Development of welding, cutting and bolting tools for ITER blanket remote maintenance

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This paper reports on the development of the remote maintenance tools for the First Wall (FW) of the ITER Blanket Module (BMs). The Blanket Remote Handling System (BRHS) is crucial for the remote maintenance of the BMs after DT operations, which are attached to the Vacuum Vessel (VV). Torquing/loosening bolts, cutting/welding cooling water pipes that connect the BMs onto VV/BMs are processed when replacing the BMs. We have designed these tools for the FW maintenance to ensure positioning accuracy and maintenance reliability. Additionally, we have conducted tests on some of the key elements and demonstrated the intended functions for those tools.

Introduction

Positioning accuracy by the precise positioning and the retention of maintenance tools, along with ensuring their reliability, are essential factors for the feasibility of remote maintenance operations. The Blanket Remote Handling System (BRHS) replaces Blanket Modules (BMs) and performs maintenance inside the Vacuum Vessel (VV) with manipulators under radiation. The maintenance tools are essential for the maintenance of the BMs, which consist of a First Wall (FW) and Shield Block (SB), in the ITER project as shown in Fig.1 [1]. Since bolts secure the SB to the VV and the FW to the SB, tightening or loosening of the bolts is required in case of the BM replacement. Since cooling water pipes pass through the BM, cutting and welding are required for the BM replacement. To achieve the processing accuracy of the welding or cutting, a Tool Base must be prepared to position these tools relative to the target maintenance pipes and maintain their stability against the reaction forces.

This paper provides an overview of the development status of the Tool Base, Welding Tool, Cutting Tool, and Bolting Tool for FW maintenance, and the development and verification results of the key elements are detailed in the following sections.

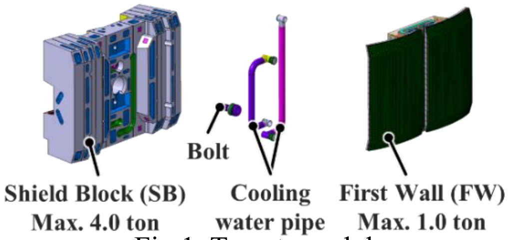

Fig.1 Target module

Completion of conceptual design for maintenance tools

Table.1 shows an overview of the requirements, current development results, and future work.

Table. 1 Overview of development status of maintenance tools

Tool	Requirements	Current development results	Future work
Tool Base	The position of the Tool Base itself and Cutting/Welding Tools shall be precisely positioned and rigidly kept against reaction forces.	Each element of the Tool Base was designed. The layout considerations for adapting all FW variants were completed. A Gripping Finger, one of the elements of the Tool Base, for fixing the Tool Base onto the FW was prototyped, and feasibility was demonstrated through element tests.	The other elements of the Tool Base (e.g. Tool Fixing Unit) will be prototyped and evaluated.
Cutting Tool/ Welding Tool	Cutting: The falling of cutting swarf into the VV shall be minimized. Welding: The full penetration welding from the inner side of the pipe shall be performed.	The Cutting/Welding Tools were designed and prototyped for conducting each element test. The water pipe was cut with the cutter, while the centering mechanism needs improvement. The full penetration weld was successfully done. Refinement of welding parameters is necessary to achieve welding quality.	The centering mechanism of the Cutting Tool will be redesigned. Welding conditions will be optimized.
Bolting Tool	The bolt shall be tightened to 8.4 kNm which is a criterion of tightening torque for the bolt.	The Bolting Tool was designed to apply 8.4 kNm and accommodate expected misalignment between the FW and SB. The test of applying 8.4 kNm was demonstrated.	The layout consideration for adapting all variants will be conducted.

We detail the development of the key elements of each tool as follows.

