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Effects of Magnetic Island Induced Symmetry Breaking on Plasma Confinement and Island Evolution in Tokamaks

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Magnetic islands exist in most tokamak discharges. The toroidal symmetry in $|\boldsymbol{B}|$ is broken when an island is embedded in the equilibrium magnetic field $\boldsymbol{B}$ in tokamaks [1]. Plasma confinement properties in the vicinity of an island are different from those in the region away from the island [2]. Interesting plasma confinement properties include, besides the usual particle and energy fluxes, the momentum transport and the bootstrap current. Here, we present a theory for plasma confinement improvement in snakes, and the effects of the island induced bootstrap current on island evolution.

A snake is a long lasting helical structure usually centered on the $q = 1$ surface with $m = n = 1$ observed in tokamak experiments [3], where q is the safety factor, m is the poloidal mode number, and n is the toroidal mode number. It is believed that this helical structure is a magnetic island. The particle confinement time in snakes can be of the order of the neoclassical value [4,5]. The theory for improved plasma confinement in snakes is developed based on the momentum transport process that results from the symmetry-breaking-induced plasma viscosity, and its consequences on the plasma confinement due to a combination of the turbulence suppression [6,7] and the effects of the orbit squeezing [8]. The mechanism is the same as the plasma confinement improvement in high confinement mode (H-mode) except that the momentum transport mechanism in a naturally occurred H-mode is dominated by the ion orbit loss [9], and in an electrode-induced H-mode by the electrode current [10]. The plasma flow speed and the radial electric field are calculated inside the island using plasma viscosity derived for a model suitable for an $m = 1$ island to illustrate plasma confinement improvement in snakes.

Besides improving plasma confinement in the vicinity of the island, symmetry breaking induced plasma viscosity also generates an additional bootstrap current density [11]. This island induced bootstrap current density has different collision frequency dependence from that of the standard neoclassical tokamak bootstrap current, and it modifies the island evolution equation. A theory is developed to include this island induced bootstrap current density in the island evolution equation for $m > 1$ islands. It is found that the island induced bootstrap current density has stabilizing influence on island stability for high poloidal beta β_p plasmas by imposing a lower limit on the absolute value of the tearing mode stability parameter $|\Delta'|$ for instability [12]. Here, β_p is the ratio of the plasma pressure to the poloidal magnetic field pressure. This may provide an alternative route to stabilize the islands.

We have developed a theory to describe improved plasma confinement in snakes in tokamak discharges, and a theory to include the effects of the island induced bootstrap current on island evolution. These theories can be tested in experiments. They can all be included in the modeling codes to simulate transport phenomena in existing tokamak experiments.

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