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New Plasma Regime and Physics Research in JT-60SA towards ITER and DEMO
JT-60SAにおける新しいプラズマ領域とITERおよび原型炉に向けた物理研究

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The JT-60SA device is a highly shaped large superconducting tokamak with a variety of plasma actuators. The JT-60SA will explore new plasma regimes and resolve key physics issues associated with ITER and DEMO in the areas including particle/heat transport, MHD stability, non-inductive current drive, high energy particle physics, ELMs and particle/heat control with divertor. By integrating these studies, steady-state sustainment of integrated performance required for DEMO will studied in JT-60SA, aiming at establishment of control scenarios with minimum actuators.

1. Introduction

The JT-60SA Project [1] is a combined project of the Broader Approach (BA) Satellite Tokamak Program, jointly implemented by Europe and Japan, and the Japanese national program. The mission of JT-60SA is to contribute to early realization of fusion energy by supporting the exploitation of ITER and research towards DEMO [2]. This paper reports the new plasma regimes and physics research to be addressed in JT-60SA towards ITER and DEMO.

2. Device Features and Status of Construction

The JT-60SA device has superconducting toroidal and poloidal field (TF and PF) coils. The maximum plasma current (I_p) is 5.5 MA and the toroidal field (B_t) is 2.25 T. A highly shaped configuration (major radius R = 2.96 m, minor radius a = 1.18 m, aspect ratio A = 2.5, elongation $\kappa_x = 1.95$, triangularity $\delta_x = 0.53$) is possible. The poloidal cross-section of the device in shown in Fig. 1. The superconducting coils consist of 18 TF coils, 4 central solenoid (CS) modules and 6 equilibrium field (EF) coils. In the vacuum vessel, 3 sets of copper coils will be installed; fast plasma position control coils (upper and lower axisymmetric coils), error field correction coils (3 poloidal × 6 toroidal) and Resistive Wall Mode (RWM) control coils (3 poloidal × 6 toroidal). Furthermore, a stabilizing plate (shell) is equipped for suppressing the vertical stability and RWM. All of the plasma facing components are water-cooled. The divertor has vertical CFC monoblock targets that will handle high heat flux up to 15 MW/m^2. Cryopanels will be installed beneath the divertor cassette for pumping. A remote handling system will be prepared for maintenance of in-vessel components including the divertor cassette without manned entry after high power deuterium operation. Metallic targets will be installed in the later phase.

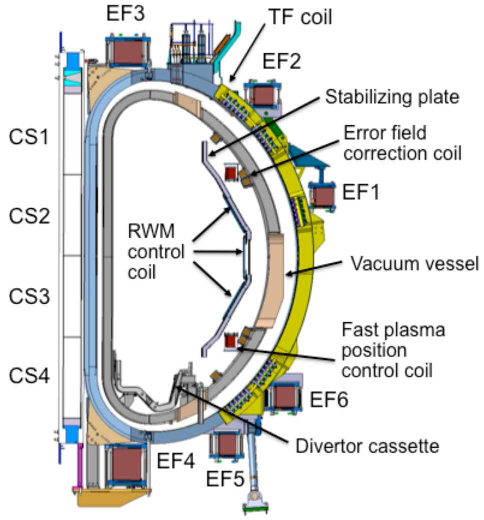

Fig.1. Cross-section of the JT-60SA tokamak.

The heating system provides 34 MW of NB injection, including 24 MW of positive ion NB (P-NB) and 10 MW of 500 keV negative ion NB (N-NB), and 7 MW of ECRF for up to 100 s. The N-NB will be tangentially injected into a half radius region of the plasma. This is one of the unique features of JT-60SA, which will enable weak or reversed magnetic shear configuration for advanced tokamak operation.

Construction of JT-60SA is in progress toward the first plasma foreseen in 2016. Fabrication of PF coils, the vacuum vessel and the cryostat base was started, and the first 40 degree sector of the vacuum vessel was completed. Disassembly of the JT-60U device is underway and will be completed by 2012.

3. New Plasma Regimes and Physics Research

Non-dimensional plasma parameters (beta, normalized poloidal gyroradius, normalized collisionality) will be closer to the values in ITER and DEMO than all existing devices, as shown in Fig. 2, under reactor-relevant heating conditions (dominant electron heating and low central fueling and low external torque input), which will enable heat and particle transport study, in the core and also at the pedestal, for ITER and DEMO. Plasma characteristics including beta limit and confinement properties will be studied in a regime with A~2.5 which is relevant to the economic DEMO design.

