CONFERENCE PRE-PRINT

DEVELOPMENT OF WELDING, CUTTING AND BOLTING TOOLS FOR ITER BLANKET REMOTE MAINTENANCE

T. Tanaka
National Institutes for Quantum Science and Technology
Naka, Ibaraki, Japan
Email: tanaka.takeyuki@qst.go.jp

K. Nakata
National Institutes for Quantum Science and Technology
Naka, Ibaraki, Japan

T. Yashiro
National Institutes for Quantum Science and Technology
Naka, Ibaraki, Japan

K. Sakamoto
National Institutes for Quantum Science and Technology
Naka, Ibaraki, Japan

K. Nagayama
National Institutes for Quantum Science and Technology
Naka, Ibaraki, Japan

Y. Ito
National Institutes for Quantum Science and Technology
Naka, Ibaraki, Japan

Y. Noguchi
National Institutes for Quantum Science and Technology
Naka, Ibaraki, Japan

N. Takeda
National Institutes for Quantum Science and Technology
Naka, Ibaraki, Japan

Abstract

The paper reports on the development of remote maintenance tools for the First Wall (FW) panels of the ITER. The maintenance task for FW must be performed remotely, due to the high levels of radiation environment inside the Vacuum Vessel (VV). Replacement of FW requires various operations such as torquing/loosening bolts, cutting/welding cooling water pipes that connect the Blanket Modules (BMs) onto VV/BMs. Positioning accuracies of such process specific tooling are essential for the successful remote maintenance operations, which need to be ensured by the precise positioning and the reliable retention of the maintenance tools. Bolting Tool, Cutting Tool, Welding Tool, and Tool Base were designed to achieve positioning accuracy and maintenance reliability, with the Tool Base positioning the Cutting or Welding Tools with a high degree of precision for the FW maintenance. Verification tests were conducted on some of the key elements and demonstrated the intended functions of those tools.

1. INTRODUCTION

Precisely aligning the maintenance tool accommodating the positional deviations on the Blanket Module (BM) side, and maintaining its position relative to the BM, is essential for enabling accurate execution of the intended maintenance tasks. Remote maintenance of BMs, which consist of a First Wall (FW) and Shield Block (SB), inside a Vacuum Vessel (VV) is required because the BMs may be damaged by high temperatures and neutron bombardment during the plasma reaction (see BM structure: Fig. 1). Since the radiation levels inside the VV during the BMs' maintenance are predicted to eventually reach up to 500 Gy/h, humans will not be able to enter the VV to perform any maintenance work. For this reason, a Blanket Remote Handling System (BRHS) that is viable within such a radiation environment is necessary and is therefore being developed for maintaining the BMs inside the ITER fusion device[1][2][3][4]. Maintenance processes consist of various types of procedures using different maintenance tools[5][6]. Bolting Tools for tightening the bolts to achieve the target tightening value or loosening of the bolts are required in case of the BM replacement, as bolts secure the SB to the VV and the FW to the SB. Cutting Tools and Welding Tools are essential for the pipe maintenance before or after BM replacement, as cooling water pipes pass through the BMs. Tool Bases must be prepared to position these tools relative to the target maintenance pipes and maintain their stability against the reaction forces, in order to achieve the required processing accuracy of the welding or cutting.

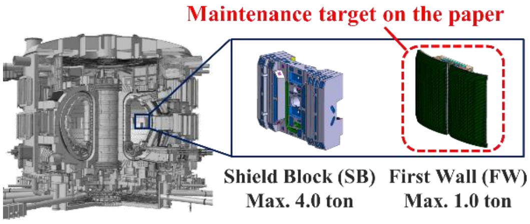


FIG. 1. BM structure

Requirements for various maintenance tools necessary for remote blanket maintenance, along with the corresponding development outcomes to meet those requirements, are described below for each FW tool.

