§83. Origin of Intrinsic Rotation and Physics of Rotation Reversal in Non-inductive Plasma

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Spontaneous toroidal rotation of plasma is observed in the spherical tokamak QUEST with the help of ECRH and without the use of any externally injected momentum. Several vertical magnetic field (B_z) configurations with varying mirror ratio (M) (a measure of field curvature) are applied and evolution of rotation is studied with the help of Doppler spectroscopy of bulk and impurity ions. Significant toroidal rotation ($V_\phi \sim 6$ km/s) is initiated in the open magnetic field configuration during the initial plasma breakdown phase, which is later sustained ($V_\phi \sim 20$ km/s) in a closed magnetic field configuration in the steady state [1]. Rotation velocity is primarily along the co-current direction and is found to be proportional to the B_z strength and the resulting plasma current. High M and B_z are demonstrated to be the two specific external controls by which, rotation can be initiated in plasma. Rotation is in open field lines is found to be initiated at the ECR resonance layer in slab-like plasma, which is evolved to produce a sustained rotation in the natural divertor IPN equilibrium in QUEST [2]. Mirror ratio, which can be set by different combination of PF coils are crucial in QUEST plasma operation. A high M utilizes a larger portion of effectively trapped energetic electrons to enhance plasma nonthermal pressure sufficient enough to encounter an equilibrium poloidal beta limit. Due to the equilibrium limit, plasma manifests into an unique natural inboard divertor configuration called Inboard Poloidal field Null (IPN)[1]. However at lower M, plasma remains in an inboard limiter (IL) configuration. Therefore, to study the effect of configuration arising from different M, plasmas are created with different sets of PF coils to produce M = 1.2 and 2. Figure 1 shows comparison of such plasma discharges and corresponding rotation profiles for the two different M. The corresponding profiles of V_ϕ are shown for the two discrete times in figure 1b. It is rather distinctly observed that V_ϕ for low M (IL) configuration is nonsignificant, whereas, it is prominent along the co-current direction for the high M (IPN) configuration.

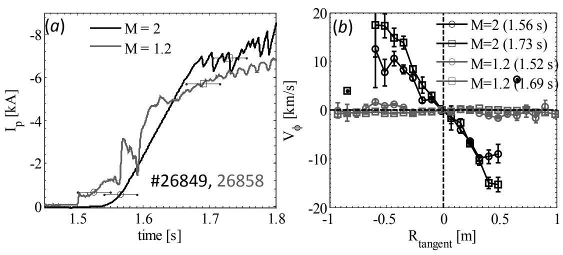

Fig. 1. Plasma current (Ip) and rotation ($V\varphi$) evolution in time for two most similar plasma discharges at two different times are shown. The red traces represent the discharge at M = 1.2 (IL plasma) and the black traces represent the discharge at M = 2 (IPN plasma). Spectrometer exposure time is shown as the horizontal bars on the Ip traces. Finite rotation is observed only in the IPN plasma. The error bars on $V\varphi$ traces show 95% confidence level in Gaussian fittings of the raw line spectra.

In pure slab plasma without B_z no rotation is seen. With increment in puff and thereby density, I_p starts to decrease and finally goes to zero at a finite B_z. This plasma we call Slab like plasma, where the vertically elongated ECR plasma can be seen clearly in a visible camera. In this plasma case, no closed magnetic field line exists and the field lines are open. Rotation measurement is done in this slab like plasma and is shown in figure 2.

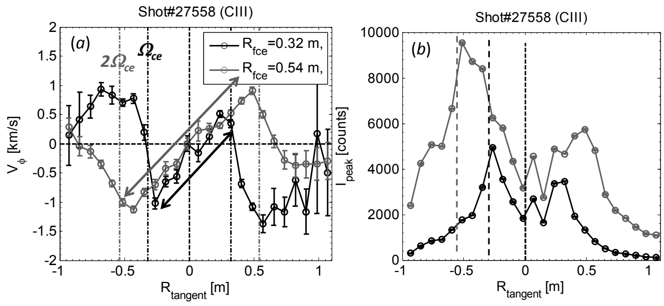

Fig. 2. (a) Toroidal rotation (V_ϕ) profile in Slab like plasma at two different EC resonance (R_{fce}) locations. The pivot point, where V_ϕ changes slope has a very good correspondence with R_{fce} (b) CIII line Intensity profiles for the same discharge are shown. The peak intensity also coincides with R_{fce} .

It shows a finite bidirectional V_ϕ directed counter-current inside the ECR layer and along co-current direction outside it.Fig. 2 shows a comparison of V_ϕ at B_z = 5 mT and at two different ECR locations namely, R_{fce} = 0.32 and 0.54 m. It can be seen that the line intensity peaks close to R_{fce} location, which actually corresponds to the ECR layer. The position at which V_ϕ changes its slope also follows the ECR layer.

In conclusion, intrinsic rotation in a pure EC driven non-inductive tokamak plasma without any external momentum injection is observed. The rotation is predominantly in the toroidal direction and up to a 20 km/s velocity measured. Rotation is found to be dependent on the magnetic field geometry and equilibrium configuration. It is found that high mirror ratio is favorable for rotation in IPN configuration and its magnitude is proportional to B_z. Rotation is predominantly in co-current direction and flips with the direction of plasma current. Rotation is found to be present even in a simple slab ECR plasma with open magnetic field geometry and originate at the resonance layer.

[1] K. Mishra, NF **55**, 083009, 2015
[2] K. Mishra, IEEE transaction on plasma science 44 441-447 (2016)