EBW Technology Applied on the ICRF Antenna Component

Qing Xi Yang, Yun Tao Song, Yong Sheng Wang, Jean-Marie Noterdaeme, and Helmut Funfgelder

***Abstract*— Central conductor is one of the key components of ion cyclotron ranges of heating antenna, which is usually formed by welding due to the complex structures. High level of welding seam quality and small deformation are very important to central conductor. Electron beam welding (EBW) is suggested as the central conductor welding. To meet EBW requirements and reduce the risk, complex and high level of the accuracy welding fixture have been designed for central conductor EBW. Some samples were manufactured to do test and examination for EBW qualification before central conductor welding. Based on the welding parameters, thermal analysis using finite element method for the welding seam have been carried out. One mockup of central conductor for EBW has been made for proving welding parameters. In addition, some postwelding process were employed after one central conductor EBW. Results of examination and inspection of one central conductor using EBW are presented in this paper.**

***Index Terms*— Central conductor, electron beam welding (EBW), finite element method (FEM), ion cyclotron ranges of heating (ICRF) antenna, mockup.**

I. Introduction

IN THE fusion machines, ohmic heating is employed for the initial heating of plasma, with the temperature increase, the capacity of ohmic heating is limited [1]. Therefore, it is necessary to provide an auxiliary means for the needed temperature of a reactor. Ion cyclotron ranges of heating (ICRF) as one of the heating resources with tens of MHz has long development history and it has been applied to RF heating system of the magnetically confined fusion devices such as Tokamak and stellarator. An upgraded ICRF antenna for Max Planck Institute of Plasma Physics, Garching, Germany, have been designed and manufactured via cooperating with the Institute of Plasma Physics, Chinese Academy of Sciences. The new ICRF antenna system is composed of high power supply system, RF transmitter, transmission lines, matching system, vacuum feedthrough, antenna, and so on. Regarding to the antenna, central conductor is one of the important components, which has the function of coupling power to plasma during operation. Since high tolerance and welding quality requirements for central conductor, electron beam welding (EBW) is employed. Compared with Tungsten Inert Gas (TIG) welding, EBW has advantages of very low heat input to the weld, resulting in low distortion in components, as a consequence it is being increasingly used in industrial manufacturing and is of growing importance in industry [2].

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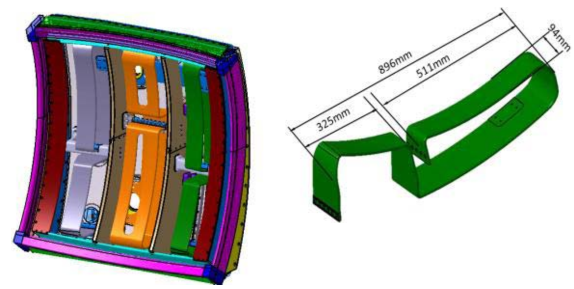


Fig. 1. Central conductor assembly (left) and structure of central conductor (right).

II. Motivation of EBW Applied on the Central Conductor

For the upgraded ICRF antenna of ASDEX Tokamak, three central conductors have been designed and manufactured to be assembled in an array on the return conductor. Layout of central conductors on the antenna is shown in Fig. 1. As shown in Fig. 1, central conductor has complex structure with several winding, if it is formed by manufacturing by one thickness plate, the cost is very high and time will be much long, the welding is employed for central conductor forming. As the central conductor is required with low permeability ($\mu \leq 1.05$) and high precision geometry, the EBW method is employed. Comparison of Tungsten Inert Gas (TIG) welding, the EBW has the following advantages [3]–[5].

1) Electron beam penetrating ability, weld aspect ratio.
2) Welding speed, small heat affected zone (HAZ), and small welding deformation.
3) Good welding quality for welding in the vacuum environment.
4) Easily welding in different zones even with long distance from the beam gun.
5) Easily control the electron beam during welding.

The advantages of EBW method listed above are indicated that EBW is much better than TIG welding .

III. EBW Qualification for Central Conductor

Before the product of central conductor starts welding, some small workpieces were fabricated to do EBW test for achieving satisfactory welding parameters (welding speed, electron beam

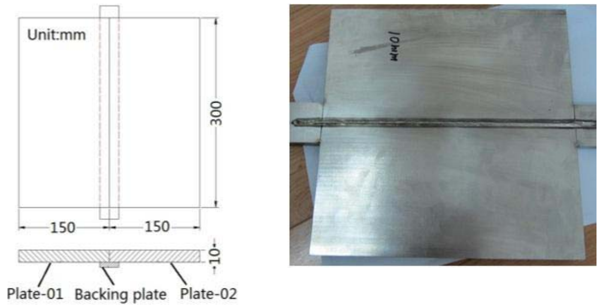


Fig. 2. Workpiece dimension and postweld weldment.

