Development of advanced tokamak operation scenarios in JT-60U and JT-60SA

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The JT-60U program was conducted in order to contribute to ITER and DEMO, providing physics basis and advanced tokamak (AT) operation scenarios. In August 2008, JT-60U successfully finished operation, and construction of superconducting tokamak JT-60SA is now in progress. JT-60SA supports ITER and contributes to early realization of fusion energy in DEMO by complementing ITER. AT operation scenarios were introduced in contrast to the conventional inductive H-mode tokamak operation scenario, and are intensively studied worldwide. AT operation scenarios in view of ITER and DEMO (such as SlimCS [1]) should satisfy the following requirements; 1) fully non-inductively driven plasma current (fraction of non-inductively driven current to plasma current f_{CD}=1), 2) realization of steady-state in current and pressure profiles, 3) high bootstrap current fraction f_{BS}~0.5-0.75, 4) high normalized beta β_N~2.9-4.3, 5) reasonably low q_{95}~5-6. What is called steady-state operation scenario in ITER is designed based on these requirements. Here we present development of such AT operation scenarios in JT-60U and prospects of JT-60SA.

In terms of steady sustainment (concerning the above requests #1-3 and #5), fully non-inductive discharge with steady current profile was realized at f_{BS}=0.5 and reasonably low q_{95}~5.8 in weak magnetic-shear plasma regime [2]. The steady-state full current drive (CD) condition was realized using combination of neutral beam (NB) current drive (including 1.2 MW N-NB at 320 keV) and 1.8 MW off-axis lower-hybrid current drive that aligned with total current profile. Operation regime was extended as shown in Fig. 1. Achieved β_N~1.6 in this discharge was not limited by any MHD stability, but by current drive capability, since non-inductively driven current decreased at higher density by larger heating power. In terms of high plasma performance (concerning the requests #3-5), high performance plasma having f_{BS}~0.92 and β_N~2.7 above the no-wall beta limit ~1.9 were transiently realized at slightly low f_{CD}~0.94 and reasonably low q_{95}~5.3 in reversed magnetic-shear regime, using wall stabilization of resistive wall mode (RWM) [3]. The discharge was terminated by the RWM at β_N~2.7 (close to ideal-wall beta limit ~2.9) because of decrease in plasma rotation at outer q=3 surface due to change in q profile. Thus, realization of the steady current profile (the request #2) is essential in stable sustainment of such high performance plasma.

The AT operation scenario simultaneously fulfilling all the above requirements should be realized in JT-60SA, where strong current drive capability of 10 MW N-NB at 500 keV and active RWM stabilization by external magnetic field perturbation will help operation scenario development.

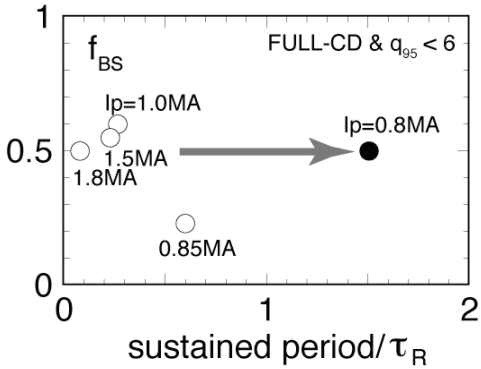

Fig. 1: The JT-60U operation regime was extended toward steady-state sustainment of full-CD plasma at high f_{BS}. Filled circle is achieved in 2008, and open circles are before 2008.

[1] K. Tobita *et al.*, Nucl. Fusion **49** (2009) 075029.
[2] T. Suzuki *et al.*, Nucl. Fusion **49** (2009) 085003.
[3] Y. Sakamoto *et al.*, Nucl. Fusion **49** (2009) 095017.