MACHINE ENHANCEMENT OF TOKAMAK DEVICE FOR THE JT-60SA NEXT OPERATION

H. KAYANO, A. OWADA, A. KAMINAGA, T. NISHIYAMA, T. MORIMOTO, K. FUKUI, J. YAGYU and Y. SHIBAMA

National Institutes for Quantum Science and Technology (QST), Naka, Ibaraki-ken 311-0193, Japan

Email: kayano.hiroki@qst.go.jp

The Integrated Commissioning (IC) were conducted in 2020-2021 and 2023 on the JT-60SA (Super Advanced) tokamak device. In the IC, the vacuum vessel (VV) was exhausted to achieve a high vacuum for plasma generation and the cryostat was exhausted to keep the Superconducting Coils (SC) at cryogenic temperature.

The JT-60SA tokamak device is under machine enhancement, such as additional 18 ports penetrations for plasma diagnostics and heating system including Neutral Beam Injector (NBI). NBI used on the JT-60U will be re-utilized to achieve high-density and high-temperature plasma in the next operation, as described in Fig. 1. In addition, cooling water circulation system will be introduced to remove high heat flux on the in-vessel components. As for cryostat vacuum, a vacuum interlock (I/L) system was introduced to achieve safe termination of the SC. To make the system redundant, additional three I/L vacuum gauges are planned to be installed inside the cryostat. Regarding vacuum pumping system, failures of two Dry Vacuum Pumps (DRPs) happened during the IC in 2023. One of the causes was solidified machining oil and resin that were used on machining works in the cryostat. To avoid these failures in the next operation, improvements such as baking the inlet-side piping of DRPs to exhaust gas without solidification are planned.

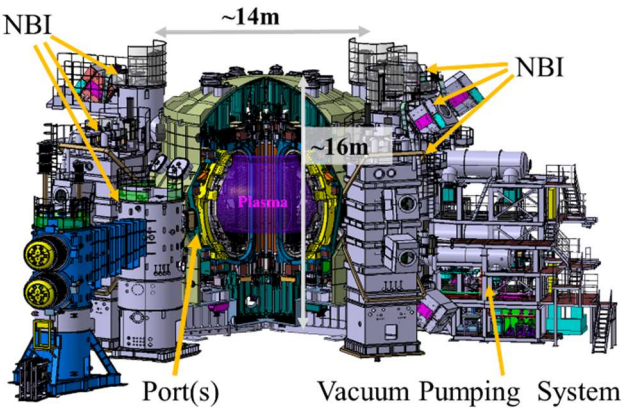

FIG. 1 bird's eye view of the JT-60SA

In this paper, we report on the recent machine enhancement of the tokamak device such as the installation of ports, the introduction of a water-cooling system, the improvement of the vacuum pumping system. In addition, tokamak behaviour during the IC and unexpected events were monitored and analysed by using gauges to measure temperature, strain, displacement and vacuum on the tokamak device. These details of the enhancement of the JT-60SA and tokamak behaviour in commissioning will contribute to prevent unexpected rework in ITER and DEMO.

1. MACHINE ENHANCEMENT TO REALIZE HIGH-DENSITY AND HIGH-TEMPERATURE PLASMA

To install NBI and plasma diagnostics, additional 18 ports are being installed on the VV with tolerances of ±2 mm for NBI ports and ±5 mm for the other ports. Port positions are measured using laser trackers to achieve these tolerances, and 10 ports have already been installed by 7 February 2025, as shown in Fig. 2. In order to weld the huge port with precision, a restraining jig during welding is manufactured and welding deformation repair methods have been considered. These jig and methods are applied to other ports. In addition, an active water cooling is introduced to remove high heat flux on the in-vessel components such as first wall, divertor, etc, to confine the plasma up to 100 s. Water lines have been designed considering the operation scenario, and the installation procedures in the narrow area surrounded by in-vessel components have been constructed. Then, the installation work has been started.

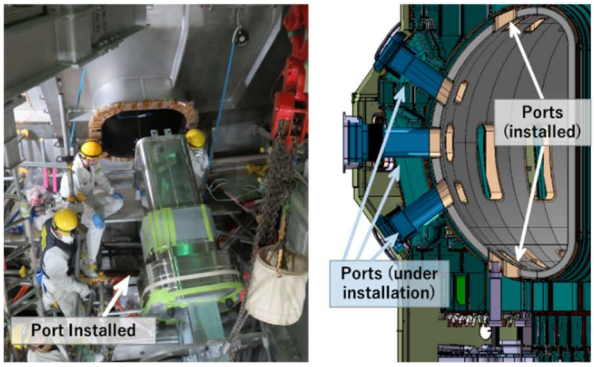

FIG. 1 onsite port installation (left) and ports (right)

