

# INTEGRATION TEST OF ITER FULL-SCALE VACUUM VESSEL SECTOR

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## Abstract

The full-scale Sector Model Project, which was initiated in 1995 as one of the Large Seven ITER R&D Projects, completed all R&D activities planned in the ITER-EDA period with the joint effort of the ITER Joint Central Team (JCT), the Japanese, the Russian Federation (RF) and the United States (US) Home Teams. The fabrication of a full-scale 18 toroidal sector, which is composed of two 9 sectors spliced at the port center, was successfully completed in September 1997 with the dimensional accuracy of  $\pm 3$  mm for the total height and total width. Both sectors were shipped to the test site in JAERI and the integration test was begun in October 1997. The integration test involves the adjustment of field joints, automatic Narrow Gap Tungsten Inert Gas (NG-TIG) welding of field joints with splice plates, and inspection of the joint by ultrasonic testing (UT), which are required for the initial assembly of ITER vacuum vessel. This first demonstration of field joint welding and performance test on the mechanical characteristics were completed in May 1998 and the all results obtained have satisfied the ITER design. In addition to these tests, the integration with the mid plane port extension fabricated by the Russian Home Team, and the cutting and re-welding test of field joints by using full-remotized welding and cutting system developed by the US Home Team, are planned as post EDA activities.

## 1. INTRODUCTION

The ITER vacuum vessel is designed to be a water cooled, double-walled structure made of 316L+N stainless steel with a D-shaped cross section approximately 9 m in radial width and 15 m in vertical height [1]. Since the vessel forms the first radioactivity confinement barrier for the reactor, the vacuum vessel must be designed to withstand electromagnetic loads during plasma disruptions and vertical displacement events (VDE) and to withstand off-normal events without losing confinement. The vacuum vessel is toroidally divided into 20 sectors which are joined by field welding at the central plane of the ports during initial assembly. According to this requirement, the fabrication tolerances for the whole vessel including field assembly are specified to be  $\pm 20$  mm for the total height and total width, and  $\pm 5$  mm for the sector wall thickness. Due to its large scale and tight manufacturing tolerances, the fabrication and testing of a prototype vacuum vessel were essential to assure the structural integrity of the ITER vacuum vessel. To meet this requirement, a full-scale development program [2] was initiated in 1995. Two major technical objectives of the project are 1) to develop and demonstrate the fabrication technologies of double-walled ITER vacuum vessel, and 2) to perform the demonstration test of field joint welding between sectors which is required in the initial assembly. In order to achieve these objectives, the project was conducted with the joint effort of the ITER JCT, the Japanese, the RF and the US Home Teams. The two main parts of the project are the fabrication and testing of the full-scale sector model performed by the Japanese Home Team and the full-scale mid plane port extension being done by the RF

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Home Team and they are integrated into a demonstration test at Japan Atomic Energy Research Institute (JAERI). In parallel with these activities, the R&Ds required for the development of the remotized welding and cutting tools for sector-to-sector connection were conducted by the US Home Team as related R&D tasks. This paper describes the major achievements of the Full-scale Sector Model Project obtained in the ITER-EDA period.

## 2. FABRICATION OF A FULL-SCALE SECTOR MODEL

Following the completion of the model design, the fabrication of the full-scale sector model began in December 1995. The full-scale sector model corresponds to an 18° toroidal sector is composed of two 9° sectors, Sector-A and B, which are spliced and welded at the port center according to the current ITER design. In order to satisfy tight manufacturing tolerances and structural integrity, a combination of TIG/EB (electron beam) welding and TIG/MAG (metal active gas) welding has been adopted for Sector-A and B, respectively. As shown in Fig. 1 and Fig. 2, both Sectors A and B were completed in September 1997 on schedule and structural integrity was tested by pressure and vacuum leak testing. Although the different fabrication procedures and welding techniques were employed for the fabrication, the final dimensions of both sectors at field joint edge have successfully satisfied the dimensional accuracy of  $\pm 3$  mm to the total height, total width and total wall thickness. As the result of fabrication, the essential technologies and procedures required for the fabrication of ITER vacuum vessel have been successfully developed and demonstrated.



FIG. 1 View of the ITER full-scale vacuum vessel sector A



FIG. 2 View of the ITER full-scale vacuum vessel sector B

### 3. INTEGRATION TEST OF SECTORS A AND B

Both sectors were shipped to the test site in JAERI for the final assembly and integration test began in October 1997. This final assembly involves the field joint welding of two 9 sectors that simulating the initial assembly of ITER vacuum vessel in cryostat, and the measurement of mechanical behavior after the completion of assembly. The most important test performed in the test site was the first demonstration of the automatic NG-TIG welding of field joints with splice plates and non-destructive inspection of the joint by penetrant testing (PT) and UT method. Fig. 3 shows the automatic NG-TIG welding system used for the field joint welding between outer shells. For the assembly of Sector A and B, two types of automatic NG-TIG welding system, which have an average deposition rate of more than 30 g/min. in all welding positions, were developed and employed for the field joint welding. The butt weld joint and splice plate joint were adopted for outer shell and inner shell, respectively and the narrow U-groove with a groove angle of 8° was employed for minimizing welding distortion. The initial gap and offset between the root faces were adjusted less than 0.8 mm to assure the quality of weld joint. The deformation of the D-shape was measured and minimized by the combination of symmetrical welding sequence, block welding sequence and back step welding. Although the original work plan was ambitious, the final assembly of Sector A and B was completed at the end of May 1998. No unacceptable weld flaws were detected by PT and UT inspection. After the completion of assembly, the supporting structures were removed from the inner bore of two sectors for the measurement of final dimension and mechanical behavior. The maximum deformation of inner bore of Sector A and B due to field joint welding was + 3.0 mm in horizontal direction and - 1.0 mm in vertical direction. Since the deformation due to the removal of support structures was + 2.0 mm in horizontal, and - 0.5 mm in vertical direction, the dimensional change due to final assembly was + 5.0 mm in horizontal and - 1.0 mm in vertical direction. Based on these results, it has been demonstrated that the dimensional tolerance of current ITER design, - 20 mm in total width and total height, is feasible for the actual fabrication and assembly.

