§37. Fueling and Profile Control by Compact Toroid Injection on LHD

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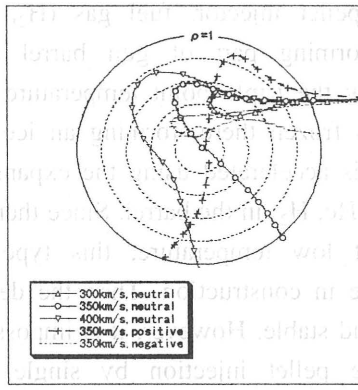
Compact Toroid Injection (CTI) is thought to be one of the ultimate fueling method on fusion plasma. This method utilizes a dense plasmoid called Compact Toroid (CT) generated as a spheromak. A spheromak is a magnetic configuration where both toroidal and poloidal magnetic fields are generated and sustained by the current flowing inside the spheromak itself. Usually, a CT is formed using co-axial magnetized plasma gun, and after the formation, it is accelerated to several hundreds of km/s of velocity before the injection using co-axial acceleration electrode. CTI experiments have been already carried out successfully on several tokamaks, although there is no example of CTI into helical plasma. The most important merit of CTI compared with other fueling methods such as gas-puffing or ice pellet injection is the possibility of the center fueling. This is due to its high kinetic energy. The largest force working on CT that is moving in magnetically confined plasma is the magnetic pressure on its surface and thus the magnetic pressure gradient pushes the CT out to the weaker magnetic field region. In this sense, the energy of the magnetic field eliminated from the volume of CT $B^2V_{CT}/(2\mu_0)$ gives a potential energy, and the kinetic energy $m_{CT}v_{CT}^2/2$ should be larger than the potential energy to inject the CT into the magnetic field of B. In a helical device, the magnetic field has three-dimensionally complicated nature, and thus the CT traces three-dimensional trajectory. This implies that the CT motion sometimes directs a tangential direction with the ambient magnetic field. In such a case, the large CT momentum might be transferred to the main plasma as CT decays. Using this, we are planning to induce the rotation of the main plasma, which is thought to be a fundamental of good confinement as shown in H-mode studies in tokamaks. In some cases, the CT trajectory is largely bent and one cannot achieve the center fueling nor the rotation induction by CTI. To avoid such a miss, one should carefully design the CT injector and choose proper position for setting up. So, we solve the equation of motion of a CT inside the LHD field starting from various points, while changing its initial velocity. The most favorable trajectory should pass nearby the plasma center, and to use the CT momentum effectively, we thought that the trajectory should align the magnetic field. From these points of view, we found some optimum points to set up the CT injector. Some of the CT trajectories injected from one of the optimum injection points are depicted in Fig. 1(a). The trajectories shown in the figure are the projection on a plane given by the normalized radius ρ and the poloidal angle θ of the orbits. We also tried to expect the density deposition profile given by a shot of CTI, and some of the results are shown in Fig.1(b). To calculate such an deposition profile, we assumed a simple model to describe the decay of CT. In the model, CT volume decays as $V_{CT} = V_{CT0}\exp(-t/\tau_{CT})$, where τ_{CT} is the life time of CT, and CT density is assumed to be constant. In our calculation, τ_{CT} is assumed to be 50 μ sec, which is the same order as the resistive decay time. Finally, we find out that the center fueling is possible with a CT with about 400km/s of initial velocity, 0.1mg mass and 0.001m³ volume in 1.5T standard magnetic configuration of LHD. And the deposition profile can be controlled almost arbitrary by changing the initial velocity of CT, without any modification of the injector.

(a)



(b)

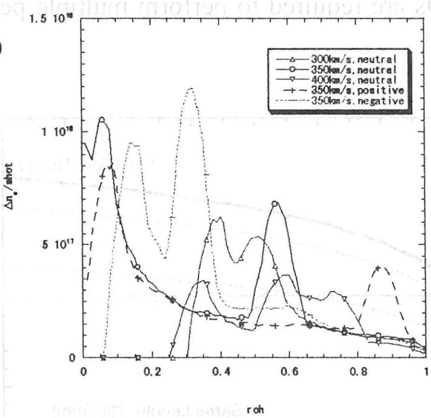


Fig. 1. (a) Examples of CT trajectories projected on x-y plane. These are calculated from the normalized radius ρ and poloidal angle θ. And (b) examples of the density deposition profile, obtained using flux surfaces approximated by ovals.