§51. Role of Energetic Electrons on Non-inductive Current Start-up and Formation of Inboard Poloidal Field Null Configuration in the Spherical Tokamak QUEST

Isobe, M., Tashima, S. (IGSES, Kyushu Univ.),
Zushi, H. (RIAM, Kyushu Univ.), Okamura, S.

Non-inductive plasma current startup using ECH has been conducted on several tokamaks and spherical tokamaks (STs). Recently, it has been suggested that I_p is generated by trapped particles in STs. In QUEST, a new startup scenario has been tested using ECH at a high toroidal magnetic mirror ratio M_{OMFC} of ~2 (=decay index $n^* \approx 0.5$) with high B_z and B_z/B_t of 10% at the fundamental resonance layer R_{res1}[1,2]. The increments of B_z and M_{OMFC} are favorable for trapped fast electron confinement. In these experiments, because of high β_p plasma, under high M_{OMFC} and ECW-driven current, the inboard poloidal null configurations are observed in steady state.

Next, we described the manner in which confined fast electrons contribute to electron pressure and plasma equilibrium through β_p using fast electrons effective temperature T_{HX} by measuring hard X-ray (HXR) energy spectrum. To study electrons in $v_\perp > v_{//}$, the measurement with vertical line of sight is conducted for different M_{OMFC} values. The relation between I_p and B_z is expressed as[3],

$$B_z=\mu_0 I_p(In(8R/a)+l_i/2-3/2+\beta_p)/4pR \qquad (1)$$

where l_i is the internal inductance. The effects of M_{OMFC} on $\beta_p=(\beta_p^{bulk}+\beta_p^{hot})$ is investigated. Relations between I_p and B_z are plotted in Fig. 1(a) for different M_{OMFC} values. The solid lines stand for time traces in the B_z-I_p space. The symbols correspond to steady state I_ps under constant B_zs. For M_{OMFC}=1.2, I_p increased linearly up to 5 kA as B_z increased to 1.7 mT, but it dropped to <1 kA at B_z>1.8 mT. On the other hand, at B_z ramp-up discharge, I_p reached 15 kA at 4 mT. These cases of B_z constant and ramp-up show the same proportional constant for M_{OMFC}=1.2. For M_{OMFC}=1.8, 2, and 2.7, a drop or saturation of I_p was not observed. In addition, the proportional constant of the I_p-B_z relation was maintained. For M_{OMFC}=1.2, 1.4, and 2, the inverse of proportional constants B_z/I_p was 0.3, 0.5, and 1 mT/kA, respectively, in steady state $I_p \approx 15$ kA. This suggests that stronger B_z is required to attain the same I_p as M_{OMFC} is increased up to 2. Fig. 1(b) to (e) shows the reconstructed closed flux surfaces for M_{OMFC}=1.2, 1.4, 1.8, and 2 at $I_p \approx 15 \pm 1$ kA taken at B_z=4.79, 8.47, and 15 mT, respectively. The plasma shown in Fig. 1(b) is noncircular, which is characterized by an elongation κ=1.14 and triangularity δ=0.24 with an aspect ratio A_p(=R_0=<a>=0.69 m/0.45 m) of 1.63, and Shafranov shift Δ=0.047. The value of β_p is evaluated as 0.64 from Eq. (1) with an assumption of internal inductance l_i=1.2 and the parabolic profile of I_p. A typical low-aspect-ratio ST was present. Fig. 1(c) shows the oblate shape with parameters <a>=0.2 m, R_0=0.73 m, A=2.9, κ=0.63, Δ=0.106, and β_p evaluated as 3.7. For Figs. 1(d) and (e), the poloidal field null points appear, which is caused by increase of β_p. Fig. 2 shows β_p and T_{HX} at $I_p \approx 15 \pm 1$ kA as a function of M_{OMFC}. T_{HX} is evaluated in the energy range of <200 keV, indicating that β_p and T_{HX} increased with M_{OMFC}. The high value of T_{HX} is probably due to the better confinement of fast electrons caused by the high M_{OMFC} and B_z configurations. Thereafter, the confined fast electrons contribute to the formation of high β_p plasma.

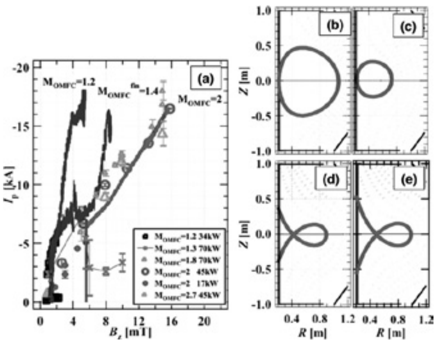

Fig. 1(a) I_p-B_z relations for M_{OMFC}=1.2, 1.3, 1.4, 1.8, 2, and 2.7. Poloidal flux contours for (b)M_{OMFC}=1.2, (c)M_{OMFC}=1.4, (d)M_{OMFC}=1.8, and (e)M_{OMFC}=2.

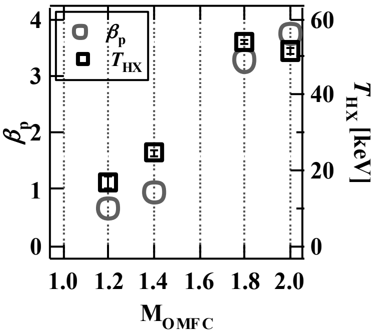

Fig. 2. β_p and T_{HX} as a function of M_{OMFC}.

In summary, to study the effects of fast electron confinement on β_p equilibrium, experiments with different confinement regimes of trapped particles were performed. The experiments indicated that stronger B_z is required for equilibrium at the same I_p values. Furthermore, the natural poloidal field null configuration, which is caused by high β_p, appeared as M_{OMFC} increased. The peak position of the radial profile of T_{HX} agrees with reconstructed magnetic flux surfaces.

1) Zushi, H. et al. : 24th IAEA Fusion Energy Conference, EX/P2-14 (2012).

2) Tashima, S. et al. : accepted for publication in Plasma and Fusion Res.

3) Shafranov, V.D. et al. : Reviews of Plasma Physics Vol. 2, (Consultants Bureau, New York, 1966).