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Investigation of Plasma Rotation in Open Magnetic Field Line Configuration in QUEST

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Intrinsic plasma rotation in slab annular plasma with open magnetic field configuration is investigated using Doppler shift spectroscopy of bulk and low mass impurity ions in the spherical tokamak QUEST. Slab plasma with open magnetic field configuration is produced with 8.2 GHz ECRH at the fundamental resonance. Magnetic mirror ratio is varied in this slab configuration with the help of 4 pairs of poloidal field (PF) coils. Toroidal rotation measurements are done with 25 channel fiber array based 1 m grating spectrometer system. Strong toroidal rotation with velocities up to 9 km/s are observed in various magnetic topology and their origin and evolution will be reported in this paper.

1. Introduction

Plasma rotation have many beneficial effects on plasma stability and confinement. For example, a strong shear in the plasma rotation is widely believed to be a key factor [1] for regulation of instabilities, turbulence suppression, the formation of transport barriers and divertor heat flux, which are considered as promising candidates for fusion reactor operation regimes in a non inductive current drive state. Strong plasma rotation is mainly driven by Neutral Beams Injection (NBI) heating, which provides a significant external momentum source. However, in ITER and fusion reactor, NBI is not expected to provide much external momentum partly due to the required high injection energy. Consequently, it is of interest to consider other mechanisms leading to plasma rotation, as those underlying the intriguing so-called "intrinsic" plasma rotation, where no or a little external torque is applied, reported by several tokamak experiments, e.g. in JET, Alcator C-Mod and Tore Supra. In order to utilize such intrinsic rotation property of plasma for the beneficial of a fusion grade reactor, one must understand the origin and external controlling parameters of this spontaneous rotation. Several mechanisms are cited to drive these flows like toroidal rotation, ionization imbalances, Pfirsch-Schluter (PS) flow, cross-field drift and ballooning transport initiated by NBI, ICRH or magnetic perturbation. In this paper we however, report spontaneous rotation of plasma by Electron Cyclotron (EC) waves injection under specific magnetic configuration and in open magnetic field line configuration. The rotation profile is measured with the passive Doppler spectroscopy of impurity and bulk ions.

The paper is organized as follows: Device description and along with diagnostics is given in section 2. Section 3 gives toroidal rotation measurements at different magnetic field curvature and section 4 accounts for rotation profile evolution under different PF coil current and toroidal field strength. Section 4 concludes the paper.

2. Experimental Device and Diagnostics

QUEST [2] is a medium sized spherical tokamak with the major and minor radii of 0.68 and 0.4 m, respectively. The center stack (CS), which holds the Ohmic (OH) coil has an outer diameter of 0.2 m and the outer wall of the vacuum vessel is at R_{out} = 1.4 m with the flat divertor plates at z ~ ± 1 m from the mid-plane. Inboard plasma boundary is defined by a set of water cooled tungsten limiters on the CS at R_{cs} = 0.22 m. Working gas is either Hydrogen or Helium or both supplied from electrically controlled piezo valves located on the CS or the outboard side. Plasma is initiated by fully non-inductive EC by applying high vertical field [3] (B_z/B_t ~ 0.1). Under favorable magnetic geometry, energetic electrons generated by EC interaction are well confined and constitute majority part of the plasma current (I_p).

Plasma rotation is measured by a set of 25 channel fiber array installed at the low field side mid-plane port of the vacuum vessel, which collects plasma emission over the visible spectrum generated by majority impurity (CIII) or bulk ions (HeII). The visible light is carried by the fiber bundle to a 1 m grating spectrometer. A 512 x 2028 CCD detector records the line shape of emission which is acquired by the attached computer for further analysis. Doppler shifted line wavelength (λ_s) is compared with un-shifted line (λ_0) determined from standard lamps calibration as well as cold ECR plasma formed using EC systems at B_z = 0, I_p = 0. Ion velocity is calculated from $v= c\ (\lambda_s - \lambda_0)/\ \lambda_0$, c is velocity of light.