— Tool Base: The Tool Base is required to be precisely positioned and rigidly maintained, along with the Cutting/Welding Tools, in order to withstand reaction forces. Each element of the Tool Base was designed to meet the requirement for precise positioning and rigid fixation against reaction forces, with layout considerations completed to accommodate all FW variants, and a Gripping Finger—used to fix the Tool Base onto the FW—was prototyped and its feasibility demonstrated through element-level testing.
— Cutting Tool: The Cutting Tool is essential for performing cutting operations suitable for re-welding. During this process, it is required to minimize the falling of cutting swarf into the VV, and to minimize deformation during the cutting process. A centering mechanism for the Cutting Tool was developed to align the tool with the maintenance pipe, and cutting tests using a prototype tool demonstrated that successful cutting was achieved without generating swarf, while also identifying cutting conditions under which pipe deformation was limited to 0.3 mm.
— Welding Tool: The Welding Tool is required to perform full penetration welding from the inner side of the maintenance pipe. Welding tests were conducted using the pipes that had been cut with the Cutting Tool, and the results confirmed that full circumferential welding was successfully achieved.
— Bolting Tool: The Bolting Tool must be capable of accommodating the expected misalignment on the Blanket side and applying a high torque of 8.4 kNm to the central bolt in order to securely fasten the FW to the SB. The preliminary design of the Bolting Tool was completed, and tests using the prototype demonstrated that the wrench was properly inserted into the central bolt even under the maximum expected misalignment, and that the specified torque was successfully applied.

We describe details of these developments in sections 2 to 6. Section 2 provides an overview of a Blanket remote maintenance and explains the necessity of each tool, Section 3 presents technical challenges and development results of the Tool Base, Section 4 covers the Cutting Tool, Section 5 describes the Welding Tool, and Section 6 presents the Bolting Tool.

2. BLANKET REMOTE MAINTENANCE OVERVIEW AND NECESSITY OF EACH TOOL

An outline of the BM design, the maintenance target of the BRHS, is presented, followed by the corresponding maintenance procedures. 440 BMs are tightly installed along the entire inner wall of the VV to withstand the high temperatures generated during fusion reactions. 18 BMs are positioned on the VV, with their shapes varying depending on their locations, as shown in Fig. 2 when viewed in the poloidal cross-section. The interfaces and positions of the cooling water pipes relevant to the BM maintenance with the BRHS are composed of 31 specific variants. The BM consists of the FW and the SB with the SB mounted onto the VV and the FW mounted onto the SB. The FW is mounted onto the SB with one central bolt and two FW electrical strap bolts. Cooling water pipes pass through the BM. As part of the FW replacement process, before removing the FW, the cap that closes the end of the FW cooling water pipe is removed, the cooling water pipes welded between the FW and SB are cut, and the central bolt and electrical strap bolts are removed. Then, the FW is removed from the SB with the FW Gripper. After installing the new FW onto the SB with the FW Gripper, the new FW is fixed onto the SB by the central bolt and the electrical strap bolts. The tip of the cooling water pipe of the FW and that of the SB are then aligned, and, provided proper alignment is maintained, the cooling water pipes are then welded together with TIG welding. The cap is then positioned and welded onto the tip of the FW cooling water pipe, completing the FW replacement processes[7][8].

These BM replacements are carried out by BRHS. The BRHS mainly consists of a Rail, Vehicle Manipulator, End Effectors, such as a Gripper for handling the BM and Tool Base, and Light-duty Manipulator for mounting maintenance tools onto the Tool Base as shown in Fig. 3. These maintenance processes are carried out using the Vehicle Manipulator to transport items weighing over 50 kg, such as the FW itself, FW gripper, Tool Base and Bolting Tool. The other maintenance processes are carried out using the Light-duty Manipulator to transport the maintenance tools and perform the remote maintenance work.

