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Commissioning of JT-60SA cryogenic system with active control to mitigate heat load fluctuation

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ABSTRACT

- The commissioning and annual operations of JT-60SA cryogenic system have been performed. During the commissioning of the cryogenic system, performances for each component and the automatically controlled operation sequence have been confirmed.
- An active control method for cryogenic heat load fluctuation has been established.
- The commissioning and annual operations were successfully completed. Cool down and magnet operation have been started as the integrated commissioning test of the whole JT-60SA tokamak for the first plasma discharge.

BACKGROUND

- To cool the superconducting magnets and structures (about 650 tons) [1], the thermal shields (96 tons), and the cryopumps to supply cold gas for the High-Temperature Superconductor current leads (HTS-CL)[2], a cryogenic system with an equivalent refrigeration capacity of 9.5 kW at 4.5 K has been provided as a European contribution to the project [3] (FIG.1).
- The cryogenic heat load generated in the magnet system varies significantly during the plasma experiment. The variation of the heat load leads to rapid changes in the return temperature to the Refrigerator Cold Box (RCB), which has to be re-cooled by the compressors and turbines.
- The stationary 4 K heat load of 2.3 kW quickly reaches 7.4 kW during dynamic magnet operation. One of the design challenges for the cryogenic system was to mitigate the impact of the heat load fluctuation with a thermal damper system.

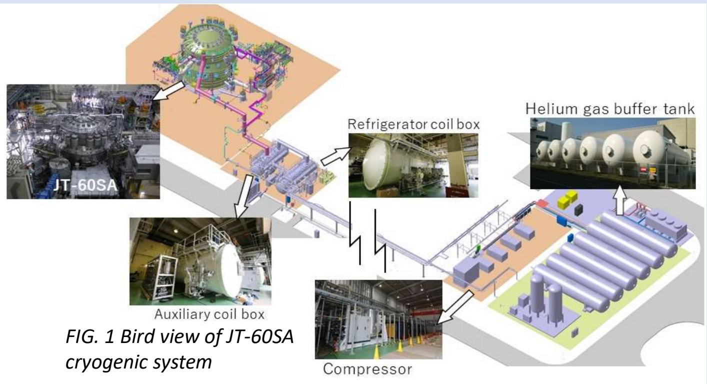

FIG. 1 Bird view of JT-60SA cryogenic system

CHALLENGES / METHODS / IMPLEMENTATION

The active control of heat load fluctuation is essential for the cryogenic system, resulting from high current variation in the superconducting magnets, also expected for ITER. However, such a control was not realized and tested yet in such a large scale cryogenic system for fusion.

Advanced active mitigation method of heat load fluctuation has been demonstrated in the following methods;

- The heat load is balanced by controlling the damper temperature/pressure. This is done by a combination of the capacity of the cold compressor and outlet valve (CV799) such that the suction pressure control of the WCS can manage the increasing low pressure return flow, which in turn results from the higher vaporization rate in the damper.
- Temporary absorption of the heat by h4elium in the 7 m^3 damper and accumulation and pressurization of the evaporated helium gas to stay within the suction capacity of the WCS.

The performance test of the cryogenic system (FIG.2) simulated the variable heat load of the plasma operation scenarios with several electric heaters.

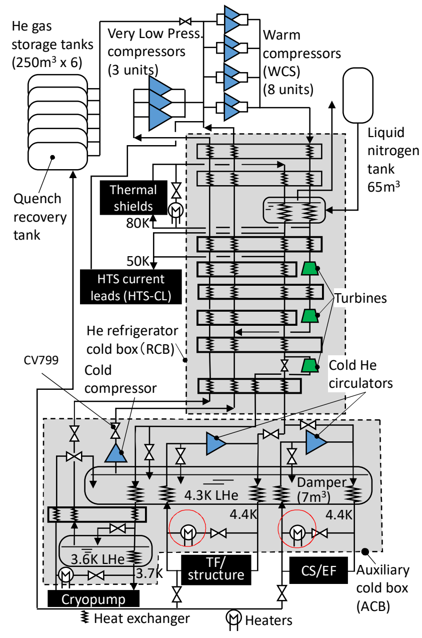

FIG. 2 JT-60SA Cryogenic system

COMMISSIONING TEST OF THE CRYOGENIC SYSTEM -OUTCOME-

Active control of heat load fluctuation (FIG.3)[4,5]

- The variable heat load during 1800 seconds was repeated three times using an electric heater, simulating the TF/PF coil heat load (5.5MA, 60 s plasma operation) .
- The damper pressure was controlled, resulting in a reduced return mass flow to the WCS to mitigate impact on the cryogenic system rotating machines such as WCS and turbine expanders.