2. MEASURES TOWARD FAILURE ON THE CRYOSTAT VACUUM PUMPING SYSTEM

In the cryostat, vacuum exhaust is performed under more severe conditions for vacuum pumps than in the VV, because it contains carbon compounds such as polyamide and polyester composing multi-layer insulation, resins for the electronic insulation. The cryostat is exhausted with vacuum pumping system, as shown in Fig. 3. One of the issues during the IC in 2023 was the failure of two DRPs (out of five) used in the cryostat vacuum pumping system. In that case of the IC in 2023, the cryostat was exhausted using other foreline pumps through the bypass line prepared in advance. One of the causes of the failure is inflow of solid impurities such as machining oil and resin, another is rust due to unexpected amount of H_2O in the inflow gas. The cryostat is open to the atmosphere and repair works using resin were performed inside the cryostat. To prevent DRPs from failure in the next operation, some measures, such as baking of the inlet-side piping to exhaust the gas without solidification and installation of the water drain piping at the exhaust port are planned.

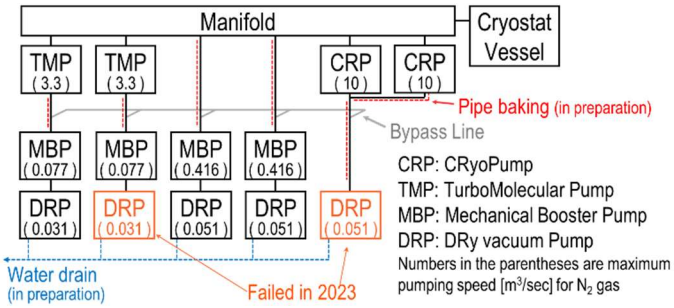

FIG. 2 schematic diagram of the cryostat vacuum pumping

3. EXTENSION OF THE VACUUM INTERLOCK SYSTEM FOR THE SUPERCONDUCTING COIL PROTECTION

In the event of vacuum leak on the cryostat, to reduce the risk of discharge on the SC according to Paschen's law, a vacuum I/L system was developed to achieve safe termination of the SC. In order to detect degradation of vacuum quickly and precisely, a cold-cathode-gauge (INFICON MAG070) was installed at port section 2 of the lower space of the cryostat (P02CCG) [1]. I/L vacuum gauge was tested in actual equipment using helium gas of ~25 Pam^3 during the IC in 2023, as described in Fig. 4. In this test, pressure at the P02CCG exceeded threshold (10^{-4} Pa) at 1.39 s after injection, and the controller of P02CCG output setpoint signals at 1.41 s. It is confirmed that all of the SC power supply starts to decrease to zero in about 0.5 s after I/L system receive setpoint signal. As time-evolution of pressure of Fig. 4 shows, pressure rise time delays owing to conductance between pressure-measuring spot and leak spot. For the fast response and the vacuum I/L system redundancy, we are preparing to install three additional I/L vacuum gauges on the upper space and lower space of the cryostat. Using value of conductance calculated by time-evolution of pressure, we are estimating range of reduction in detection-time by this extension, and analysing the risks to achieve safe termination for possible leak event.

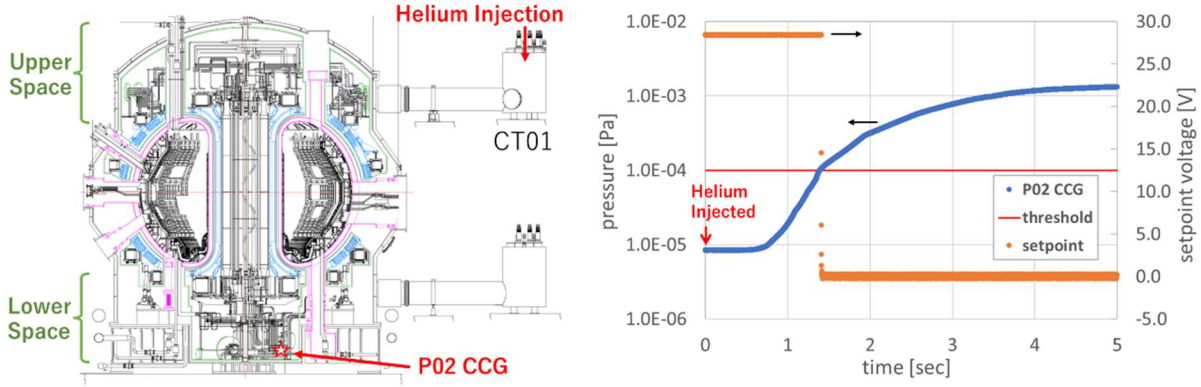

FIG. 4 tests of I/L vacuum gauge (left) and time-evolution of pressure (right)

REFERENCES

[1] H. Shirai, et al., "Recent progress of JT-60SA project toward plasma operation" Nucl. Fusion 64 (2024) 112008