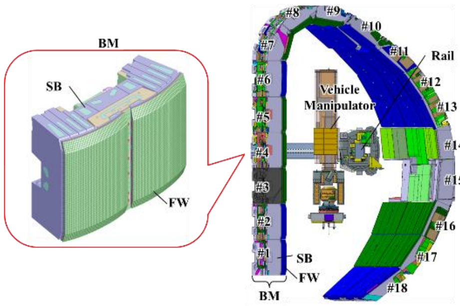


FIG. 2. Poloidal section of the vacuum vessel and 18 BMs arranged around the entire circumference of the VV

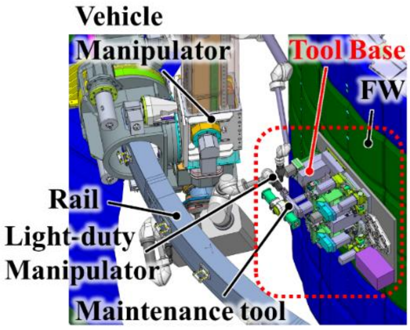


FIG. 3. The BRHS consists a Rail, Vehicle Manipulator, Light-duty Manipulator and Tool Base, and the maintenance tool is inserted into the Tool Base positioned on the FW

Dedicated maintenance tools are needed to address each specific maintenance task, which necessitates individual development for each BM maintenance operation. Welding and Cutting Tools are crucial to ensure a weld with full penetration around the entire circumference of the pipe, as well as precise cutting with minimal deformation during the cutting process, in order to achieve rewelding of the cooling water pipes passing through the BM. Accurate positioning of several tools must be maintained during operation to enable high-precision processing. However, the Light-duty Manipulator used in the BRHS is not only challenging to meet the requirements for positioning the maintenance tools but also lacks the rigidity to withstand the reaction forces occurring during the maintenance process. Lightweight tools, such as those used for welding and cutting, cannot be handled by the VMNP, which is designed for heavy tools or BM objects weighing up to 4 tons. For these reasons, the Tool Base is required to securely hold the Cutting Tools and Welding Tools, accurately position the tools relative to the maintenance target hole and withstand the reaction forces occurring during the maintenance process. The FW is tightened to the SB using the central bolt, which requires an extremely high tightening torque of 8.4 kNm. Misalignment between the central bolt integrated into the FW and the threaded hole on the SB side is anticipated, due to manufacturing and assembly tolerances. Consequently, the Bolting Tool must be capable of accommodating the expected misalignment while simultaneously applying a torque as high as 8.4 kNm. The Tool Base, Bolting Tool, Cutting Tool, and Welding Tool are used for their respective processes as part of the BRHS during maintenance work. We have been developing the Tool Base, Cutting Tool, Welding Tool, and Bolting Tool required for the remote maintenance of the FW. From Sections 3 through 6, we provide details regarding the challenges and the development results for each tool.

3. DEVELOPMENT RESULTS ON TOOL BASE

We completed the preliminary design of the Tool Base, as shown in Fig. 4, mainly developing two essential elements: the Gripping Finger element and the Tool Fixing element. The Gripping Finger element for fixing the FW Tool Base was designed for miniaturization, based on the Gripping Finger element for the FW Gripper, to avoid interference with surrounding components on the FW Tool Base and to accommodate all FW variants. A solenoid was adopted as a driving mechanism for the movement of the gripping finger hooks, to achieve compactness. As a result, the height of the Gripping Finger was reduced from 426 mm to 369 mm as shown in Fig. 5.

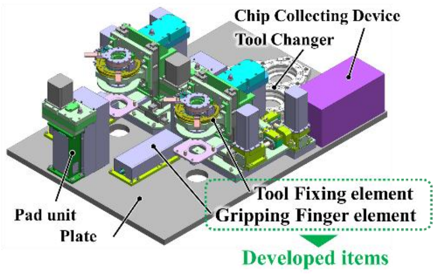


FIG. 4. *The Tool Base design result and the two technical challenges presented in the paper*

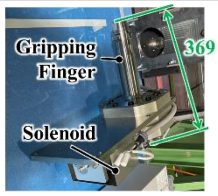
Finger type	For FW Gripper	For FW Tool Base
Design result		

FIG. 5. *The newly developed Gripping Finger element for the Tool Base achieves miniaturization*

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. We fabricated a test stand that simulates the Gripping Finger element and can apply the expected load as it would occur under actual VV conditions. The test stand has a simplified structure for the Pad Pressing element, allowing a constant load to be applied in the horizontal direction. The load in the upward direction is applied by lifting the plate part (a simplified shape assuming the Tool Base) that fixes the Gripping Finger with a chain block. This mimics the application of the expected load as it would occur under actual conditions. Using this test stand, we conducted the following two tests.

