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Manufacture and test of prototype water pipe chase barrier in ITER Magnet Feeder system

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ABSTRACT

The Magnet Feeder system in the International Thermonuclear Experimental Reactor (ITER) deploys electrical currents and supercritical helium to the superconducting magnets and the magnet diagnostic signals to the operators. In the current design, the feeders located in the upper L3 level of the Tokamak gallery penetrate the Tokamak coolant water system vault, the biological shield and the cryostat. As a secondary confinement to contain the activated coolant water in the vault in the case of water pipe burst accident, a water barrier is welded between the penetration in the water pipe chase outer wall and the mid-plane of the vacuum jacket of the Feeder Coil Terminal Box (CTB). A thin-wall stainless steel diaphragm with an omega shape profile is welded around the CTB as the water barrier to endure 2 bar hydraulic pressure. In addition, the barrier is designed as a flexible compensator to withstand a maximum of 15 mm of axial displacement of the CTB in case of helium leak accident without failure. This paper presents the detail configuration, the manufacturing and assembly processes of the water barrier. Test results of the prototype water barrier under simulated accident conditions are also reported. Successful qualification of the design and manufacturing process of the water barrier lays a good foundation for the series production of this subsystem.

1. Introduction

ITER feeder systems transfer electric power, cryogenic coolant and control/diagnostic signals between the cryogenic magnet system and the Tokamak machine control/supporting units. The combined Coil Terminal Box and S-bend Box (CTB&SBB) houses the cold–warm transitions with the high temperature superconducting (HTS) current leads, the NbTi S-bend busbars, and the cryo-control valves for regulating the liquid helium supply to the coils and feeder busbars.

In 2010 design, the 8 m long CTB/SBB is designed to penetrate the outer wall of the machine cooling water pipe chase and the bioshield wall. In between the walls the CTB/SBB is sharing the common space with high-pressure pipes containing radioactive water. The leakage of water from cooling pipe in the worst case would fill the pipe chase with steam at an over-pressure (to atmosphere) of 1 bar. In accordance with ITER nuclear safety requirements, a secondary containment at the penetrations must be provided to confine the radioactive material in case of this water pipe leak accident. Since 2011, ITER has been listed as nuclear facility INB-174 by the French Nuclear Safety Authority. The ITER safety provision satisfies the French nuclear safety requirements. The present report focuses on the water barrier defined as Class-2 Protection Important Component (PIC-2) and ITER Safety Important Class-2 (SIC-2) component is positioned at the CTB/SBB penetration of the outer wall of the cooling water pipe chase.

The water barrier is welded between the steel frame embedded in the concrete wall at the penetration and the mid-plane of the vacuum jacket of the feeder CTB&SBB [1,2]. A thin-wall stainless steel diaphragm with an omega shape profile is welded around the CTB&SBB as the water barrier to endure 2 bar hydraulic pressure. In addition, the barrier is designed as a flexible compensator to withstand a maximum of 15 mm of axial displacement of the CTB&SBB without failure, which caused by the thermal shrinkage of the room temperature vacuum jacket in an helium leak accident. Fig. 1 shows the integrated water barrier welded with CTB&SBB box, and Fig. 2 details the configuration of omega shape compensator.

In order to qualify the manufacturing process and the performance in a simulated accidental condition, a full-size prototype water barrier was fabricated and tested. A thorough manufacturing

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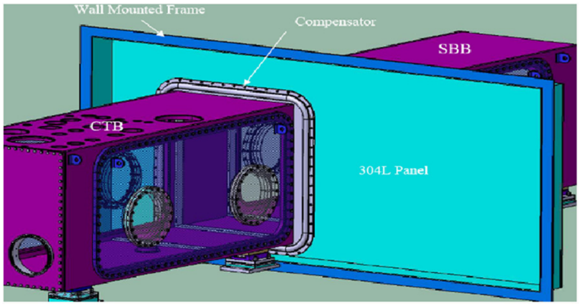

Fig. 1. Overview of water barrier welded with CTB&SBB.

