connected to yoke via yoke pins, the force transmission between the vehicles is shown in Figure 1 and 2. When the vehicle is under the traction power, the process of force transmission is: the coupler → yoke pin → yoke → buffer → follower → front draft lug → stub sill; when the vehicle is under the impact of shock, the process of force transmission is: the coupler → follower → buffer → rear draft lug → stub sill. Therefore, the structural strength of the yoke, the level of fatigue reliability will directly impact on safety and efficiency of the railway transportation.

It is well known that different vehicles use couplers of different mechanism principle and the type, the different couplers must be matched with a dedicated yoke. At present, the normal yokes used on China railway wagon are Type 13A, Type 13B, Type 16 and Type 17.

3. STRUCTURE DESIGN AND CHARACTERISTICS OF THE FORGING YOKE

3.1 Structure design of forging yoke

Basing on ensuring interchangeability and application of the yoke, and the analysis results of optimized finite element structure, combining with the characteristics of the forging process, redesign on the basis of original "casting" yoke structure; the original "casting integration" structure is changed to the yoke design of "Forged main structure, overall welded structure", the yoke design is split into two sections of yoke frame and the connecting plate, to be formed as yoke via mold forging and welding. The welding seam position is selected at the low stress area of the head part of the yoke based on the optimized analysis results, without any affects on the strength and service life of the yoke, as shown in Figure 3. Under the premise of ensure product performance and functions, the characteristics and requirements of forging process are fully taken into consideration to reduce manufacturing costs and improve the production capacity.

The whole forging yoke is of long rectangular-ambulatory-plane frame, the frame is of U shape structure frame; it requires the same direction of the flow of metal fibers of the frame plate and tail part and the direction of the yoke bearing force during the forging process; in order to improve the manufacture quality of the corner of the tail part, it requires
to use machining method for manufacturing; at the same time, in order to improve the production efficiency, combine with the forging process characteristics, cancel the process on the original cast yoke and weight reducing hole for the structural design of the forging yoke.

Type 17, Type 16 forging yoke is shown in Figure 4. Type 16, Type 17 forging yoke will be assembled for using with Type 16 and Type 17 coupler as the replacing products of Type 17, Type 16 casting yokes. Type 16 coupler is connected with the rotating kit installed in the yoke frame via yoke pin, since the rotating kit can rotate 360° within the yoke, it can realize the relative rotating power between coupler and yoke.

Type 13B forging yoke. The main structure is same as the standard yoke with the change of bearing manner of yoke, by using plug-in pin-support-carrying yoke, improves the security and reliability of the coupler buffering system, to prevent the separation accident of the train caused by the release of yoke pin. Type 13B forging yoke and plug support are shown in Figure 5.
### 3.2 The main features of the forging yoke

1) **Long fatigue life, high reliability**

Since the density of the forgings is better than that of castings, and avoid the sand hole, air hole and shrinkage and other special manufacture defects, especially can ensure and improve the manufacture quality of the rear corners of the yoke parts, can significantly improve the fatigue life and reliability of the yoke, reduce the incidence rate of yoke crack, can effectively prevent the train separation accidents caused by yoke breaking, and provides technical support for running safety. For the P-S-N curves of different E-grade material, refer to Figure 6.

![Figure 6: The P-S-N Curve of E-grade Steel Materials](image)

2) **High structural strength**

Forging yoke is manufactured with E-Class forged steel, the minimum limit load is greater than 4005kN, its designed structural strength and casting yoke strength are equivalent, but the actual structural strength is significantly higher than the casting yoke, to ensure the strength match with the train coupler buffering device of Type 16, Type 17 and Type 13 series products.

3) **Good interchangeability**

The main structural size of the forging yoke of Type 16, Type 17, and Type 13B should be same with that of the casting yokes of Type 16, Type 17 and Type 13 series respectively, and can be used matching with the train coupler buffering of Type 16, Type 17 and Type 13 series, with good interchangeability; at the same time, forging yoke of Type 16 can meet the requirements of the operation of the wagon tipper.

4) **Reduce the maintenance workload, reduce the operation cost.**

Since the forging yoke structure has high strength, good wear resistance and long fatigue life, it can reduce the operation, regular inspection workload and costs, meet the requirement of the development of railway wagon overhaul reform.