(1) Evaluation of the deformational and operational impacts on the Gripping Finger when applying the expected load under actual VV conditions
(2) Clarification of the minimum voltage that the solenoid can hold and remain activated and evaluation of performance maintenance during prolonged holding

Evaluation of deformation and operability of the Gripping Finger was conducted. The solenoid was activated and a load was applied to the Gripping Finger by emulating a pad unit of the Tool Base under test conditions. Then, a load of 885 kgf—the maximum expected under actual VV conditions—was applied to the Gripping Finger using a chain block and held for 5 minutes to evaluate whether any immediate damage occurred. After that, the load was removed, and the solenoid was operated multiple times to check for any changes in operation. In addition, the Gripping Finger was visually inspected for deformation. The results of this test are shown in Fig. 6. We confirmed that the solenoid operated without any issues after unloading. Additionally, no significant deformation or scratches were observed in a visual inspection. These results indicate that the Gripping Finger can maintain sufficient robustness even when subjected to the maximum load expected under actual VV conditions.

Testing to evaluate solenoid performance during prolonged holding was conducted with the goal of eliminating or at least substantially reducing the possibility that the solenoid might overheat and release its hold during prolonged holding. Continuous operation of the solenoid at its rated voltage of 7.6 V resulted in a temperature rise beyond its criterion of 110°C. We first clarified the minimum voltage at which the solenoid can still effectively hold by gradually lowering the solenoid's command voltage to determine the minimum operable voltage and holding voltage. More specifically, we determined that the solenoid operated at a minimum of 3.8V. The prolonged holding test was then conducted at a command voltage of 5.4V—1.5 times the minimum of 3.8V—to provide a margin of safety. The results of the prolonged holding of the solenoid are shown in Fig. 7. We confirmed that the maximum temperature did not exceed 60°C and remained well below the threshold of 110°C after conducting the second prolonged holding test for 4 hours. We confirmed the effectiveness of applying the solenoid to the Gripping Finger element, as the temperature trend suggests no further rise even with operation beyond 4 hours.

FIG. 6. *Confirmation that there are not any deformations in the Gripping Finger after applying the load*

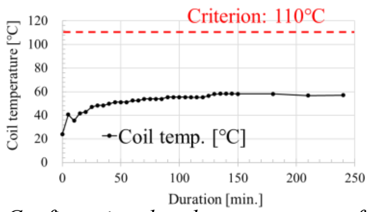


FIG. 7. *Confirmation that the temperature of the solenoid operating the Gripping Finger remains stable beyond 4 hours*

The preliminary design of the Tool Fixing element—which fixes the maintenance tools onto the Tool Base and is designed to optimize their position and angle relative to the specific FW holes targeted for maintenance—was completed, as shown in Fig. 8. The Tool Fixing element must allow the maintenance tools to be aligned and fixed to the target maintenance pipes regardless of their position and angle within a narrow range of tolerance. We adopted two linear guides on the front/back and left/right axes for achieving optimal positioning and adopted a spherical bearing for achieving optimal angle alignment to satisfy these requirements. In addition, we designed a structure that allows mechanical positioning with the inner diameter of the spherical bearing and a positioning pin on the maintenance tool side for fixing the maintenance tools. We will prototype the Tool Fixing element in accordance with the design results and then conduct the feasibility evaluation.