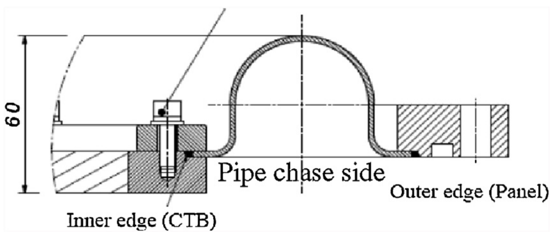

Fig. 2. Configuration of omega shape compensator.

and inspection plan, including welding, assembly procedures and a test plan as part of the Protection Important Activity (PIA) were developed before the fabrication [3].

2. Manufacture and assembly of water barrier

2.1. Manufacturing of omega shape compensator

The most challenging component of the water barrier is the picture-frame shaped compensator with omega profile, which was fabricated by welding together an assembly of short segments. Four straight lengths and four corner segments containing bend and straight sections were manufactured by die punching tools. Fig. 3 shows the punching tool and one of the bend sections.

After all pieces of the omega compensator were punched and inspected, they were placed on a platform for positioning before assembly welding. The detailed welding procedure was defined with the welding parameters and sequence to ensure the welding quality and reduce the welding deformation. Fig. 4 shows the whole omega shape compensator after welding.

2.2. Weld-assembly of water barrier panel

As shown in Fig. 1 and in the left picture in Fig. 5, a large outer panel of this water barrier is made of 304L stainless steel. The rectangular hole was machined to accommodate the vacuum box of CTB&SBB. One side of omega shape compensator is bolted to this large panel, and another side is welded around the CTB&SBB box.

Fig. 3. Punch tool and part of omega shape compensator.

Fig. 4. Whole omega shape compensator.

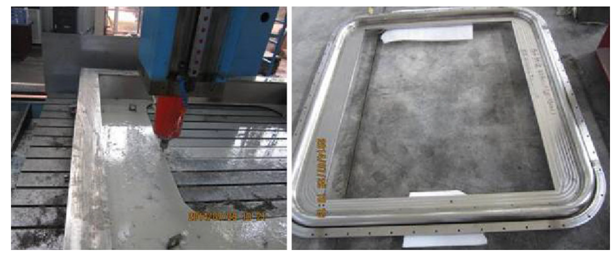

Fig. 5. Machining of frame and omega shape compensator.

Fig. 5 shows the machining of this panel and the omega shape compensator welded to a mock-up simulating the CTB&SBB box.

2.3. Assembly of water barrier for test

For the final hydraulic pressure test, the water barrier panel and the omega shape compensator were assembled together, and with a large cover reinforced with test tooling. There are two compensators manufactured for two side-by-side CTB&SBB boxes during qualification. The outer flange of the compensators and the panel were bolted together and sealed by a rubber ring for water tightness. The steel back panel is to simulate the interface with CTB&SBB box.

A test tooling was designed and fabricated. It was welded from strong stainless steel beams to provide mechanical strength to withstand the pressure and displacement without additional deformation or movement so the water barrier is tested under the correct accident conditions of 2 bar pressure (Fig. 6).

3. Test of water barrier

3.1. Hydraulic pressure test before displacement

The first step is to close and seal the test space between work piece and the steel cover with rubber ring and sealant, and then weld the stainless steel I-beams to fix one of the CTB&SBB Box mock ups, use tooling and hydraulic jack to fix a second mock up, which was the test volume, as shown in Fig. 7.

After above process, the test volume was charged with pressurized water. The displacement of the compensator was measured by the height difference between the edge of embedded plate and points A1, B1, C1, D1 with corresponding points A2, B2, C2, and D2 at back surface, as seen in Fig. 8. Point P near omega shape

Fig. 6. Whole omega shape compensator.