### 4. MAIN PERFORMANCE PARAMETERS AND DIMENSIONS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yoke minimum limit load</td>
<td>4005kN</td>
</tr>
<tr>
<td>Yoke maximum permanent deformation (3340kN)</td>
<td>0.8mm</td>
</tr>
<tr>
<td>Type 17 forging yoke: Diam. of tail pin hole</td>
<td>φ92 +0.87 -0.35mm</td>
</tr>
<tr>
<td>The distance between center of tail pin hole</td>
<td>235 +3 -1mm</td>
</tr>
<tr>
<td>Bearing surface</td>
<td>161+1.5 0mm</td>
</tr>
<tr>
<td>Distance between the carrying surface of yoke</td>
<td>834±2mm</td>
</tr>
<tr>
<td>Weight</td>
<td>102.2kg</td>
</tr>
<tr>
<td>Application</td>
<td>70t-class, 80t-class new wagon and heavy haul wagon</td>
</tr>
</tbody>
</table>

Type 16 forging yoke:
- Head inner circle diameter: φ270 +0.2-1.5mm
- Inner block height of yoke: 235 +3-1mm
- Distance between the carrying surface of yoke pin and yoke center: 161+1.5 0mm
- Distance between traction surface to the rear bearing surface: 834 ± 2mm
- Weight: 126kg
- Application: Used for various heavy haul wagon unloading without disconnecting the couplers

Type 13B forging yoke:
- The length of yoke pin hole: 106 +1.0 -0.8mm
- Inner block height of yoke: 235 +3-1mm
- Distance between the front end of the yoke pin hole and the inside of the tail: 777 ±3.0 0mm
- Weight: 100kg
- Application: Use for load of 60t-class various wagon and special wagon

### 5. FINITE ELEMENT ANALYSIS OF STATIC STRENGTH AND FATIGUE LIFE ASSESSMENT

In course of design of technology plan, with the purpose to ensure the structural strength and fatigue life and good reliability of the forging yoke, QRRS conducts static strength finite element analysis on Type 17, Type 16 forging yoke and Type 13B forging yoke, and China Beijing Jiaotong University is invited to perform fatigue life and reliability assessment and analysis on the yoke.

#### 5.1 Type 17 forging yoke

Based on the analysis results of finite element analysis,
under the longitudinal traction force of 1780kN of the first working condition of ten thousand tons train, the stress comparison between Type 17 forging yoke and casting yoke stress is indicated in Table 1.

**Table 1: Stress Comparison of Type 17 Forging Yoke and Casting Yoke**  
unit: Mpa

<table>
<thead>
<tr>
<th></th>
<th>Traction pin hole</th>
<th>Frame plate converting to cross-section part</th>
<th>Inner corner area of tail part</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forging</td>
<td>391.6</td>
<td>320.4</td>
<td>342.6</td>
</tr>
<tr>
<td>Casting</td>
<td>415</td>
<td>375.9</td>
<td>384.8</td>
</tr>
</tbody>
</table>

From Table 1, we can see that the stress of various parts of Type 17 forging yoke is much less than the material yield limit of 690 MPa, with large reserves of strength. Fatigue life assessment of Type 17 forging yoke adopts one-time zooming of the actually measured load spectrum and linear cumulative damage method for calculation and analysis of Shanghai Railway University in the early 1990s.

The fatigue life simulation and assessment results indicate that: Type 17 forging yoke, even under the serious defects (99% reliability), its fatigue life exceeds 5 million kilometers. Since the welding head of the horizontal connecting plate at the head of yoke is set at the low stress area, the welded joints do not have the problem of insufficient fatigue strength.

**5.2 Type 16 forging yoke**

Based on the finite element analysis results, under the longitudinal traction force of 1780kN of the first working condition of ten thousand tons train, the stress comparison of Type 16 forging yoke and casting yoke is indicated in Table 2, as for the stress cloud figure, see Figure 3.

<table>
<thead>
<tr>
<th></th>
<th>Center area of external of tail section</th>
<th>Inner corner area of tail section</th>
<th>Frame plate converting to cross-section part</th>
<th>Edge area of the head hole</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forging</td>
<td>390</td>
<td>374</td>
<td>358</td>
<td>329</td>
</tr>
<tr>
<td>Casting</td>
<td>463</td>
<td>454</td>
<td>397</td>
<td>350</td>
</tr>
</tbody>
</table>

Fatigue life assessment of Type 16 forging yoke adopts heavy haul coupler load spectrum and linear cumulative damage method for simulation calculation and analysis on the 90.7 tons hopper car stated in Chapter 7 of AAR M-1001-97 "Wagon Design Manufacture Specification".