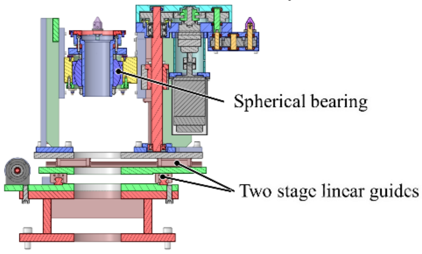


FIG. 8. The designed Tool Fixing element is equipped with two stage linear guides for position adjustment and a spherical bearing for angle adjustment

4. DEVELOPMENT RESULTS ON CUTTING TOOL

We completed the design of the Cutting Tool. The Cutting Tool incorporates a centering mechanism that precisely aligns with the center of the cooling water pipe, thereby minimizing pipe deformation during cutting and suppressing post-cut pipe displacement caused by residual stress as shown in Fig. 9. The center position between the Cutting Tool and the pipe can be accurately determined by mechanically pressing a pad against the inner diameter of the pipe during cutting. The pipe can be cut without causing tool deflection due to the reaction force of the swage cutter, thanks to the centering mechanism. Furthermore, the pipe movement caused by residual stress can be suppressed by holding the pipe in place after cutting, using the centering mechanism. The centering mechanism is designed to maintain its position independently of the cutter's rotation. The Cutting Tool has been prototyped based on the preliminary design, and evaluation tests were carried out in order to assess the cutting performance and centering capability at a tool length representative of actual conditions.

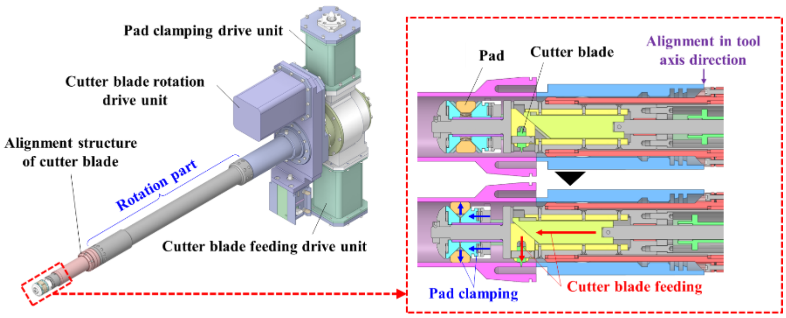


FIG. 9. Pipe Cutting Tool with centering mechanism

We evaluated cutting performance. When a pipe sample was cut, the Cutting Tool was inserted into the pipe sample, and the centering mechanism was actuated to align the Cutting Tool with the pipe. Subsequently, the swage cutter was fed in the direction of the pipe's inner surface while rotating, and the cutting test was conducted. We monitored the motor loads while cutting and evaluated the diameter of the pipe before and after cutting with a caliper. We fixed the swage cutter rotation speed at 5 rpm and set the swage cutter feed speed to four conditions: 0.004, 0.01, 0.02, and 0.04 mm/s.

Table 1. Pipe diameter after cutting

Conditions	Deformation amount [mm]
1	0.20~0.25
2	0.40~0.60
3	1.00~1.10
4	1.40~1.55

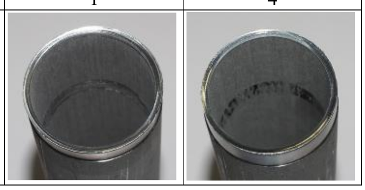
	Cutting conditions	
	1	4
Photos after cutting		

FIG. 10. Pipe Cutting section photos

The cutting results are shown in Table 1 and Fig. 10. We confirmed that the pipe deformation after cutting is less than 0.3 mm under the condition of the feed rate of 0.004 mm/s and clarified that the amount of the pipe deformation increased as the feed rates became faster. Plastic deformation increased as the feed rate became faster, due to the high elongation of the cooling pipe material, which was approximately 40%. We confirmed that there is sufficient margin with respect to the motor's capacity and clarified the possibility of tool weight reduction through redesigning of the driving mechanism in the future, as shown in Fig. 11.