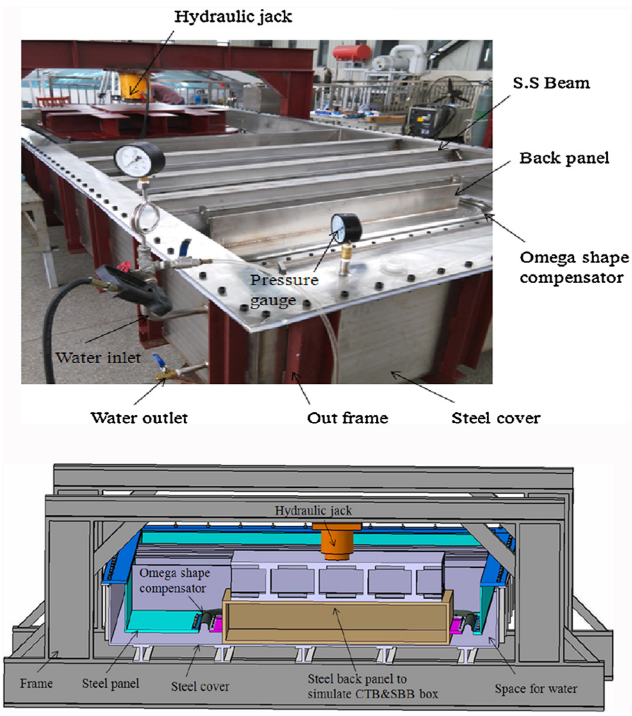

Fig. 7. Connection of hydraulic pressure testing tooling.

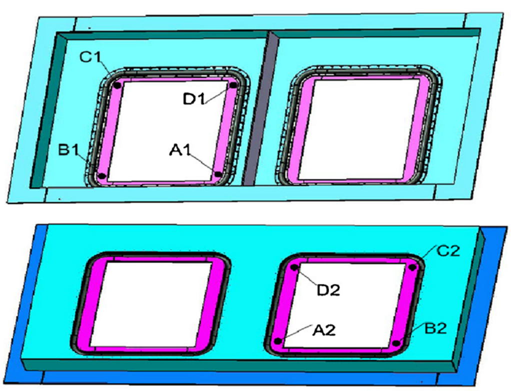

Fig. 8. Position of different test points.

compensator was monitored with a laser tracker before, during and after the pressure held for a required duration to monitor the deformation of the CTB&SBB connection plate.

During this process, when the water pressure was raised to 0.175 MPa, some deformation in the steel back panel was observed. The pressure was held for 10 min before being dropped to 0.16 MPa. The VT results showed that there was no water droplet or condensation on any welded joints or connection.

As the results shown in Table 1, it can be found that the distance was 250 mm before test, but the theoretical value is 290 mm. The source of discrepancy is that the operators filled the water into the tooling without fixing the initial position of the movable CTB&SBB

Table 1
Results of hydraulic test before displacement.

Record	Point to datum point level (mm)				
	A1	B1	C1	D1	P (real time point)
Point to the edge of embedded level, theoretical value 290 mm					
Before test	250.702	252.276	251.973	250.69	173.16
After test	262.376	258.335	252.917	257.805	/
After drain	297.53	287.23	296.27	287.617	/

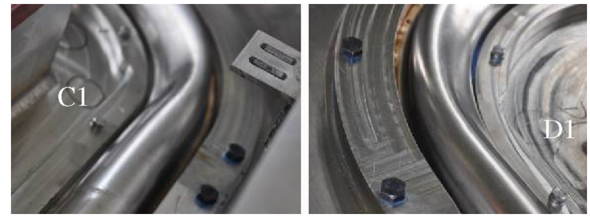

Fig. 9. C1 and D1 position.

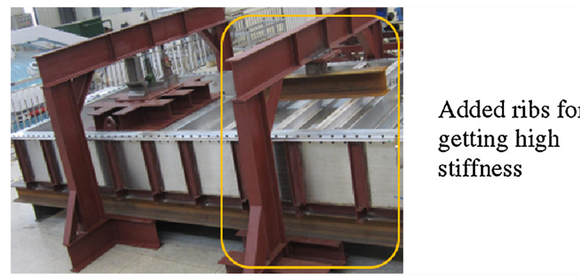

Fig. 10. Improved test facility.

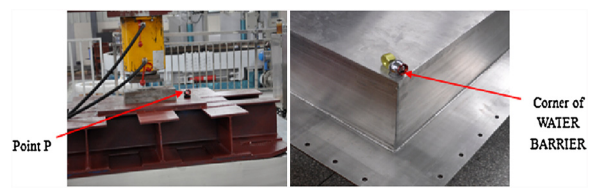

Fig. 11. The position of P point and corner point.

mock-up during the preparation step. So the movable CTB&SBB mock-up moved up by an unexpectedly 40 mm.

When the hold time was over, the valve was opened to release the water pressure, but the hydraulic pressure was not shut down. The movable CTB&SBB mock-up was pushed by another long distance that cause plastic deformation in the omega compensator at the C1 and D1 positions, as shown in Fig. 9.