A long pulse, high current, high beta reversed shear plasma with full non-inductive current drive is expected using off-axis NBCD. Figure 3 shows profiles of density, temperature, current density and safety factor q in a reference scenario where $I_p = 2.3$ MA, the normalized beta $\beta_N = 4.3$, the confinement enhancement factor $H_{98y2} = 1.3$, and the bootstrap current fraction $f_{BS} = 0.68$ with the injected power of 37 MW (N-NB: 10 MW, P-NB: 20 MW and ECRF: 7 MW). The MARG2D analysis confirms that this plasma is stable for the $n \leq 4$ kink ballooning mode with ideal wall. The pedestal is stable for the $n < 40$ peeling-ballooning mode. Sustainment of high beta above the no-wall beta limit will be extended up to 100 s, as shown in Fig. 4, by using the stabilizing shell, the RWM control coils and the error field correction coils as well as by plasma toroidal rotation scan with co- and counter injected NBs. Interactions between high energy ions and MHD instabilities will also be studied with N-NB injection that will realize reactor-relevant high energy particle conditions with $\beta_{fast} = 0.2$–1% and $V_{fast\text{-}ion}/V_{alfven} = 1.5$–$2$. The high power long pulse N-NB will also enable non-inductive current ramp experiment, which is indispensable for a slim CS DEMO.

The ELM study including the type-I ELM energy loss and ELM mitigation using resonant magnetic perturbation (RMP) and pellet pacing will be studied at the ITER-relevant collisionality at the pedestal in the ITER-like plasma shape. For DEMO, JT-60SA expands the Grassy ELM regime in the high triangularity shape. At divertor, the particle control will be achieved by changing the pumping speed of cryopanels. Impurity seeding will be employed to achieve high radiation power for a plasma with full non-inductive current drive and with relatively low edge density.

By integrating the above studies, steady-state sustainment of integrated performance required for DEMO will studied in JT-60SA, aiming at establishment of control scenarios with minimum actuators. A plasma simulator code with integrated models for core and SOL/divertor plasmas is under development, in order to predict plasma characteristics and develop control scenarios in JT-60SA and ITER.

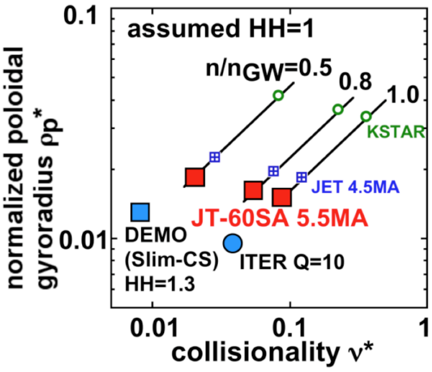

Fig.2. Normalized poloidal gyroradius and normalized collisionality.

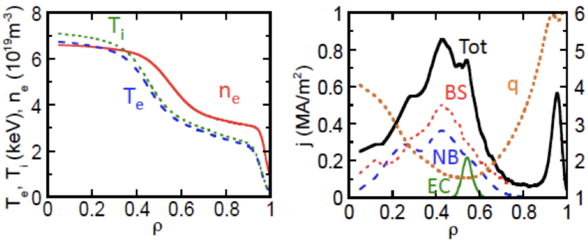

Fig.3. A high beta plasma with full non-inductive current drive.

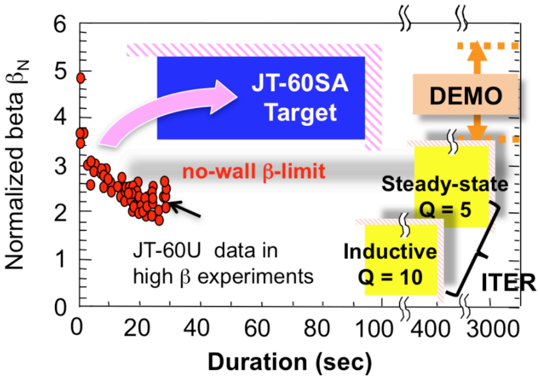

Fig.4. High β_N target regime of JT-60SA.

References

[1] S. Ishida et al.: Nucl. Fusion **51** (2011) 094018.
[2] Y. Kamada et al.: Nucl. Fusion **51** (2011) 073011.