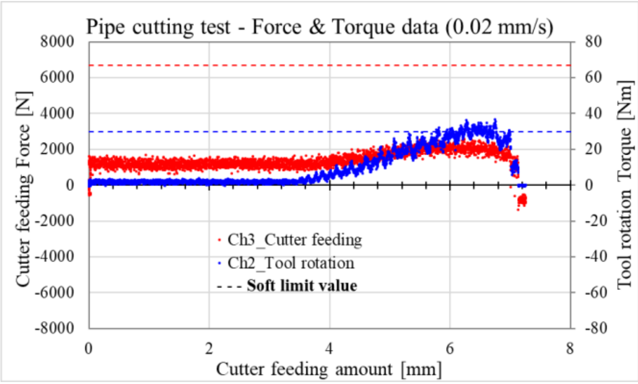


FIG. 11. Processing load result during cutting (0.02 mm/s)

On the other hand, although we achieved the initial aim of aligning the Cutting Tool and the cooling pipe with the pad, the pad rubbed against the cooling pipe, causing scratches on the inner diameter. The pad was unable to remain fixed because the friction coefficient was higher than anticipated, resulting in pad rotation under the cutting reaction force. To address this, we plan to modify the structure to center the Cutting Tool and the cooling water pipe without damaging the inner pipe when cutting.

5. DEVELOPMENT RESULTS ON WELDING TOOL

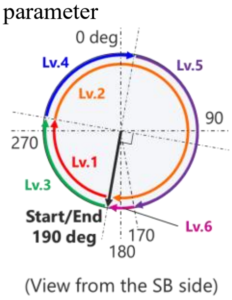
We evaluated the weldability using the pipe samples cut with the swage cutter shown in Section 4. Welding of the cooling water pipes—previously cut using a swage cutter—is required under conditions where precise bevel alignment is necessary and residual stresses remain in the pipes, during the actual remote maintenance phase. The welding technology has been developed in stages due to the involvement of many development elements. In this study, we evaluated the feasibility using the pipe samples that were expanded to four different diameters. Welding tests were conducted under the conditions shown in Table 2. This welding condition was selected for comparison purposes, as it had previously enabled full penetration welding using machined bevels with no bevel misalignment. The pipe orientation was set to the most challenging condition—horizontal position—where welding defects are more likely to occur due to molten metal sagging under the influence of gravity during welding for these tests. Table 3 shows the welding passes and welding parameters. These welding were performed in two full rotations (720 degrees) with the welding current adjusted during the process.

Table 2. Welding condition in the test

Item	Specification
Welding posture	Horizontal
Operation current and voltage	See the Table 3
Shield gas	Ar 50% + He 50%
O_2 concentration at inside of pipe sample	Less than 100 ppm
O_2 concentration at outside of pipe sample	Less than 100 ppm
Misalignment of pipes groove	Less than 0.05 mm

Table 3. Welding passes and parameter

Lv.	Position [deg]	Current [A] Peak	Current [A] Base	Voltage [V] Peak	Voltage [V] Base	Speed [mm/min]
1	190~280 (+90)	50	50	11.6	12	80
2	280~550 (+360)	90	35	11.6	12	80
3	550~640 (+450)	90	40	11.6	12	80
4	640~730 (+540)	90	35	11.6	12	80
5	730~890 (+700)	75	35	11.6	12	80
6	890~910 (+720)	50	50	11.6	12	80



The welding results are shown in Table 4. Although localized welding defects were observed in all samples, a continuous weld bead was successfully formed around the entire circumference of the pipe. Burrs remained on the bevel sections of the pipe samples after cutting, but since no melting or dropout occurred during welding, they did not significantly hinder the welding process. It is possible that the burr acted similarly to filler metal. Fusion defects were found at the 270-degree position in all samples (Table 4, red-circled areas). It is necessary to eliminate fusion defects by adjusting the welding parameters, as they are unacceptable in ITER blanket remote maintenance. Furthermore, it was found that the larger the pipe diameter before welding, the more the weld bead tended to meander around the 180-degree position. This may be due to deformation near the bevel area, which caused misalignment between the bevels of the two pipe samples. In response to these results, we will pursue welding conditions that can achieve good welding quality in future studies.