For improving the stiffness of the back panel, some ribs were welded on the frame. This improvement will ensure the back panel is strong enough without displacement under 2 bar water pressure. New structure is shown in Fig. 10.

3.2. Displacement test

Because of the deformation of CTB&SBB mock-up at the first hydraulic test step, it became useless to measure the height difference between two CTB&SBB mock-up and frame. It was found that one point at the corner, as shown in Fig. 11, was strong enough as measurement reference.

The height distances between points and the new reference corner point were measured. The theoretical height distance is −4 mm. After 15 mm of displacement, it turned to −19 mm. According to the measurement results before test, the real maximum displacement was 21.3 mm. Table 2 shows the displacements results of every

Table 2
Results of displacement test.

Record	Point to datum point level (mm)				
	A2	B2	C2	D2	P (real time point)
Point to the corner of water barrier bottom level, theoretical value −4(mm)					
Before test	2.3	−7.9	−8.7	1.6	/
After21.3 mm displacement	−18.4	−27.2	−26.5	−16.4	/
After test	−21.8	−30.3	−29.4	−19.1	/

Table 3
Results of hydraulic test after displacement test.

Record	Point to datum point level (mm)				
	A1	B1	C1	D1	P (real time point)
Point to the certain point outside of tooling level (mm)					
Before test	−883.64	−874.63	−870.52	−880.03	−449.13
After test	−884.54	−872.03	−857.54	−870.69	−446.53

Table 4
Results of displacement back to zero.

Record	Point to datum point level (mm)				
	A1	B1	C1	D1	P (real time point)
Point to the certain point outside of tooling level (mm)					
Before test	888.73	878.20	867.45	−878.54	−451.94
After test	895.13	894.13	887.66	−889.07	−467.76

point. All exceeded 15 mm of displacement as required in the feeder procurement arrangement.

The visual test results showed no cracks on welding seams of water barrier.

3.3. Hydraulic pressure test after displacement test

The hydraulic pressure test was implemented again after the displacement test. The test volume was pressurized to 0.2 MPa, maintain the pressure at this level for 2 h. The visual inspection results showed that there was no water droplet or condensation on any welded joint or connection (Table 3).

3.4. Displacement back to zero test

The water barrier is designed to withstand a maximum of 15 mm of axial displacement under 2 bar pressure, and then can recover to the normal position without leak. Thus, water tightness after the compensator was displaced back to zero is part of the qualification.

The hydraulic pressure was powered to increase the displacement of the press until the displacement reached 290 mm. Table 4 shows the displacement readings in A1, B1, C1, and D1 before and after the test. No crack on welding seam of water barrier was observed.

3.5. Hydraulic pressure test

The last test is to verify the water barrier can withstand long time pressure without leaks. So, the test process is to use hydraulic jacks to fix the movable CTB&SBB mock-up, pressurize the test volume with water to 0.2 MPa design pressure, then shut off the inlet valve at the pressure head to maintain this pressure for 24 h.

Table 5
Results of long time hydraulic pressure test.

Record	Point to datum point level (mm)				
	A1	B1	C1	D1	P (real time point)
Point to the certain point outside of tooling level (mm)					
Before test	−825.97	−827.72	−830.67	−827.26	–
After test	−833.28	−835.45	−843.19	−839.71	–

The VT results showed that there was no water droplet or condensation on any welded joint or connection. And during the 24 h, the water pressure remained constant.

The results in Table 5 showed the deformations of A1, B1, C1 and D1 points caused by hydraulic test were about 7.3–12.5 mm.

4. Conclusion

Although the first pressure test was performed under reduced pressure, it was followed by other two tests at defined pressure, which sufficiently showed that the water barrier fulfils one of the requirements in the ITER procurement arrangement to demonstrate the water leak tightness of the SIC-2 containment before and after two axial movements 15 mm of the compensator. Both barriers are water leak tight under an applied water pressure of 0.2 MPa from the pipe chase side.

All the inspections and test results justify that the design of the water barrier can meet the ITER feeder requirements for the water pipe chase barrier. The successfully qualified manufacturing experience will be used for component production.

This manufacturing and test work on water barrier prototype was based on the current design. The final design and calculation are still ongoing accounting the evolving interface.

Acknowledgments

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