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中心ソレノイドコイルを用いないトカマク運転

Tokamak Operation Without the Use of Center Solenoid Coil

高瀬雄一

東京大学　大学院新領域創成科学研究科

Yuichi Takase

Graduate School of Frontier Sciences, The University of Tokyo

In conventional tokamak operation, plasma current is ramped up and maintained by the center solenoid (CS) coil located on the inboard side of the torus. If operation without the use of the CS coil could be realized, economic competitiveness of the tokamak fusion reactor could be improved by enabling a more compact and higher field design. In particular, this is a crucial requirement for the low aspect ratio spherical tokamak (ST).

It has long been proven that it is possible to ramp up the plasma current by noninductive current drive. However, plasmas created in such a way has so far been limited to low density plasmas, and there is a drawback that the time scale for current ramp up is very long, determined by the L/R time. This year, a joint team consisting of university and JAERI scientists has successfully demonstrated plasma current ramp-up and achievement of high performance plasma without the use of the CS coil in JT-60U (Fig. 1). This was accomplished by a novel operation consisting of induction by vertical field and shaping coils, noninductive current drive (mainly by LHCD), and self-driven (bootstrap) current. This plasma had features of the advanced tokamak, with high β (poloidal beta $\beta_p = 3.6$, normalized beta $\beta_N = 1.6$), high confinement (enhancement factor over the H-mode scaling $H_{H98y2} = 1.6$), and high bootstrap fraction ($f_{BS} \geq 90\%$) at a plasma current of 0.6 MA. The safety factor (q) profile is deeply reversed (characteristic of a high-bootstrap-fraction plasma with a "current hole"), and there are steep gradient regions near the minimum of q at $r/a = 0.7$ and at the plasma edge ($r/a = 1$), indicating the presence of both the internal transport barrier (ITB) and the edge transport barrier (H-mode). Stability analysis indicates that this plasma is marginally stable against the $n = 1$ kink-ballooning mode. This result, combined with previously obtained results on JT-60U, demonstrates that it is possible to ramp up the plasma, maintain high performance plasma in steady state, and ramp down the plasma in a controlled manner without using the CS coil.

In this experiment, noninductive ramp-up was limited in time by the coil operation limit, but in a reactor it should be possible to ramp up to higher currents by extending the duration of noninductive current ramp-up. Problems remaining to be solved include establishment of control methods applicable to autonomic burning plasmas with high bootstrap current fraction. In particular, it is crucial to develop a way to restore the burning condition after the plasma has lost stored energy due to a β collapse. It is also important to increase β_N further by profile control and active control, without compromising the bootstrap fraction or good confinement.

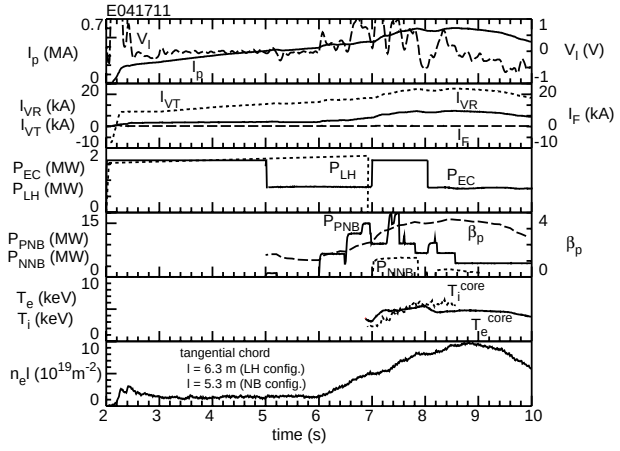

Fig. 1. Integrated scenario from plasma start-up to achievement of advanced tokamak plasma without the use of CS coil.