Table 4. Welding results

		Cutter blade feeding speed [mm/s]			
		0.004	0.01	0.02	0.04
Position	180 deg (Near the welding start and end point)				
	270 deg				

6. DEVELOPMENT RESULTS ON BOLTING TOOL

We completed the preliminary design of the Bolting Tool capable of absorbing positional and angular misalignments during the FW assembly and applying a high torque of 8.4 kNm. The central bolt that secures the FW to the SB is located deep inside the FW, accessible through a φ59 access hole from the FW surface. Therefore, a high-strength maraging steel with a yield stress above 2 GPa was selected for the wrench to enable the application of a high torque of 8.4 kNm. The rear end of the wrench is equipped with a spherical seat and a spring, and a clearance is provided between the wrench and the torque transmission section. This allows the system to accommodate the expected maximum misalignment of 3.5 mm in position and 1.3 degrees in angle, taking into account not only the misalignment of the central bolt itself but also that of the gripping finger interface of the FW where the Bolting Tool is mounted. Furthermore, to ensure deployability of the Bolting Tool into the VV and proper insertion of the wrench into the central bolt thread, a motor-driven wrench elevation mechanism is implemented. This mechanism enables the wrench to rotate while being pressed against the tip of the central bolt, in combination with the spring installed in the wrench. Even if the alignment between the wrench and the central bolt thread is initially misaligned, the spring force allows the wrench to engage with the central bolt thread at the moment the phases align, ensuring successful insertion and fastening. The following evaluations were conducted:

(1) Evaluation of wrench insertion into the central bolt thread under expected positional and angular misalignments, simulating actual VV conditions.
(2) Evaluation of the Torquing element's ability to apply 8.4 kNm of torque.

Evaluation of the wrench's insertion capability into the bolt thread was conducted. We assessed insertion performance under the following scenarios as test conditions:

(1) No positional or angular misalignment
(2) Positional misalignment of 3.5 mm in position only
(3) Combined misalignment of 3.5 mm in position and 1.3 degrees in angle

The wrench failed to reach the bottom of the central bolt thread and became stuck midway when only the 3.5 mm positional misalignment was present. Molybdenum disulfide spray was applied to the central bolt thread to improve lubrication as the countermeasure. The wrench was successfully inserted completely, following a re-evaluation. These results indicate that a dry lubrication coating must be applied to the wrench to reduce the friction coefficient and ensure reliable insertion.

Evaluations of the torquing element's ability to apply high torque of 8.4 kNm were conducted. The torque was applied under the three scenarios described above as test conditions. The Torquing element successfully applied the target torque of 8.4 kNm under all conditions as shown in Fig. 12. It was also confirmed that angular misalignment led to an increase in the wrench rotation angle required to reach the target torque. The surface of the central bolt thread was inspected after torque was applied three times under each condition. As a result, minor burrs were observed at the entrance of the central bolt thread only under the condition with 3.5 mm positional misalignment as shown in Fig. 13. No other damage, such as scratches or indentations, was observed under any condition, and therefore, no structural damage was identified. The designed torquing element was been demonstrated to be capable of applying the high torque of 8.4 kNm even under conditions with the expected positional and angular misalignments based on the results of the two evaluation tests.

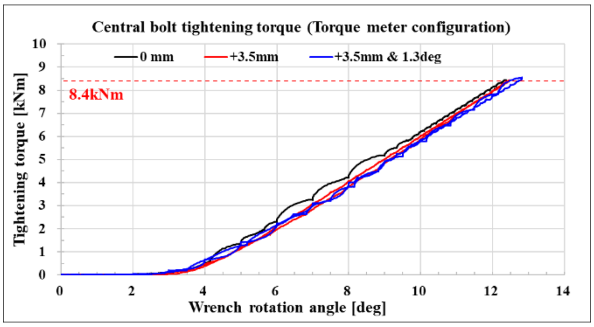


FIG. 12. Central bolt tightening torque data (Torque meter configuration)