The fatigue life assessment results show that: short-lived parts of Type 16 forging yoke locates at the center area of external side of tail section, inner corner area of tail section, frame plate conversion to cross-section area and hole edge of head part, taking the condition of air to weight ratio of 1:1, under serious defects of severe environment load spectrum, fatigue stress concentration factor of 3, the heavy haul fatigue life of Type 16 forging yoke exceeds 5 million kilometers, it is much more than that of casting yoke.

**5.3 Type 13B forging yoke**

Static strength finite element analysis of Type 13B forging yoke takes the condition of the first working condition of 1780kN of ten thousand tons train and destructive load of 4005kN applied as longitudinal traction force, at the same time, apply vertical load on the yoke pin supporting structure with the maximum force of 118kN which is the force from yoke pin to pin supporting under the traction load of 1780kN under the first working condition of ten thousand tons train.

The calculation results show that the Type 13 Forging yoke structure of the tail of tensile stress zone in the tensile 1780kN conditions of maximum stress 286MPa, far less than the material yield limit 690 MPa; in 4005kN load under the tail tensile stress zone of maximum stress 801MPa less than the fracture strength of 830MPa, to meet the strength requirements; 13 type forging yoke pin care part of the structure in the vertical 118kN conditions stress maximum is 150 MPa, and far less than the allowable stress of 400MPa strength to meet the requirements.

**6. FORGING YOKE MANUFACTURING PROCESS**

The production process of forging yoke basically includes making billet, mold forging, trimming, bending, shaping, welding, ultrasonic defects detection, heat treatment, machining, wet magnetic particle detection and sand blasting, etc. With the purpose to improve the reliability of manufacture process, DEFORM-3D and other software are employed to perform value simulation optimization analysis on the forging process in course of process design, to identify the process data material flow in forging process, the mold filling, forming load, mold stress, fiber flow direction, defect formation and tenacity rupture and so on.

Refer to Figure 7
Based on ensuring the products quality, with the purpose to maximize the production efficiency, reduce energy consumption, weight of rough pieces and lower manufacturing costs, the design of QRRS adopts a complete new production line, with the configuration of special continuous medium frequency induction furnace, large roll forging press, 8000t friction press, trimming machines, and dedicated simmer bending machines and other large and medium-sized equipment, heat treatment process is also updated from the original trolley kiln heat treatment process to continuous passing type heat treatment process, improves quality assurance and mass production capacity of forging yoke. The special roll forging machine is indicated in Figure 8 and 8000t friction press machine in Figure 9.

Traceability of the manufacturing logo. In order to ensure to meet the requirement of quality management of the implementation of traceability to the key and important parts requested by Chinese Ministry of Railways, special equipment and mold are developed, designed and manufactured, by means of special hot press manufacturing process, three kinds of manufacturing mark for traceability, such as "manufacturer code, manufacturing year and month, manufacturing order number" are marked at the tail part of the yoke by using thermal print.

In addition, it can also supervise the manufacturing, testing, and inspecting of the forging yoke, and a dedicated "forging yoke manufacturing technology conditions" is prepared as well.

7. TEST SITUATION

7.1 Static strength test

In order to inspect and verify the structural strength of the forging yoke, QRRS performed verification test on the structural strength of the various types of forging yokes, and the results show that the strength meets the design requirements.

For example, the static strength test is performed on Type 16 forging yokes, measure the stress value at the main force bearing part of Type 16 forging yoke under the tensile force. The test results show that: under the load of 1780kN of the maximum longitudinal tensile strength of the first conditions requested by longitudinal force of ten thousand tons train, the average stress value of internal and external of the tail part corner of Type 16 forging yoke are respectively 31.036 MPa and 48.96 MPa, all less than the allowable stress; under the load of 2250kN of the maximum longitudinal tensile force of the first conditions requested by the test standard of longitudinal force of twenty thousand tons train, the average stress value of internal and external of the tail part corner of Type 16 forging yoke are respectively 392.93 MPa and 60.47 MPa, all less than the allowable stress; the strength meets the requirements.

7.2 Static load destructive test

Type 17, Type 16, Type 13B forging yoke made by QRRS have passed the static load test performed at the rolling stock and locomotives components inspection station of Quality supervision and inspection center of China.
Ministry of Railways respectively. The test results show that the maximum permanent deformation of the yoke under the load of 3340KN is less than 0.8mm, the minimum limit load is greater than 4005KN, the strength meets the requirements.