- Tool Base: The Gripping Finger element for fixing the FW Tool Base has been designed for miniaturization to avoid interference with surrounding components on the FW Tool Base and to accommodate all FW variants. A solenoid has been adopted as a driving mechanism for the gripping finger hooks movement instead of a motor that is commonly used on radiation conditions. As a result, the height of the Gripping Finger was reduced from 426 mm to 369 mm as shown in Fig.2. We evaluated the durability of the solenoid to address a concern that it may release the actuated position due to prolonged use or external load.

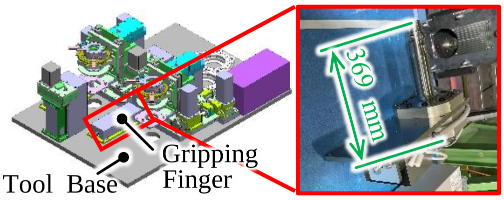

Fig.2 Gripping Finger

- Cutting/Welding Tool: For the pipe maintenance, centering elements have been designed to center the Welding/Cutting Tools with the target pipes and align the SB pipe with the FW pipe as shown in Fig.3. These centering elements can independently operate against welding torch/cutter operation to keep the welding/cutting quality. We needed to accommodate the centering and welding/cutting elements to these tools within a limited diameter of less than 27 mm.

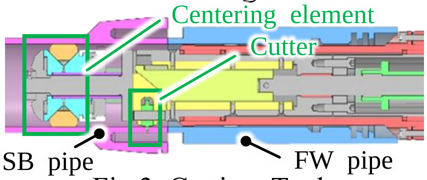

Fig.3 Cutting Tool

- Bolting Tool: The mechanical challenge of applying 8.4 kNm of torque through a narrow 59 mm FW access hole required a wrench made of high-strength maraging steel with a yield stress above 2 GPa. After stress concentration minimization design, strength of the wrench was tested.

<u>Demonstrations of key elements of maintenance tools</u>

We have demonstrated mockup testing of the key elements which affect the processing accuracy and reliability of each tool. We have earned achievements as follows through each test.

- Tool Base: The Gripping Finger element has been prototyped, and two types of tests have been conducted to evaluate its feasibility.
  - Deformational and operational impact: We demonstrated the durability of the Gripping finger by applying a load of 885 kgf, which is the expected load under actual VV conditions. We also demonstrated that the solenoid operated without any problems.
  - Long-term holding test of solenoid: We demonstrated the adaptability of the solenoid. The solenoid coil temperature stayed below 60 degrees for 4 hours, which is the activation time inside the VV, against the criterion of the maximum coil temperature is 110 degrees.
- Cutting/Welding Tool: As shown in Fig. 4, the Pipe Cutting Tool has been prototyped to demonstrate the cutting of the cooling water pipe and the centering mechanism of the tool. In addition, the welding tests using the pipes that were cut with the Pipe Cutting Tool have been implemented to confirm the weldability under conditions established using the pipes by machining. As a result, we have clarified the cutting condition to minimize the pipe deformation to less than 0.3 mm. Since the centering mechanism caused damage to the pipe by rotating together with the cutting tool during processing, we will reconsider its mechanism. As we have confirmed the meandering of the weld bead and lack of fusion, the welding condition will need to be optimized in the future.

Fig.4 Prototyped Cutting Tool

- Bolting Tool: The torquing test of the bolt tightening the FW to the SB has been completed. We confirmed the feasibility of the maraging steel wrench, simulating the actual tool length used inside the VV, under an applied torque of 8.4 kNm without causing any damage as shown in Fig. 5. The alignment tests of the position and angle between the wrench and bolt have been completed.

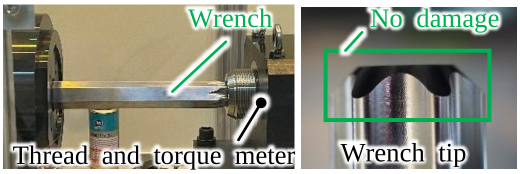

Fig.5 Torquing test and result

<u>References</u>

[1] Y. Noguchi, et al., Fusion Engineering and Design, (2021) 112048