Development of ITER Divertor Outer Vertical Target

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1. Summary

The ITER Divertor Outer Vertical Target (OVT) comprises a Plasma-Facing Unit (PFU) and Steel Support Structure (SSS). The one OVT is split into independent components (Left- and Right-OVT) to reduce the electromagnetic loads. The PFU and SSS have cooling channels and are actively cooled by water to withstand cyclic heat loads up to 20 MW/m^2. OVT is an in-vessel component, because high durability for cyclic high heat load and high leak tightness are required. Development of high-heat flux (HHF) testing and leak testing technologies are needed to ensure the performance of OVT during series production. In addition, stringent dimensional tolerances are required to the OVT to suppress melting at the leading edge. National Institutes for Quantum Science and Technology (QST) completed in the establishment of HHF testing and leak testing technologies and manufacturing of a full-scale OVT prototype, and it confirmed that the OVT prototype meets all acceptance criteria. The prototyping phase of OVT has been successfully completed.

2. Results and discussion

In the series production phase of OVT, stability of the quality of materials and joints is important to ensure the performance of OVT. For the main material of PFU such as W (plasma-facing material) and CuCrZr-IG (cooling tube), it was confirmed that the stable material quality during mass production [1,2]. For joints, 100% non-destructive testing is planned. In addition, the high-heat flux (HHF) testing of a small-scale mock-up of PFU (PFU test sample) is planned to ensure the heat removal capability of PFU during the series production. The PFU test sample shall be manufactured using the same process and brazed in the same batch as PFUs. The PFU test samples are to be subjected to the cyclic heat load of 100 cycles at 11.2 MW/m^2 and 300 cycles at 20.0 MW/m^2 to evaluate the heat removal capability. Important factors for the HHF testing are the flatness of the heat flux ($\pm$5%) and the precise temperature monitoring on heat loaded surface of the PFU test sample. The electron beam gun and 2-dimensional beam deflection system were developed, and the flatness of heat load could be ensured as shown in Fig.1 by optimizing electron beam condition, scanning pattern, vacuum level in a test chamber, etc. The measurement system was also improved to obtain data on temperature and surface conditions every cycle, achieving high precision in testing.

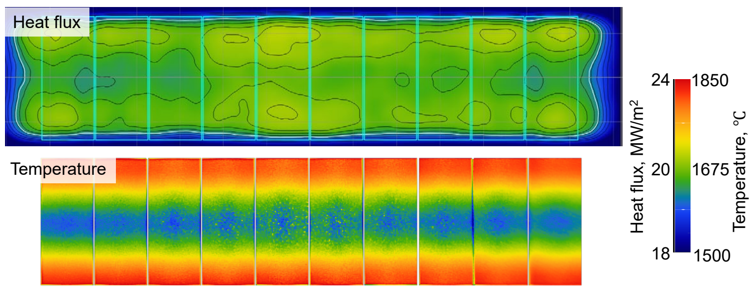

Figure 1. Profiles of heat flux and temperature during heat load at 20 MW/m^2.

The leak tightness of OVT must be ensured by the total leak rate $\leq 1 \times 10^{-10}$ Pa·m^3/s at room temperature and 250 ºC. However, no technology or know-how for large-scale leak inspection equipment that can uniformly heat the OVT to 250°C and has high leak detection sensitivity in a high-temperature environment, and a new leak test facility was manufactured in QST. To achieve high leak sensitivity, helium was selected as tracer gas, and a vacuum chamber method was adopted. In addition, the entire OVT was surrounded by 30 heater panels. The temperature was monitored by thermocouples attached to the OVT, and uniform heating was made possible by controlling the output of each heater panel. The leak tests were performed for prototypes of Left-OVT and Right-OVT. Figure 2 shows the temperature history of the Right-OVT prototype. It was confirmed that the Left-OVT prototype was heated to 250 °C while maintaining a temperature difference of $\leq$ 40 °C. Figure 3 shows the leak test result at 250 °C. During the test, inside of the Right-OVT prototype was pressurized to 4.2 MPa by nitrogen and helium, although the increase in leak rate was not observed, and the leak tightness was confirmed.