3. Spontaneous Rotation in Open field lines

Spontaneous toroidal rotation is observed during the breakdown phase of IPN plasma as well as in the flat-top of the I_p. Two different types of Bz are applied to study the rotation behavior during start-up and flat-top phase of the discharge. Four pairs of Poloidal magnetic Field (PF) coils generate different curvatures of field lines that are characterized by magnetic mirror ratio $M = Bt_{\mathrm{start}}/Bt_{\mathrm{end}}$, along a field line. With low M = 1.2, plasma configuration attains a inboard limiter (IL) state, while at M > 2, plasma boundary becomes Inboard Poloidal field Null [4] (IPN). Figure 1 shows radial profiles of line of sight toroidal rotation velocity (V_ϕ) of CIII for these two discharges at t = 1.5 s. With almost similar I_p = 1 kA

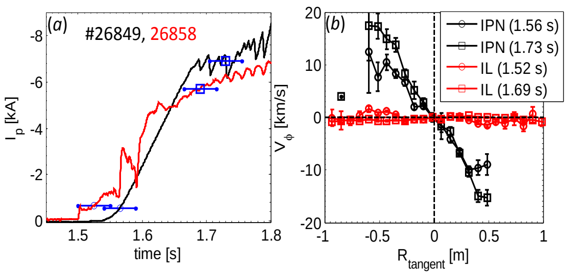

Fig. 1: Plasma current (I_p) and rotation (V_ϕ) evolution in time for two mirror ratio plasma discharge is shown. Finite rotation is observed in IL plasma.

low M start-up plasma absolutely does not rotate while, high M start up rotate, plasma is found to rotate along co-current direction. V_ϕ increases with increase in I_p

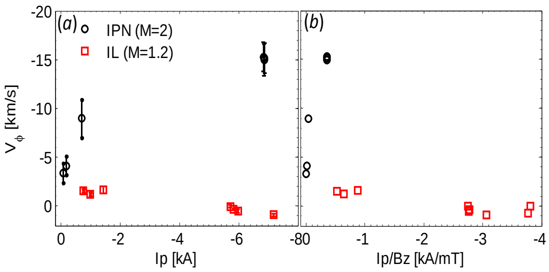

Fig. 2 : $V_\phi \sim I_p$ and $V_\phi \sim I_p\ /B_z$ relation is shown for two type of plasma IL and IPN under different M = 1.2 and 2 respectively.

for high M plasma, which eventually attains IPN configuration with formation of closed flux surfaces I_p > 5 kA with a stable co-current rotation. However, in fully open magnetic field line configuration where I_p < 1 kA, V_ϕ up to 9 km/s is obtained. In the above discharges, generally high B_z = 20 mT is applied in IPN plasma start-up as compared to B_z = 8 mT in IL start-up. Figure 2 shows ($V_\phi \sim I_p$) and ($V_\phi \sim I_p\ /B_z$) relationship from two sets of discharges at M = 1.2 and 2. It shows V_ϕ increases with I_p for M = 2 configuration, whereas, it remains less than ± 2 km/s for M = 1.2 case. From fig 2 (b) it is clear that at similar $I_p\ /B_z$ = -0.5 kA/mT, only IPN plasma generated by high M, which is in turn high curvature, generates spontaneous plasma rotation in steady state.

4. Spontaneous Rotation at different B_t

In this set of experiments, spontaneous rotation during start up at different toroidal field (B_t) is investigated. Figure 3 shows rotation profile at Bt = 50 and 30 kA, corresponding to fundamental resonance location R_{fce} = 0.52 m and 0.32 m respectively. PF coil current (PF352) is varied at 0.2, 0.5 and 1 kA range. It can be seen that at low PF352 = 0.1 kA, V_ϕ is in counter current direction and as it is varied, V_ϕ increases gradually to have an maxima at R_{tan} = 0.6 m, close to R_{fce}. At B_t = 30 kA, this peak is slightly shifted inward corresponding to inboard shift of R_{fce}. This indicates the high density slab plasma created at Rfce and applied Bz facilitates toroidal rotations along the connecting field lines. The rotation which is generated during this phase is found to be sustained in steadystate as the plasma current is fully evolved.

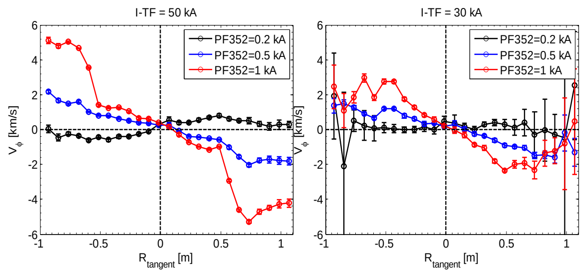

Fig. 4: V_ϕ at R_{tan} = 0.7 m and t = 4 s in flattop of IPN discharges at M =2 is shown for different B_z and resulting I_p.

5. Conclusions

Spontaneous toroidal rotation is observed in QUEST under high magnetic curvature and found to be proportional to applied field strength, thus external controls for intrinsic rotation is identified successfully. The rotation is always in co-current direction and sustained in steadystate without any external momentum input.

References

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