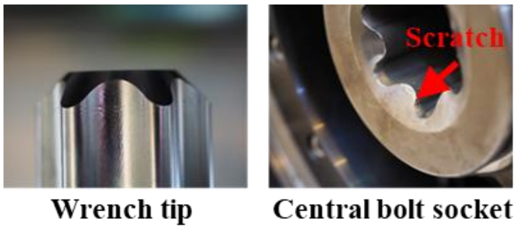


FIG. 13. Visual of wrench and central bolt socket after tightening test (+3.5 mm, 8.4 kNm, 3 times)

7. CONCLUSION

The paper reports on the development results of the Tool Base, Cutting Tool, Welding Tool, and Bolting Tool for the FW maintenance, as described below. In addition, the future implementation plans for each tool are presented.

- Tool Base: We developed the Tool Fixing element and Gripping Finger element designed specifically for the Tool Base, and through two tests, we confirmed that the Gripping Finger element is applicable to the Tool Base. We will prototype the Tool Fixing element and evaluate its effectiveness from now on.
- Cutting Tool: We validated that the centering element enables alignment between the Cutting Tool and the pipe, resulting in stable cutting. We also identified cutting conditions under which the deformation remains below 0.3 mm. We will proceed with design modifications to prevent rotation of the centering element during cutting, and conduct an evaluation of the cutter's service life.
- Welding Tool: We presented that welding is possible even on the pipes cut with the swage cutter. We will continue to investigate welding conditions that enable full penetration.
- Bolting Tool: We demonstrated that even with the maximum expected positional deviation of 3.5 mm and angular deviation of 1.3 degrees during remote maintenance, it was still possible to insert the wrench into the central bolt and apply the high torque of 8.4 kNm.

ACKNOWLEDGEMENTS

We would like to express our deepest gratitude to everyone at Sugino Machine Limited, TOKO SHOJI Co., Ltd., and Aichi Sangyo Co., Ltd. for their generous support and cooperation throughout the course of this research.

REFERENCES

[1] AYMAR, R., BARABASCHI, P., et al., The ITER design, Plasma Phys. Control. Fusion 44 (2002) 519–565.
[2] TESINI, A., PALMER, J., The ITER remote maintenance system, Fusion Eng. Des. 83 (2008) 810–816.
[3] NOGUCHI, Y., NAKATA, K., et al., Design updates of ITER blanket remote handling system to accommodate in-vessel environment, Fusion Eng. Des. 194 (2023) 113918.
[4] SAITO, M., ANZAI, K., et al., Development of radiation hard components for ITER blanket remote handling system, Fusion Eng. Des. 109–111 (2016) 1502–1506.
[5] TANIGAWA, H., ABURADANI, A, et al., Comparative study of laser and TIG welding for application to ITER blanket hydraulic connection, Fusion Eng. Des. 87 (2012) 999–1003.
[6] SHIGEMATSU, S., TANIGAWA, H., et al., Verification test results of a cutting technique for the ITER blanket cooling pipes, Fusion Eng. Des. 87 (2012) 1218–1223.
[7] NOGUCHI, Y., NAKATA, K., et al., Development of bolting tool for remote handling of ITER first wall central bolt, Fusion Eng. Des. 164 (2021) 112048.
[8] NOGUCHI, Y., MARUYAMA, T., et al., Development of in-vessel pipe alignment tool for ITER blanket remote maintenance, Fusion Eng. Des. 124 (2017) 623–627.
[9] KODAMA, S., OGAWA, S., et al., Development of the force feedback algorithm of 2-peg-in-hole for remote maintenance system for the fusion device, 2024 SICE Festival with Annual Conference (SICE FES), IEEE, p. 518–523 (2024).
[10] OGAWA, S., MARUYAMA, T., et al., Proposal of an integration policy for heavy object handling technology in a radiation environment for the fusion device, 2024 SICE Festival with Annual Conference (SICE FES), IEEE, p. 776–781 (2024).