Welding Distortion Prediction and Process Optimization of Turbine Component by Electron Beam Welding

Yichen Huang, Liqun Li, Bo Pan
State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, Harbin, P.R.China
Email: hyc@stu.hit.edu.cn

Abstract. A turbine component with 130 blades requests high dimensional precision to ensure the assembly requirements. The dimensional precision is significantly influenced by welding distortion. In this research work, welding distortion in the turbine component by electron beam welding was predicted through elastic finite element method based on inherent strain theory. The inherent strains of single blade welding joints with different welding process and fix condition were obtained through thermal elastic plastic finite element method calculation. The simulation results indicated coherence between the predicted and measured distortion value. The final welding distortion of turbine component in different assembly sequences were compared, by utilizing the inherent deformations of optimized single blade welding joints simulation. An optimized welding procedure and assembly sequence was proposed to reduce the welding distortion. The results verify that 180-degree symmetrical welding can significantly reduce the plastic deformation.

1. Introduction
Welding distortion is one of the key factors that affects the dimensional precision of welded components. In particular, the control of welding distortion is more critical for the components with amount of welds. It will expend huge cost and long time to determine welding parameters and welding sequence through the experiment. By means of numerical simulation, some experimental work can be reduced. R C Reed[1] developed a process model for electron beam welding to predict the stress field and thermal distortion of single butt weld by utilizing thermal elastic plastic finite element method, Paolo Ferro[2] confirmed the deleterious effects of the fusion zone curvature under the nail head and the thermal stresses concentration, promoter of hot cracking by means of thermal elastic plastic FEM. Most researchers study the stress and strain for a single weld but the welding sequence is seldom to be simulated and optimized because it will expend a long time to carry out numerical simulation with thermal elastic plastic FEM for the complex component with a large number of welds. Instead of it, in the prediction of the welding deformation of large sheet structural components, the inherent strain method can be applied better. In this method, the inherent strain value is computed by the inherent deformation which is obtained from the result of small-scale welding joints, and introduced to large structure. Dean Deng and Hidekazu Murakawa[3] developed an elastic FEM based on inherent strain to predict welding distortion for large welded structures, the experimental results shown agreement with the simulation results. In further studies[4][5], they proof that the developed elastic FEM based on inherent strain theory and interface element formulation can predict the distortions during all process of welding assembly by utilizing a simple ship and block model as an example. N. Ma[6] studied welding deformation and inherent
deformation under with and without temporary tacking, and proved that inherent deformation under the temporary tacking and its released states is the same.

A turbine component with 130 blades requests high dimensional precision to ensure the assembly requirements. Each blade needs to be welded to the substrate by electron beam welding. The purpose of this study is to predict and optimize the welding distortion and welding sequence of the turbine component through inherent strain method, and provide theoretical guidance for practical welding process.

2. Research methods
In this research work, the welding distortion in the turbine component by electron beam welding was predicted through elastic finite element method based on inherent strain theory. The inherent strains of single blade welding joints with different welding process and fix condition were obtained through thermal elastic plastic finite element method calculation. The overall structure of the turbine component is shown in figure 1. The turbine component is composed of inner ring, outer ring and blades, and the blades with bases are welded to the outer ring by girth butt welds as shown in figure 2.

![Figure 1. The turbine component](image1)

![Figure 2. Girth butt weld of single blade](image2)

For the numerical simulation of typical single blade weld joint, the accuracy of the simulation result is evaluated by comparing the temperature contour with the metallographic of the weld section. The temperature contour of the weld joint in a certain time is shown figure 3. As shown in figure 4, the comparison between the simulation results and the metallographic indicates that the simulation of weld joint has good credibility.