### 4. FABRICATION OF PORT EXTENSION

The fabrication of a full-scale model of the mid plane port extension, which was contributed by the RF Home Team, was completed in May 1998. The model is 2.2 m wide and 3.4 m tall and 1.5 m long.

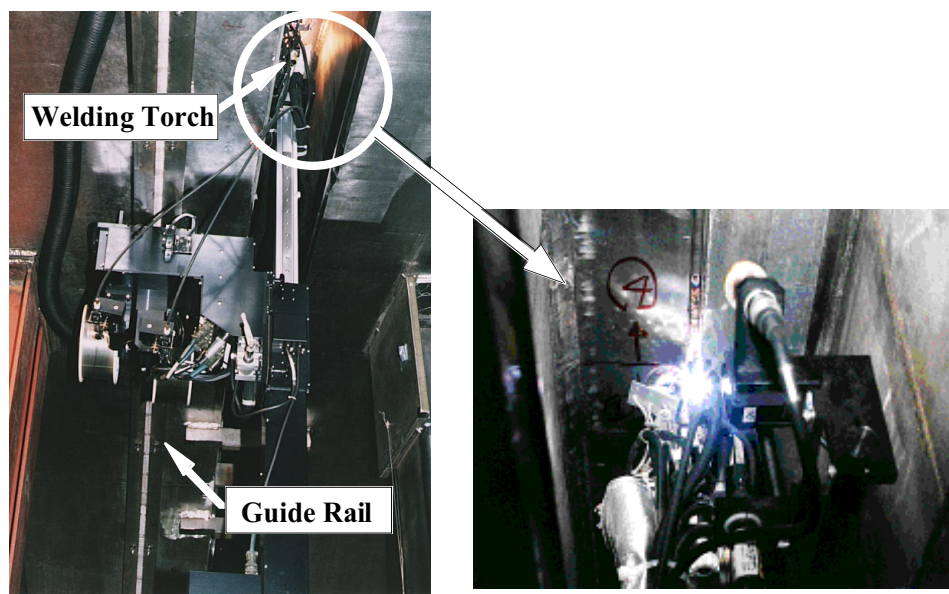


FIG. 3 Automatic NG-TIG welding system for the field joint welding between outer shells



FIG. 4 View of the full-scale mid plane port extension shipped to Japan

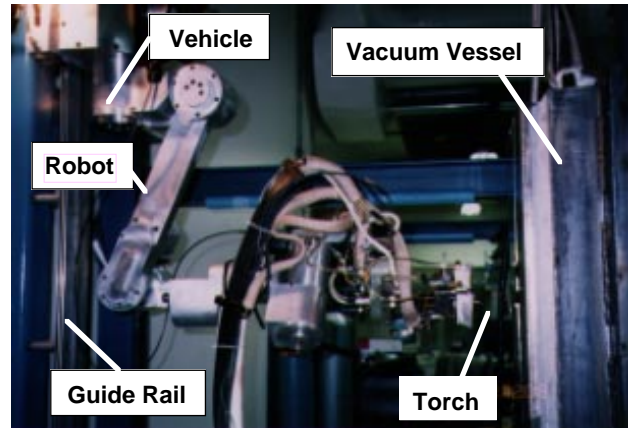


FIG. 5 View of the full remote welding robot in the mock-up test

The fabrication was successfully completed with the dimensional accuracy of  $\pm 4.0$  mm. The model was shipped to Japan in July 1998 for the integration with the sector model. Fig. 4 shows the port extension as it arrived at the Yokohama Port in August 22. The port extension was transported to the test site in JAERI on September 8 1998.

## 5. DEVELOPMENT OF REMOTE CUTTING AND WELDING SYSTEM

The development of full remote welding and cutting tools, which was contributed by the US Home Team, was completed in June 1998. The NG-TIG welding head was assembled to a 6 degree-of-freedom robot. The view of the welding robot is shown in Fig. 5. The feasibility of the full remote system was successfully demonstrated on a full-scale partial mock-up of the lower outboard region of the vacuum vessel.

## 6. CONCLUSION

The original objectives of the Vacuum Vessel Sector Model Project in the ITER-EDA period have been successfully achieved with the joint effort of the JCT, the Japanese, the RF and the US Home Teams. As a result of a series of tests and analysis on component fabrication and final assembly, testing and analyses, a sufficient technical data base on the fabrication and initial assembly technology for the ITER vacuum vessel has been obtained and verified the feasibility of current ITER design.

## ACKNOWLEDGMENTS

The authors would like to express their sincere appreciation to Drs. S. Matsuda and R. Parker for their continuous encouragement on this program. They are grateful to members of the Home Teams, Hitachi Ltd. and Toshiba Co. who are cooperating in the fabrication and assembly test of the full-scale sector models.

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