Development of plasma control schemes and plan of plasma physics studies in JT-60SA

H. Urano[1], and the JT-60SA Team
[1] National Institutes for Quantum Radiological Science and Technology, Naka Fusion Institute
e-mail (speaker): urano.hajime@qst.go.jp

The main objectives of JT-60SA project are to conduct supportive and complementary works for ITER towards DEMO under the framework of the Broader Approach agreement by EU and Japan [1]. The project was moved to the Integrated Commissioning phase. The tasks of the plasma operation in the Integrated Commissioning are to obtain stable discharges from plasma breakdown to current ramp-down to check the controllability of plasma position/shape/equilibrium and to conduct plasma performance tests with possible plasma current, toroidal field, discharge duration and heating power. The plasma operation scenarios and operation areas are simulated by advanced computational codes together with the development of control logics, such as pre-magnetic optimization scheme, plasma equilibrium control with ISO-FLUX scheme, control gain optimization method, and strategies for accessing stable operational regimes.

An advanced ISO-FLUX equilibrium control scheme is developed and implemented in the JT-60SA equilibrium controller [2]. For a future fusion reactor, the vertical instability control by the active superconducting coils is essential due to the absence of in-vessel coils and stabilization plates, and the presence of large gap between a plasma and a vacuum vessel where the wall stabilization effect would be weak. Under the circumstances, the equilibrium controller should achieve plasma position/shape control and plasma current control by superconducting coils within limited power supply voltages, where plasma current control affects plasma position/shape control, and vice versa. The newly developed ISO-FLUX control scheme enhances the controllability under the above hybrid control of position/shape and plasma current circumstances. Furthermore, the new scheme also provides good controllability under large eddy currents conditions, which will also be expected in future superconducting tokamaks, such as JT-60SA, ITER, and DEMO due to its large inductance and high target plasma current. The JT-60SA equilibrium controller with the developed scheme is well verified by a magnetohydrodynamic equilibrium control simulator "MECS" and ready for the integrated commissioning of JT-60SA.

Under the circumstance where the position of the conducting structure is not clearly known, a breakdown optimization method in JT-60SA has been developed where the magnetic fluxes generated by the eddy currents is reconstructed with high accuracy using an inverse analysis technique [3]. This technique is based on the reconstruction of the magnetic fluxes using the external magnetic sensor signals and does not require preliminarily the precise position of the conducting structures. The plasma breakdown magnetic field has been successfully optimized in a situation where the position and shape of the conducting structures were not exactly known. This method optimizes logically the breakdown magnetic field and thus reduces efficiently the time required to achieve successful breakdown compared to the conventional experimental approach.

After the Integrated Commissioning, physics-oriented experiments will start using the validated control systems, enhanced diagnostics, particle fueling, and power of 26.5 MW (PNNB/ PPNB/ PEC=10/ 13.5/ 3 MW) at higher current up to 5.5 MA. As the only such device scheduled to come into operation prior to ITER, the commissioning and establishing of high plasma current operation on JT-60SA will provide vital information for ITER. In the Initial Research Phase I, the JT-60SA Experiment Team will focus on the program on scenario development for stable operation at high current and risk mitigation in ITER in time for its non-activated phase as well as on investigating DEMO relevant regimes [4].

The research headline of stable operation at high current in the Initial Research Phase I contains I_p ramp-up scenario development up to full-current operation, plasma shape and equilibrium control avoiding vertical instability, locked mode and kink mode avoidance during current ramp-up, EC wall conditioning, light and heavier impurity control in the core, and H-mode plasma operation. Regarding the risk mitigation in ITER for non-activated phase, basic disruption studies and L-H transition studies in hydrogen / helium plasmas are main issues. JT-60SA will play an important role in reducing the risks in ITER operation through taking advantage of its characteristics, including high plasma current, high heat and particle flux, low collisionality, and carbon wall having enough robustness to transient events.

References

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