Spontaneous Toroidal Rotation, Flow Reversal, and Flow Sustainment in Non-Inductive Steady State Tokamak Plasma on QUEST

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Intrinsic toroidal rotation V_ϕ in fully non-inductive tokamak plasma driven by electron cyclotron waves(ECW) has been investigated. Doppler shift of line emissions from intrinsic impurities (CIII) and bulk ions (HeII) have been measured with a visible spectroscopy attached with a 25 channel fiber array viewing a plasma tangentially on the mid-plane. ECWs at 8.2GHz (<100kW) are injected from the low field side and are used to start-up and drive the non-inductive plasma current [1]. In this paper rotation measurements performed in a plasma, characterized by the natural divertor configuration with an inboard polloidal field null (IPN), will be presented. Typical plasma parameters are as follows; line density < 0.1-1.2 $\times 10^{18}$m^{-2}, Te ~ 50- 600 eV, Ip~10- 20 kA, B_{t0}=0.14T at R=0.6m, and $\varepsilon\beta_p$~1. Since the vertical field B_z(~10 % of B_t) was kept constant during the start-up and whole plasma duration, Ware pinch mechanism is excluded and there is no external momentum input. In order to interpret the observed line of sight profile $<V_\phi>$, a Gauss fitting procedure is used for the spectrum integrated the local Gaussian spectra locally determined by emissivity(intensity), V_ϕ(shift) , and ion temperature(width) along a line of sight.

Spontaneous toroidal rotation V_ϕ was clearly found during the current ramping-up phase (Ip~1-2 kA), namely in the open magnetic field configuration. The direction of rotation is only determined by the sign of B_z, which decides the direction of I_p. In this sense the rotation is in the co-current direction. The velocity increases with increasing B_z. In other magnetic configurations, for example, ohmic induction plasma at high B_z/B_t >10 % and non-inductive inboard limiter plasma at low B_z/B_t < 1 %, zero or small counter-current flow was seen. Topological effects of the magnetic field configuration on acceleration mechanisms for ions in co-direction will be discussed.

Co-current toroidal angular frequency Ω_ϕ (~30 krad/s) could be sustained during the whole plasma duration. In order to investigate the flow reversal mechanisms with respect to the density, intense puff was injected from the inboard side towards the null point. As the density increases up to 1.2 $\times 10^{18}$m^{-2} within 15 msec, it decays within 0.1 sec quickly and then 0.2-0.4 $\times 10^{18}$m^{-2} is decreased gradually. During this phase the flow is reversed in the counter current direction near the inboard edge, but within 0.1-0.2 sec it is recovered in the co-direction. Based on the details of Ω_ϕ(R,t) and SOL flows plausible mechanisms will be discussed.

It is an important task to sustain the intrinsic rotation in steady state. This was demonstrated in steady state IPN plasma lasting for 600 sec. The plasma current (~16 kA) and density 2 $\times 10^{17}$m^{-2}could be feedback controlled by repetition of pulse puff to keep the recycling flux constant. It could be demonstrated that co-current $<V_\phi>$ of 20 km/s near the plasma center and poloidal rotation of ~1km/s in the ion-diamagnetic direction are sustained. The effects of particle fueling on the rotation profile will be discussed.

[1] S. Tashima, et al., Nucl. Fusion **54** (2014) 023010,