7.3 Type 16 forging yoke rotation test

The rotation test has been conducted on Type 16 forging yoke over the rotating test bench of Type 16 and Type 17 coupler of QRRS. The test is to be performed under four kinds of working conditions, i.e. under the condition of alignment of coupler longitudinal centerlines after two couplers are connected, and two working conditions of alignment of the two couplers horizontal centerline in vertical or with the height difference of vertical coupler of 75mm; when the longitudinal centerlines of two couplers shift with the displacement of 38mm in horizontal direction, under two working conditions of alignment of two coupler horizontal center surface in vertical or height difference of vertical coupler is of 75mm.

The results show that Type 16 forging yoke and Type 16 passive board, rotating sleeve, yoke pin are flexible in rotation in the testing process, without blocking phenomenon, with a good performance for rotation.

7.4 Fatigue test

In order to develop further in the reliability of coupler buffering system, QRRS and Beijing Jiaotong University cooperated for research to compile the fatigue test methods and standards for coupler buffering system, and performed a test for the comparative assessment on the adaptability of the coupler buffering system of the existing wagon. From 2008, the coupler made by QRRS and the comprehensive fatigue test bench for connecting parts (the second set worldwide, the first set is in the United States) are used initially, to perform the comparison test for the fatigue reliability of the yoke and coupler of the wagon, and coupler tongue. The preliminary test results show that under the same load spectrum, the number of times of fatigue testing of forging yoke is above 3 times of the casting yoke, the fatigue test results of different manufacturers, products are different. The fatigue test bench of QRRS is shown in Figure 10, 11.

At present, QRRS is to expand the fatigue comparative test and the related research work, continues to work with the Beijing Jiaotong University and other research institute, university to jointly develop the research, test and verification on coupler load spectrum, to accurately provide and prepare the related test standards, to offer scientific technical supports for an accurate assessment of the fatigue life of yoke. At the same time, we develop cooperation with BHP Billiton, Rio Tinto, FMG company to carry out the related tests and researches respectively.

8. PROMOTION AND APPLICATION

The development and application of forging yoke not only have increased the new varieties of China railway wagon coupler buffering device, filled a blank of China and international railway heavy haul wagon and reached the international advanced level, but also improved equipment technology level of China railway heavy haul transportation and meet the requirement of the development of China railway heavy haul technology.

Since 2005, Forging yoke have been widely promoted and applied on the new railway wagon of China, among them,
type 17 forging yoke has been fully promoted and applied on the 70t-class, 80t-class wagon purchased by tendering of 2007, Type 16 forging yoke has been fully promoted and applied on the 80t-class wagon purchased by tendering of 2008, Type 13B forging yoke has been fully promoted and applied on the new 60t-class wagon of all railways from May of 2008. In order to further promote the application of forging yoke of new technology, enhance the overall technical level of heavy haul wagon in China, according to the arrangements and requirements of the China Ministry of Railways, QRRS has issued the technology license for Type 17 forging technology, Type 16 forging yoke, Type 13B forging yoke to 24 companies in domestic respectively.

After 8 years application, the forging yokes firstly installed on wagon have not occurred any failures affecting the operating and application performance, basically solved the inertial quality problems on the domestic and international railway wagons, especially as to the problem of cracks on the rear corner of the yoke of heavy haul wagon, which is the most difficult one to resolve. By solving the problems, the application maintenance cost is reduced; at present, in course of overhaul of China Datong-Qinhuangdao Railway Company, the newly replaced yokes are mainly forging ones, and all newly procured wagons are all equipped with Type 16, Type 17 forging yokes.

The successful application of Type 16, Type 17 forging yokes has improved the operation safety and efficiency of the heavy haul wagon in China, has become one of the key technologies of the China railway wagon heavy haul transportation.

Particularly worthy of note, the forging yoke technology has been recognized by Australia’s BHP Billiton, Rio Tinto, FMG and Brazil’s Vale Companies, which are top three mining giant companies in the world, and also attracts great attention from Association of American Railroad. The technology has become one of the first choices as key technology for the 35.7t axle load wagons and 30–40 thousand tons heavy haul wagon exported to Rio Tinto, and 40t axle load wagon exported to BHP Billiton and FMG Company; at the same time, we have exported 4840 sets, 4450 sets and 300 sets forging yokes as accessories to the three companies respectively.

9. CONCLUSION

The forging yoke has the advantages of high structural strength, long fatigue life and good interchangeability, as well as the merits of advanced manufacturing process and stable product quality, and better intrinsic quality, which meet the development requirements of China railway heavy haul transportation and wagon technology.

The successful development and application of forging yoke has accelerated the upgrading of China railway wagon heavy haul transportation technology, filled the blank of the international heavy haul transport equipment technology, and reached the leading advanced level.