![Figure 3. Temperature contour of weld joint](image3)

![Figure 4. Comparison between simulation results and metallographic](image4)

3. Result and discussion

3.1. The stress and strain analysis for single blade

By observing the contour of equivalent residual stress after welding (Figure 5(a)), the maximum equivalent residual stress value is about 735 MPa, which appears at the edge of the step of the blade.
substrate. This may be caused by the stress being concentrated at the step and unable to be released. The residual stress in the weld zone was distributed between 522 MPa and 536 MPa, while the residual stress in the heat affected zone was slightly higher than 559 MPa.

It is necessary to extract the longitudinal and transverse plastic strain of the weld section before calculating the inherent strain of the weld, and the result is shown in figure 5(b). The maximum longitudinal plastic strain is about -0.015, and the maximum transverse plastic strain is about -0.067. It indicates that the transverse contraction and bending deformation is the main deformation of the blade.

![Maximum residual stress point](image)

(a) Contour of equivalent residual stress  
(b) Graph of plastic strain

**Figure 5.** Equivalent residual stress and plastic strain

For a circle weld, the overlap length, which is introduced to ensure that the weld joint is uniform from the starting position to the end, is another significant process parameter in the girth butt weld. In the research, three different overlapping length were simulated, as shown in figure 6. The results showed that the maximum deformation of the blade component increased from 0.51mm to 0.57mm where the overlap length changed from 10mm to 32mm (figure 7). It indicates that the change of overlap length does not have too much influence on the deformation for single blade. Therefore, in the actual process it may also appropriately increase the overlap length in order to improve the weld quality.

![Schematic of different overlap length](image)

Figure 6. Schematic of different overlap length

(a) overlap 10 mm  
(b) overlap 20 mm  
(c) overlap 32 mm

**Figure 7.** The weld distortion of single blade in different overlap length

3.2. **Welding distortion prediction and the optimization of welding sequence for turbine component**

Based on the above research, one set of optimized welding process parameters simulation results are selected to calculate the inherent strains. The welding distortion of the turbine component is calculated by utilizing the numerical simulation based on inherent strain theory. The turbine component mainly
adopts 150-degree sequence welding or 180-degree symmetry welding method in practical engineering as shown in figure 8. The welding deformation value of the component is evaluated by the feature point on the blades (figure 9). According to the simulation results, the axial displacement value of the feature points is less than 150-degree welding values when using 180-degree symmetry welding. The maximum deformation value can be reduced by 20% from 0.51mm to 0.40mm. The maximum radial deformation of the turbine component is about 0.27mm (Figure 10). When welding the component with the 180-degree symmetry method, the radial deformation had no obvious change.

![Figure 8. Schematic of two different welding sequences](image1)

![Figure 9. The feature point on the blade](image2)

![Figure 10. The deformation of the turbine component (x100)](image3)

4. Conclusions
In this research work, the weld distortion of a turbine component with 130 blades and welds was predicted by means of elastic FEM based on inherent strain theory. A typical single blade weld joint in the turbine component is simulated by thermal elastic plastic method, and the inherent strain value of the weld joint is obtained by the inherent deformation value. Based on the simulation results, the following conclusions are drawn:
1. The maximum equivalent residual stress appears at the edge of the step of the blade substrate;
2. The transverse contraction and bending deformation is the main deformation of the blade;
3. The change of overlap has little effect on the feature point deformation of blades.
4. By means of 180-degree symmetrical welding, the weld distortion can be significantly reduced.

References
[1] Reed R C, Stone H J, Roberts S M and Robinson J M 1997 Proc. of Inst. of Mech. Eng., Part G, J of Aerospace Eng. 211 421
[2] Ferro P, Zambon A and Bonollo F 2005 Mater. Sci. Eng. A 392 94
[3] Deng D, Murakawa H and Liang W 2007 Comput. Meth. Appl. Mech. Eng. 196 4613
[4] Murakawa H, Deng D, Ma N and Wang J 2011 Comput. Mater. Sci. 51 43
[5] Deng D, Murakawa H and Ma N 2012 Sci. Technol. Weld. Join. 17 13
[6] Ma N, Huang H, Yin X and Guo N 2016 Sci. Technol. Weld. Join. 21 389