Effects of Multi-pulsing Coaxial Helicity Injection on Two-fluid Flowing Equilibrium Configurations of Spherical Torus Plasmas

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Solenoid-less non-inductive current start-up and steady-state current drive techniques in the spherical torus (ST) plasmas using the coaxial helicity injection (CHI) have been studied. Recently, a new approach of the CHI operated in multi-pulsing CHI (M-CHI) has been proposed [1]. The M-CHI scenario is that after the plasma current partially decays, a new CHI pulse is applied and the cycle process is repeated to achieve simultaneously a quasi-steady sustainment and good confinement. To explore the usefulness of the M-CHI for ST configurations, the double pulsing operations have been started in the HIST device, verifying the flux amplification and the formation of the closed flux surfaces after not only the first CHI pulse but also the second CHI pulse [2]. We have examined the dynamo electric field associated with the two-fluid effect to understand the sustainment mechanism by the CHI. The observed steep density gradient between the central open flux column (OFC) and closed flux regions causes not only the $\boldsymbol{E}\times\boldsymbol{B}$ drift but also the ion diamagnetic drift, leading the two-fluid effect and Hall dynamo. The purpose of this study is to investigate the effects of the steep density gradient on the two-fluid equilibrium configuration. The formalism for two-fluid flowing equilibria with non-uniform density has been developed [3]. This system is described by a pair of generalized Grad-Shafranov equations for ion and electron surface variables and a generalized Bernoulli equation for density. In order to solve this system, three arbitrary functions for each species are required to be assumed as functions of the surface variables so as to reflect the experimental data by choosing appropriate function forms. Under this assumption, we have numerically determined the ST equilibria by imposing the bias poloidal flux at the boundary, and using a successive over-relaxation method for updating the poloidal flux function and a Newton-Raphson method for updating the density [4]. We have obtained the following numerical results when the density gradient steepens between the OFC and closed flux regions. The toroidal magnetic field becomes from a diamagnetic to a paramagnetic profile in the closed flux region while it remains a diamagnetic profile in the OFC region. The toroidal ion flow velocity is increased from negative to positive values in the closed flux region, and the paramagnetic poloidal field is generated there. Here, the negative ion flow velocity is the opposite direction to the toroidal current. The poloidal ion flow velocity is increased between the OFC and closed flux regions, because the ion diamagnetic drift velocity is changed in the same direction as the $\boldsymbol{E}\times\boldsymbol{B}$ drift velocity through the steep ion pressure gradient. Also, the strong shear flow and the paramagnetic toroidal field are generated in the closed flux region. Here, the ion flow velocity is the same direction as the poloidal current. The raial electric field shear is enhanced between the OFC and closed flux regions due to the strong dependence on the Lorentz force through the interation of toroidal ion flow velocity and axial magnetic field. The two-fluid effect is significant there due to the ion diamagnetic effect.

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