§58. A Study of Plasma Start-up in Spherical Tokamak Devices

Ejiri, A., Takase, Y., Tojo, H., Oosako, T., Sugiyama, J. (Frontier Sci., Univ. Tokyo),
Torii, Y. (H. T. Plasma Ctr., Univ. Tokyo),
Hasegawa, M. (RIAM, Kyushu Univ.)

Key issues in spherical tokamak (ST) research are plasma current (I_p) start-up and formation of the ST configuration without the use of a central solenoid (ohmic coil). Successful I_p start-up, ST formation and sustainment have been achieved by injecting RF power (usually in the EC frequency range) to a configuration with a toroidal field and a weak vertical field. However, the current generation mechanism is still not clearly understood. In order to determine the mechanism experimentally, dependences on such parameters as EC wave polarization and vertical field configuration are studied. In addition to the EC source, a low frequency RF source (21MHz) was used, and ST configuration was sustained by a non-EC heating method for the first time.

TST-2 is a spherical tokamak with the following typical parameters: major radius R < 0.38 m, minor radius a < 0.25 m, aspect ratio A = R/a > 1.5, toroidal magnetic field B_t < 0.3 T, and plasma current I_p < 140 kA (inductive operation). Five poloidal field coil sets (PF1, PF2, PF3, PF4, PF5) are installed to produce various vertical field configurations. EC power (2.45 GHz, up to 5 kW) was injected from the low field side with O- or X- mode polarization. RF power (21 MHz, up to 30 kW) was injected using a loop antenna, which is normally used for exciting the high harmonic fast wave (HHFW). In the low density (~$1\text{x}10^{18}$ m^{-3}) ECH start-up plasmas, HHFW is evanescent, so no wave driven current is expected, but electrons could be heated by RF induction.

Figure 1 shows typical waveforms for ECH start-up discharges. Three phases can be identified: (i) the initial current formation phase, in which I_p increases gradually, (ii) the current jump phase, and (iii) the current sustainment phase. The current in the initial current formation phase is very small, and no closed flux surface is formed. In this phase, unidirectional toroidal precession of mirror trapped electrons is believed to contribute to the current. The current ramp-up rate depends on various parameters, and it should be high enough to induce a current jump within a practical time period. The experimentally obtained dependences can be represented by a power law scaling

$$\frac{dI_p}{dt} = C_{PF} \times \frac{P_{ECH}^{2.1}}{R_{ECH}^{2.4} p_{fill}^{1.0} B_Z^{0.4}},$$

where C_{PF} is a fitting parameter which depends on the vertical field configuration, and P_{ECH} (0.8-3.8 kW) is the net injected EC power. The major radius of the fundamental EC resonance layer R_{ECH} (0.33-0.53 m) is proportional to the toroidal field strength. p_{fill} (2.7-5.9x10^{-5}Torr) is the filling pressure (hydrogen or deuterium), and B_Z (0.17-1.02 mT) is the vertical field strength. No difference was found between O- and X-mode polarizations of the incident EC wave. This independence is believed to be the result of polarization randomization caused by multiple reflections from the vacuum vessel wall. C_{PF} for the PF1, PF12, PF2, and PF3 configurations with indices (i.e., $-\partial \ln B_Z/\partial \ln R$ at R=0.38 m) 1.1, 0.65, 0.61, and 0.06, respectively, is in the ratio 1 : 1.6 : 1.4 : 0.7. This ratio implies that a moderate mirror ratio is preferable to achieve the highest current ramp-up rate. The current and the current ramp-up rate for the PF3 configuration with very small index are similar in order to other PF configurations, contrary to the expectation based on mirror trapped electrons.

When I_p reaches a critical value, I_p shows an abrupt increase (current jump). The critical value increases with the vertical field strength, suggesting that the formation of closed flux surfaces causes the current jump. After a current jump, closed flux surfaces exist and I_p is sustained. The value of I_p is proportional to B_Z, but dependences on other parameters such as the injected EC power, EC wave polarization, and vertical field configuration are very weak. The ratio of I_p to B_Z is similar to those obtained in CDX-U, LATE and CPD, but is about 2.5 times lower than TST-2@K. In these experiments, contribution of EBWCD cannot be excluded because EBW is strongly absorbed. Figure 1 demonstrates that a similar I_p can be sustained by RF power at 21 MHz. As in the case of EC sustainment, I_p does not depend on the RF power as long as the power is larger than the threshold power, which is about 10 kW in this case. Note that the current jump was induced by the addition of RF power. These results demonstrate that a low frequency RF power can be used as an important and flexible tool for starting up ST plasmas.

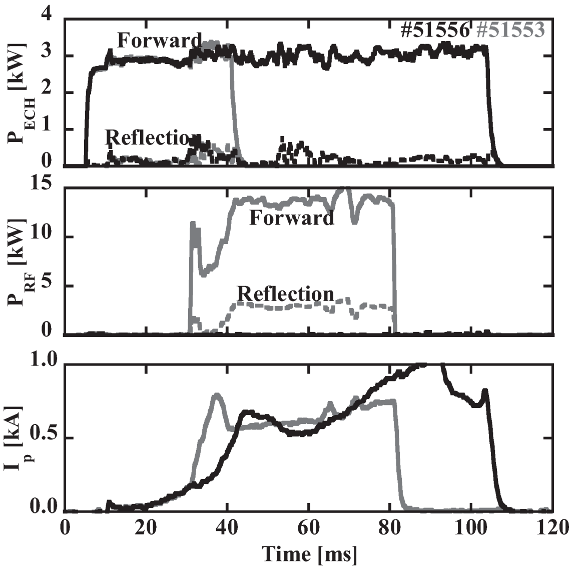

Fig.1 Time evolutions of ECH power, RF power and plasma current. Two discharges with RF (red) and without RF (black) are plotted.