Non-inductive startup of overdense spherical tokamak by electron Bernstein waves with reduced trapped electrons

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Non-inductive start-up of spherical tokamak (ST) is one of the most important issues to realize a compact and economical ST-based fusion reactor. In the Low Aspect ratio Torus Experiment (LATE) device it has been shown that the start-up of spherical tokamak is possible solely by electron Bernstein (EB) waves, where the plasma current can be rapidly ramp-up as fast as ~260 kA/s which is comparable to the lower hybrid ramp-up rate [1]. It has been also shown that EB waves can also start-up and maintain an extremely overdence tokamak in which the electron density reaches as high as 7 times the plasma cutoff density [2]. In these experiments, however, trapped electrons were significantly developed in energy and density outside the last closed flux surface (LCFS) and they were lost to the vacuum vessel wall via pitch angle scatterings. The total loss of power amounts to ~70 percents of the injected microwave power, resulting in a severe degradation in the current drive efficiency.

To suppress the trapped electrons outside LCFS, a new bottom launcher has been installed on LATE as shown Fig. 1(f). The angle of the launcher is 15 degrees with respect to the vertical. The injection mode is O-mode for the mode-conversion to EB waves via the O-X-B mode conversion method. After the mode conversion the parallel refractive index of EB waves upshifts as the waves propagate inward when the waves are below midplane for the magnetic configuration of LATE.

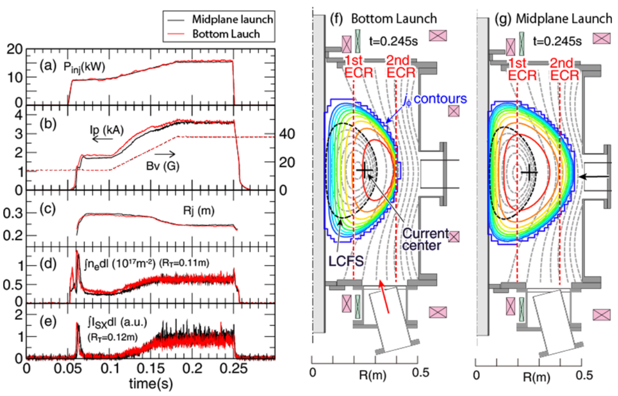

Figure1 Typical discharges for bottom (red) and midplane (black) injection. (a)-(e) time traces. (f), (g) current density (color) and poloidal flux contours (gray).

Figure 1 shows the typical discharges comparing the bottom (red) and the midplane outboard (black) microwave injection. When a microwave power of $P_{inj} \sim 8$ kW is injected under a weak B_v field of ~ 15 G, a plasma current is initiated and increases to ~ 2 kA, resulting in a formation of closed flux surfaces. The plasma current ramps up with ramps of the microwave power and the equilibrium B_v, and finally reaches $I_p \sim 3.6$ kA. The current is then maintained steadily until the end of the microwave pulse. The soft X-ray signal appears and increases with I_p as shown in Fig. 1(e), suggesting that the current is carried by EB-wave driven fast electron [1].

The plasma current for bottom injection is slightly higher than that for midplane injection throughout the discharge, suggesting an improved efficiency in current generation, although the difference in I_p is not large since the equilibrium vertical field strength B_v, which is pre-programmed, constrains I_p. Figures 1(f) and 1(g) show the current density and poloidal flux contours at t = 0.245 s estimated by the magnetic analysis [1] for bottom and midplane injection, respectively. The current distribution for midplane injection is significantly extended to the lower field side, indicating the development of trapped electrons outside the LCFS. On the other hand, they are suppressed for the bottom injection case.

The equilibrium pressure profiles are obtained using the equation for anisotropic pressure, $\boldsymbol{j} \times \boldsymbol{B} = \nabla \cdot \mathbf{P}$ ($\mathbf{P} = p_\perp \mathbf{I} + (p_\parallel - p_\perp)\boldsymbol{BB}/B^2$) and $\nabla \cdot \boldsymbol{j} = 0$, where $p_\parallel$ and $p_\perp$ are parallel and perpendicular pressure [1]. Figures 2(a) and (b) show radial profiles of $p_\parallel$ and $p_\perp$ on midplane. These indicates that the large $p_\perp$ region outside the LCFS is suppressed and, on the other hand, $p_\parallel$ near the magnetic axis increased in the case of bottom injection. Volume integrals of $p_\perp$ and $p_\parallel$ in the bottom injection case are 10 % lower and 20 % higher than those in the midplane injection, respectively. These indicates that trapped electons outside LCFS are suppressed and efficient development of current carrying passing electrons are realized.

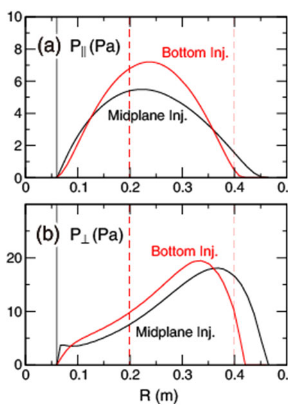

Figure2 (a), (b) Midplane profiles of $p_\parallel$ and $p_\perp$ for the plasmas at t = 0.245 s in Fig.1.

References

[1] M. Uchida *et al*., Phys. Rev. Lett. **104** 065001 (2010)
[2] M. Uchida *et al*, Proc. 24th Int. Conf on Fusion Energy 2012 IAEA-CN-197/EX/P6-