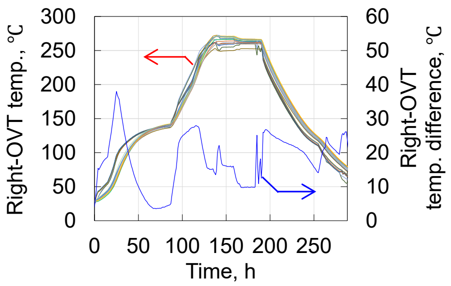

Figure 2. Temperature history and its difference of Right-OVT prototype during heating.

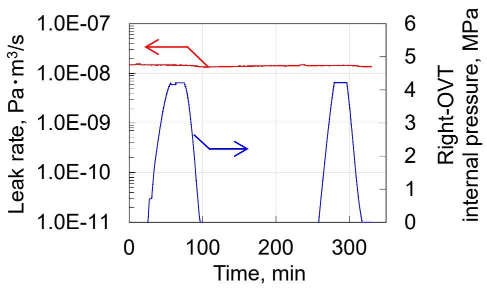

Figure 3. Leak rate during pressurization of Right-OVT prototype.

The combination dimensional test of Left- and Right-OVT prototypes was performed after the completion of all inspections for each component. There are strict requirements for the tolerances to avoid leading edge exposure and mitigate melting, especially at target part of PFU [3]. The gaps and steps on the plasma-facing surface of adjacent PFUs between Left- and Right-OVT prototypes were measured as shown in Fig.4, and it was confirmed that the measured values were within the acceptance range.

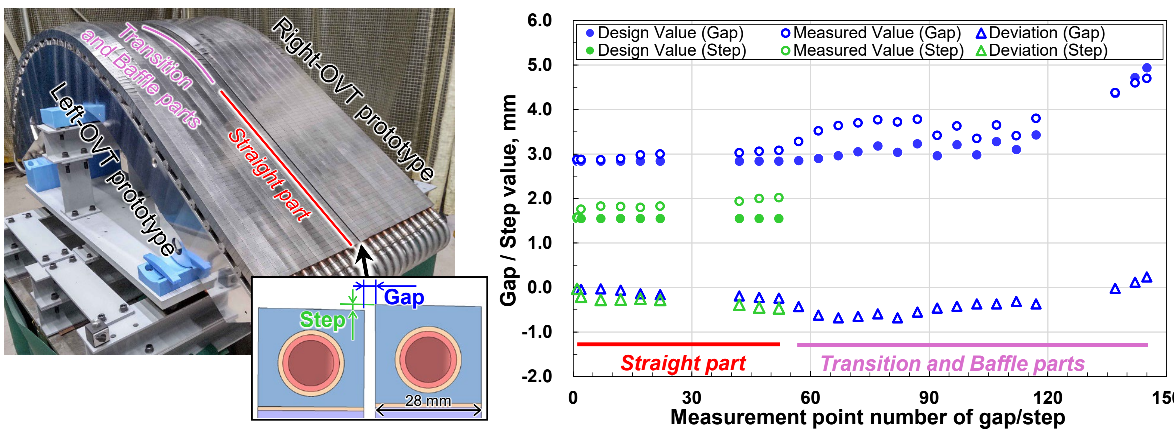

Figure 4. Measurement result of gaps and steps between Left- and Right-OVT prototypes. (The OVT has a shape that widens from the straight part to the baffle part, and the width of the W block varies from 28.0 mm to 30.3 mm. Because the variety of monoblock widths is limited, the gap design value does not change monotonically.)

Reference

[1] M. Fukuda et.al., Fusion Engineering and Design, 167, 112283 (2021)
[2] Y. Seki et.al., Plasma and Fusion Research, 17, 2405080 (2022)
[3] T. Hirai et al., Fusion Engineering and Design, 127 66-72, (2018)

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