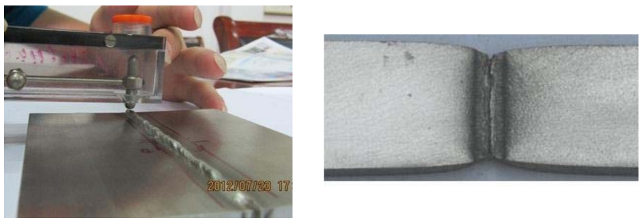


Fig. 3. Permeability inspection (left) and tensile test (right) of the weldment.

power, beam current, accelerating voltage, etc.). Since the thickness of central conductor being 10 mm and linear butt weld, two standard workpieces with 10-mm thickness and same weld joint type were fabricated and welded, are shown in Fig. 2. Based on EBW requirements, it should be cleaned to remove the contaminations on the surface of the welding joint before welding, the gap between backing plate and workpiece must be less than 0.1 mm to avoid the incompletely filled groove, in addition to no steps more than 0.05 mm, no gaps more than 0.1 mm at the joint. The backing plate was employed to prevent undercut and weld spatter at both sides of the plate, the parent material is SS316LN, which has the lower permeability affecting the beam concentration.

With purpose of obtaining valid and fittest welding parameters for antenna central conductor EBW. Based on the welding structures of the central conductor, several workpieces, were manufactured for EBW trial, nondestructive and destructive test and examination have been done for welding qualification. Regarding to the nondestructive test, three action items have been done, which are permeability, visual inspection, dye penetrant test. In addition, three action items have been carried out for destructive test including metallographic, tensile, and hardness tests. Some test pictures are shown in Figs. 3–6.

Based on the nondestructive test and examination, the results of all the weldments permeability were below the 1.05, no defect and imperfection were found on the welding seam during visual examination and dye penetration test. In addition, the tensile stress of all the weldments from the destructive test and examination is 617 MPa $\leq \sigma \leq$ 625 MPa, which is almost same as that of parent material. For the metallographic test, no defect is found and HAZ is small on the test weldment during macroscopic examination. To further confirm the heat affected zone on the weldment, a thermal analysis have been carried out by the finite element method, the results of temperature distribution on the weldment are shown in Fig. 5. From the microscopic examination, Austenite + δferrite elements are found in the welding seam zone (WSZ). Besides those, Vickers hardness test have been done for unaffected zone (UZ), HAZ and welding seaming zone of the test weldment. As shown in Fig. 6, the hardness in the HAZ is the highest, which is more than 180 HV10, in the UZ comes second, in the WSZ

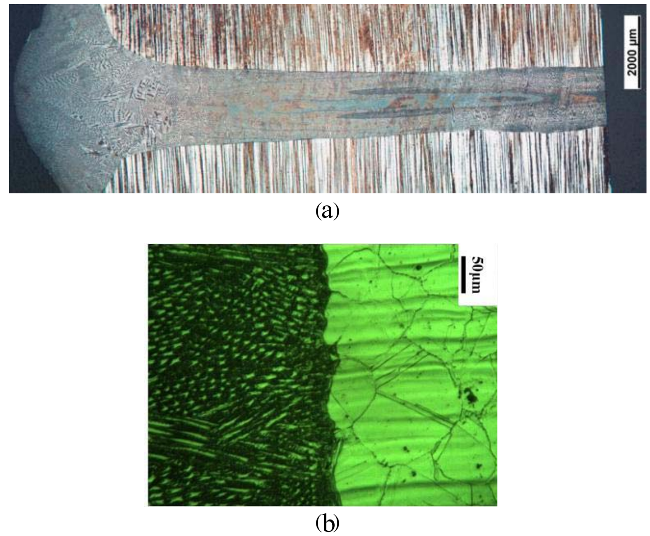


Fig. 4. (a) Macroscopic and (b) microscopic examination of weldment.

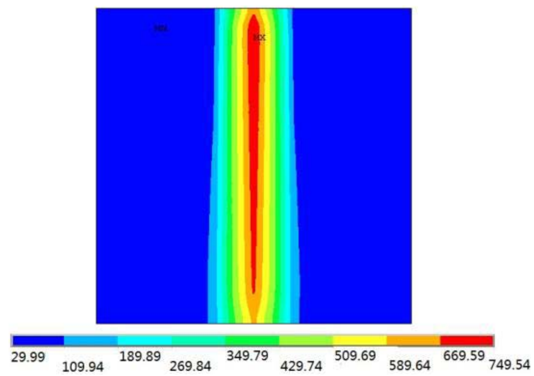


Fig. 5. Temperature distribution on the weldment at time of 30 s.