Fine tuning of control (FIG.4)

- The heat load was stepwise increased to 7.4 kW (heat load: 100%) . In a case of low heat load (50%) operation, the turbine temperature decreased below 27 K, which is close to the trip temperature of the turbine (26 K).
- Control parameters to adapt various heat load conditions have been investigated. The control system regulated the return flow to the RCB within the capacity of WCS and kept the turbine inlet temperature above 27 K.

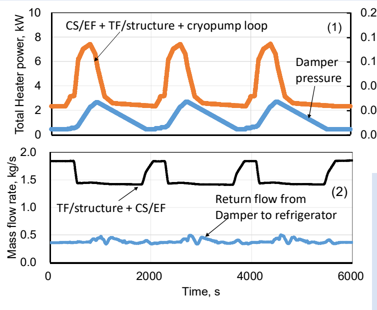

FIG. 3. Electrical heater power and controlled damper pressure (1) and controlled cold circulator and cold compressor mass flow rates (2)

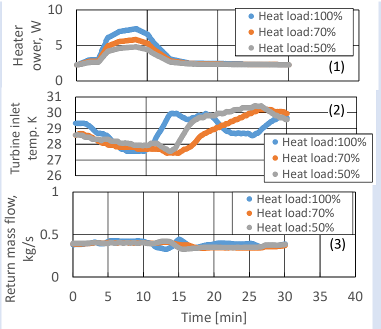

FIG. 4 Results of the heat load fluctuation test for various heat load levels (50%, 75%, 100%) after fine tuning of detection for damper peak pressure. (1) Heater power, (2)Turbine inlet temp., (3) Return flow from damper to refrigerator

INTEGRATED COMMISSIONING TEST -OUTCOME-

Cool-down of the magnet system and the thermal shields(FIG.5)

- Purification operation of helium in the cryogenic system: we reached the acceptable impurity level (N_2 <10ppm, dew point< -70^{o}C).
- Temperature control condition during cool-down are as follows;
  (1)Temperature difference inlet and outlet: <35K, (2)Temperature difference among TF coil winding: <10K , (3)Temperature difference between TF coil casing and winding pack < 25K, (4) TS temperature was kept 50 K higher than the TF coil temperature.
- The cool down of magnet system was completed within 50 days.

Magnet steady state operation (TF coil 100% (25.7kA) energization)

- Total equivalent heat load is 7.6 kW at 4.5K(FIG.6). Since TF was only energized, it is 72% of design refrigeration power (9.5 kW at 4.5K). The total electricity of WCS (2.33MW) and liquefaction of nitrogen (0.42MW) was 2.75 MW. Liquid nitrogen consumption was 1000liters/hr (nominal: 1400liter/hr)
- The cryogenic system maintained stable temperature during TF 100% energization test.

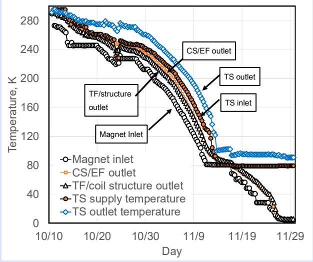

FIG. 5 Temperature at inlet and outlet of the magnet system and the thermal shields

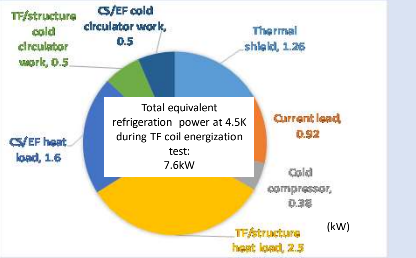

FIG. 6 Summary of equivalent heat load at 4.5K based on temperature, pressure and flow rate measurement.

CONCLUSION

- Advanced active mitigation method of varying heat loads has been developed in the JT-60SA cryogenic system.
- The process allowed stable operation of the magnet system during integrated commissioning of JT-60SA in 2020 and will provide useful information for stable operation of ITER cryogenic system.
- Cool–down has been completed and TF 100% energization has been successfully achieved. The cryogenic system maintained stable temperature during TF 100% energization.

REFERENCES

[1] Y. Koide, et al., “JT-60SA superconducting magnet system,” Nucl. Fusion 55 (2015) 086001
[2] R. Heller, et al., “Overview of JT-60SA HTS Current Lead Manufacture and Testing,”, IEEE Trans. Appl. Supercond. 28(2018)4800105
[3] Michel F et al. “Cryogenic Requirements for the JT-60SA Tokamak” Adv. in Cryo. Eng. 57(2012)78-85
[4] C Hoa, et al., “Performance of the JT-60SA cryogenic system under pulsed heat loads during acceptance tests,” IOP Conf. Series: Mat. Sci. Eng. 278 (2017) 012104
[5] K. Kamiya, et al., “Commissioning of the JT-60SA helium refrigerator,” J. Phys.: Conf. Ser. 897 (2017)012015