Research on influence of Web spacing of bogie side member on welding deformation

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Abstract. In the production process of bogie, welding is one of the important production technologies. To study and control the welding deformation of bogie frame side beam to make the deformation value within a reasonable range has very important practical significance for the production of bogie side beam. The research content of this paper will take high-speed EMU bogie frame side beam as the research object. Set different web spacing, compare the welding deformation value, explore the influence of structural stiffness on the welding deformation of side beam, and use MATLAB software to curve fitting the welding deformation value, the research shows the distribution law of transverse, longitudinal, vertical and comprehensive welding deformation, and fits the mathematical equation between the web spacing L and longitudinal deformation SX, vertical deformation SY, transverse deformation SZ.In this paper.

1. Introduction
Welding is one of the most commonly used production methods in machinery industry. In the process of welding, because of the processing characteristics of instantaneous and high temperature welding, plastic strain, phase transformation and residual stress can not be avoided, thus reducing the strength and accuracy of the workpiece, making the workpiece unable to meet the production requirements, consuming a lot of time cost and economic cost, leaving hidden dangers for the subsequent assembly and other production processes, and controlling the deformation of the workpiece during welding in one Within a reasonable range, it is particularly important, especially in the production process of high-speed EMUs[1-4].

Using simulation technology to predict the welding deformation of bogie side beam in advance and control the welding deformation is of great practical significance. It can reduce the production cost and improve the production efficiency. It has become an important technical means to control the welding deformation in the design and production stages of enterprises. Many scholars have done a lot of research on the welding deformation of bogie frame side beam and bogie frame. In 2011, Sun Kai of Southwest Jiaotong University carried out simulation calculation and analysis of K7 bogie sub frame based on thermal elastic plastic finite element method[5]. In 2012, Sun chuanzheng of Southwest Jiaotong University simulated the welding process of bogie frame, and obtained the simulation results of bogie welding deformation under actual production conditions according to the thermal elastic-plastic finite element method[5]. In 2012, Liu Huanjun of Southwest Jiaotong University simulated the welding residual stress and welding deformation of the side beam of the steering frame, and measured
the residual stress value of the selected point according to the ixrd non-destructive detection technology, and compared the measured value with the simulation value. According to the comparative analysis results, the welding process parameters were optimized, which provided a reference for the production and manufacturing of the factory. There are practical and constructive opinions[7].

In this paper, under the actual production process conditions, using computer simulation technology, the influence of structural stiffness on the welding deformation of side beam is explored. By setting different web spacing, based on the thermal elastic-plastic inherent strain method, typical local welded joints are intercepted, and the heat source check and simulation calculation of local joint are carried out by using the thermal elastic-plastic method, and the plastic strain of local joint is extracted to establish the inherent strain. According to the library, the integral model of bogie frame side beam is simulated according to the theory of inherent strain method. Then, on the basis of the calculation results of welding deformation, the curve fitting of welding deformation value is carried out by using MATLAB software, so as to find out the rule of welding deformation and web spacing.

2. Introduction of different web spacing models of bogie side beam
The main body of bogie frame side beam is mainly composed of upper and lower cover plates and left and right webs, and the distance between left and right webs is 156mm. In order to explore the influence of Web spacing on welding deformation, ten groups of different web spacing are set, which are 76mm, 86mm, 96mm, 106mm, 116mm, 126mm, 136mm, 146mm, 156mm, 166mm. The model of bogie side beam is shown in Fig. 1.

![Figure 1 geometric model of side beam](image)

3. Introduction to welding scheme
As the bogie frame side beam is multi-layer and multi pass welding, there are mainly two two-layer welds and four three-layer welds. The welding sequence of six main welding seams is involved in the simulation calculation of the overall model of the bogie side beam. In order to facilitate the introduction of the welding sequence scheme, the six main welding joints and each layer of welding seam are numbered and defined. The sequence number of the six main welding seams is shown in Fig. 2. The sequence number of each layer of each weld is shown in Fig. 3.

![Figure 2 sequence number of 6 main welds](image)
According to the integral model calculation of bogie frame side beam, the welding sequence scheme adopted in this paper is as follows: first, weld the left and right webs and the inner side of the lower cover plate by layers. After welding, weld No.3, weld No.4, weld No.5 and weld No.6 shall be welded layer by layer in anti clockwise sequence. The specific welding sequence scheme code is shown in table 1.

| Welding sequence | Explain                  | Remarks                                      |
|------------------|--------------------------|----------------------------------------------|
| 1                | 1-1→2-1                  | 1-1 is the first layer of No. 1              |
| 2                | 1-2→2-2                  | 2-2 is the second layer                      |
| 3                | 3-1→4-1→5-1→6-1         | weld 2-2 is the second layer                |
| 4                | 3-2→4-2→5-2→6-2         | of No. 2 weld, and so on.                   |
| 5                | 3-3→4-3→5-3→6-3         |                                              |

4. Relationship between web spacing and welding deformation and its analysis

Using MATLAB software, the quantitative relationship between the web spacing and the simulation value of welding deformation is explored. Taking the web spacing as the independent variable L, the longitudinal welding deformation of bogie side beam is defined as SX, the vertical welding deformation is defined as SY, the transverse welding deformation is defined as SZ, and the comprehensive welding deformation is defined as S. The curve fitting and formula fitting of welding deformation in different directions and the independent variable web spacing are carried out together. In order to evaluate the accuracy of the fitting formula, four index parameters, SSE, R-square, adjusted R-square and RMSE, were investigated. The closer SSE and RMSE indexes are, the more accurate the formula fitting is. The closer R-square and adjusted R-square indicators are to 1, the more accurate the formula fitting is.