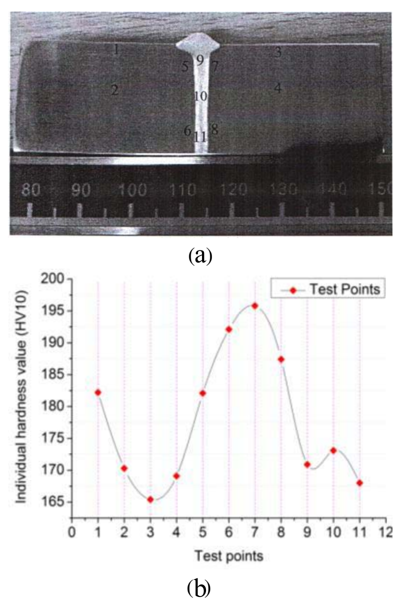


Fig. 6. (a) Test points position and (b) Vickers hardness test results.

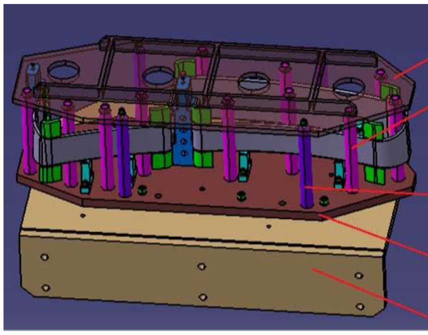


Fig. 7. Structure of welding fixture for central conductor mockup welding.

Fig. 8. Status of the central conductor after heat treatment (left) and vacuum furnace for heat treatment (right).

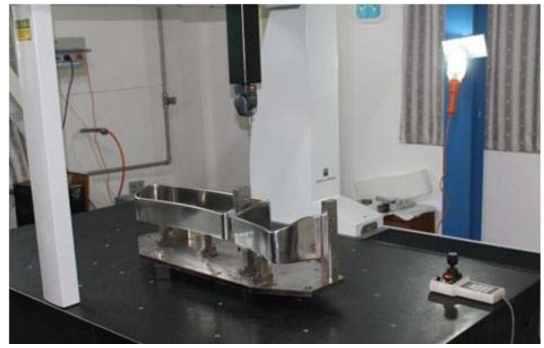
is the lowest. According to the nondestructive and destructive tests and examination for the weldments, all the results satisfy standard requirements (ISO 13919-B).

IV. Demonstration of the Central Conductor Mockup EBW

Although weldments as samples were used to do test and examination for welding qualification, the deformation, and stable-operation welding will require to be demonstrated by the mockup of central conductor. Weld quality, weld fixture feasibility, deformation, and postweld dealing can be further demonstrated and referred for the real product of central conductor EBW. Based on the structure of central conductor and EBW requirements, special welding fixture have been designed and fabricated. Structure of welding fixture and central conductor assembled for EBW are shown in Fig. 7. As shown in Fig. 7, welding fixture mainly comprises of top and bottom plates, a few fixed rods, some fasten double-screw bolts as well, the whole fixture is easily fixed and disassembled.

After central conductor EBW, a several postwelding works will be done, which include heat treatment, baking plate removal, nondestructive examination for welding seam, shape correction, polishing, and final dimension measurement. To release stress from the welding process, heat treatment for the mockup of central conductor have been carried out in the vacuum furnace, backing plate removal was followed by the heat treatment. Based on the EBW characteristic with low power input, within temperatures from 430 °C to 480 °C often used for stainless steel heat treatment, 440 °C was chosen for central conductor stress release for 4 h according to the thickness of central conductor. Central conductor after heat treatment and vacuum furnace are shown in Fig. 8. After heat treatment, inspection and examination including dye penetration, permeability examination, and visual examination were done, no defect and imperfection were found,

(a)



(b)

Fig. 9. (a) Central conductor mockup and (b) mockup measurement.

permeability of the weld seam are lower than 1.05. Although minor deformation from the EBW, shape correction was done for satisfactory figure and dimension. Since roughness of the central conductor, especial function contact surface is important, polishing was done after shape correction. The last step is to do dimension measurement. A mockup of central conductor done measurement through three coordinates measuring instrument is shown in Fig. 9 results of measurement for the mockup satisfy the design requirements.

V. Conclusion

Based on the central conductor structure and technology requirements, EBW was employed. Before real production of central conductor was welded, nondestructive and destructive test and examination on the weldments have been carried out for welding qualification, obtaining appropriate welding parameters were derived from weldments test and examination of the mockup of central conductor EBW. Postwelding jobs including nondestructive inspection, shape correction, heat treatment, polish as well as dimension measurement have been completed. Results of inspection and measurement satisfy design requirements, the welding parameters used on mockup will be employed on the productor of central conductor welding.

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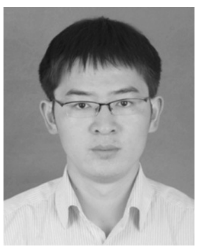

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