Table 2 is the simulation value of bogie side beam welding deformation corresponding to different web spacing, and Figure 4 is the fitting diagram of bogie side beam welding deformation curve.

| Web spacing | Longitudinal deformation value | Vertical deformation value | Lateral deformation value | Comprehensive deformation value |
|-------------|--------------------------------|----------------------------|--------------------------|--------------------------------|
| 76          | 3.909                          | 9.692                      | 4.026                    | 9.694                          |
| 86          | 3.90                           | 10.03                      | 3.457                    | 10.03                          |
| 96          | 4.149                          | 10.34                      | 3.949                    | 10.35                          |


|    |     |     |     |     |
|----|-----|-----|-----|-----|
| 106| 4.019 | 9.554 | 3.023 | 9.565 |
| 116| 3.948 | 9.384 | 3.535 | 9.385 |
| 126| 3.901 | 9.313 | 4.162 | 9.365 |
| 136| 3.867 | 9.411 | 4.037 | 9.445 |
| 146| 3.864 | 9.396 | 4.008 | 9.411 |
| 156| 3.946 | 9.203 | 4.185 | 9.238 |
| 166| 3.563 | 8.611 | 3.577 | 8.617 |

Using MATLAB software to fit the deformation value and web spacing, the mathematical relationship formula of Web spacing and longitudinal, vertical and transverse welding deformation and comprehensive deformation can be obtained respectively.

Longitudinal:

\[ SX = -0.2827L^7 + 0.04087L^6 + 0.9051L^5 - 0.2513L^4 - 0.6455L^3 + 0.2776L^2 - 0.05986L + 3.908 \]  
\[ \text{SSE} : 0.001605 \quad \text{R-square:} 0.9918 \quad \text{Adjusted R-square:} 0.9632 \quad \text{RMSE:} 0.02833 \]  

Vertical:

\[ SY = -0.5724L^7 + 0.2632L^6 + 2.231L^5 - 1.315L^4 - 2.404L^3 + 1.57L^2 + 0.2343L + 9.262 \]  
\[ \text{SSE} : 0.04155 \quad \text{R-square:} 0.9789 \quad \text{Adjusted R-square:} 0.9052 \quad \text{RMSE:} 0.1441 \]

Transverse:

\[ SZ = 2.042L^8 - 1.509L^7 - 8.47L^6 + 5.763L^5 + 10.42L^4 - 6.452L^3 - 3.762L^2 + 2.243L + 3.944 \]  
\[ \text{SSE} : 0.002512 \quad \text{R-square:} 0.9789 \quad \text{Adjusted R-square:} 0.9052 \quad \text{RMSE:} 0.1441 \]  

Comprehensive:

\[ S = -0.6405L^7 + 0.249L^6 + 2.491L^5 - 1.267L^4 - 2.689L^3 + 1.522L^2 + 0.3278L + 9.291 \]  
\[ \text{SSE} : 0.03593 \quad \text{R-square:} 0.9814 \quad \text{Adjusted R-square:} 0.9164 \quad \text{RMSE:} 0.134 \]
From the curve fitting diagram and fitting formula of welding deformation, it can be concluded that the longitudinal welding deformation presents a downward trend in the most range of 97mm to 146mm, and a slight upward trend in the range of 80mm to 97mm; the vertical welding deformation presents a downward trend in the most range of 94mm to 166mm, and a slight upward trend in the range of 79mm to 94mm; and the transverse welding deformation is in the whole range consistent with the vertical welding deformation trend, which indicates that the welding deformation of the whole side beam is mainly vertical deformation.

5. Conclusion
1. In this paper, the typical local welded joints are intercepted, the heat source of local joints is checked and simulated by thermal elastic-plastic method, and then the plastic strain of local joints is extracted to establish the inherent strain database, and then the welding deformation of the overall model of bogie frame side beam is calculated by using the theory of inherent strain method, which proves the feasibility of the method based on thermal elastic-plastic inherent strain.

2. Within the range of ten sets of Web spacing, considering the longitudinal, transverse, vertical and comprehensive deformation values, it can be found that although the lateral deformation of bogie side beam reaches the minimum value at 116mm, there is little difference between 166mm transverse deformation and 116mm transverse deformation, and the minimum value of 166mm is obtained in longitudinal, vertical and comprehensive deformation values. The welding deformation of bogie side beam is minimum.

3. According to the fitting diagram of welding deformation curve, the longitudinal, vertical and comprehensive deformation values of bogie side beam generally show a downward trend with the increase of Web spacing, but the deformation slightly presents an upward trend in the range of 80mm to 97mm. The reason is that after the web spacing is increased to 96mm, the welding deformation value of the upper and lower cover plate edge gradually decreases, In other words, the position of the maximum welding deformation changes, and the transverse deformation presents wave deformation at the opening of the circular hole of the web.

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