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Spontaneous rotation, flow reversal, and flow sustainment in non-inductive QUEST plasma QUEST
非誘導プラズマにおける自発回転誘起、回転反転、長時間回転維持に関する研究

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In non-inductive tokamak plasma driven by electron cyclotron waves (ECWs) toroidal and poloidal flows were investigated without momentum source. Using line spectra from both intrinsic impurity CIII and primary ion HeII flow velocity is decided along the line of sight. The intrinsic toroidal flow is found to be driven by ECWs depending on the vertical Bz and curved poloidal field. In a natural divertor configuration with an inboard poloidal field null IPN, the toroidal flow of 20 km/s is in co-current direction but in other ohmic and inboard limiter NI plasmas almost zero or small in the counter current. Depending on the particle source rate, the flow reversal and flow modulation are clearly seen.

Intrinsic toroidal rotation V_ϕ in fully non-inductive tokamak plasma driven by electron cyclotron waves (ECW) has been investigated [1,2]. 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, as shown in Fig.1. 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)[3,4], will be presented. Typical plasma parameters are as follows; line density < 0.1-1.2 $\times 10^{18}\mathrm{m}^{-2}$, T_e ~ 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 $V_\phi^{LOS} = c\dfrac{\Delta\lambda_p^{LOS}}{\lambda_0}$, a Gauss fitting procedure is used for the observed spectrum integrated the local Gaussian spectra locally determined by emissivity ($\varepsilon(r)$), V_ϕ($\propto \lambda - \lambda_p(r)$), and ion temperature($\propto \sigma(r)$) along a line of sight.

$$I_{chord}(\lambda) = \int \varepsilon(r)\frac{1}{\sqrt{2\pi\sigma^2}}\exp\left(-\frac{(\lambda-\lambda_p(r))^2}{2\sigma^2(r)}\right)dl$$

$$\approx \bar{\varepsilon}_{chord}\frac{1}{\sqrt{2\pi\bar{\sigma}^2}}\exp\left(-\frac{(\lambda-\bar{\lambda}_p)^2}{2\bar{\sigma}^2}\right)$$

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, as shown in Fig. 2. 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 noninductive inboard limiter plasma at low

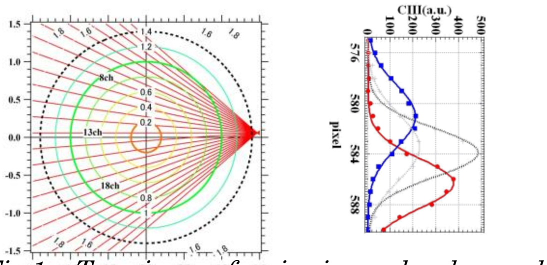

Fig.1 Top-view of viewing chords and observed spectra along opposite chords.

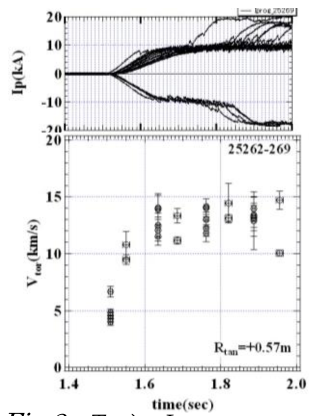

Fig.2 Top) Ip start-up , bottom) toroidal flow velocity at R_{tan}=0.57m

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

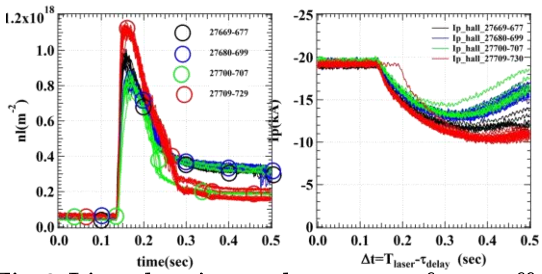

Fig.3 Line density and current after puff at t=0.135 sec.

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 0.2-0.4 $\times 10^{18} m^{-2}$ within 0.1 sec quickly and then is decreased gradually. Ip decays immediately by 5-10 kA, and then recovers to the pre-puff level with a few seconds. Although $\langle V_\phi \rangle$ at the Ip start-up phase is co-current, it seems that $\langle V_\phi \rangle$ reverses in counter-current direction in the very low density before puff. When the puff is done the flow tends to be reversed in the co-current direction within 0.1-0.2 sec. Based on the details of $\Omega_\phi(R,t)$ and SOL flows plausible mechanisms will be discussed.

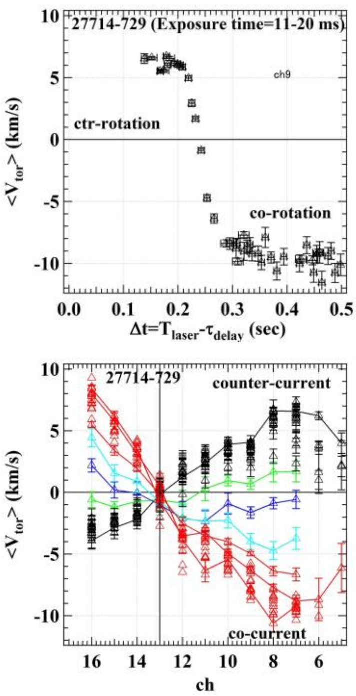

Fig. 4 (a) Flow reversal during the density decay phase at ch9, (b) tangential chord profile during the flow reversal. The chord 13 views plasma perpendicularly.

It is an important task to sustain the intrinsic rotation in steady state [5]. 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 $\langle V_\phi \rangle$ 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.

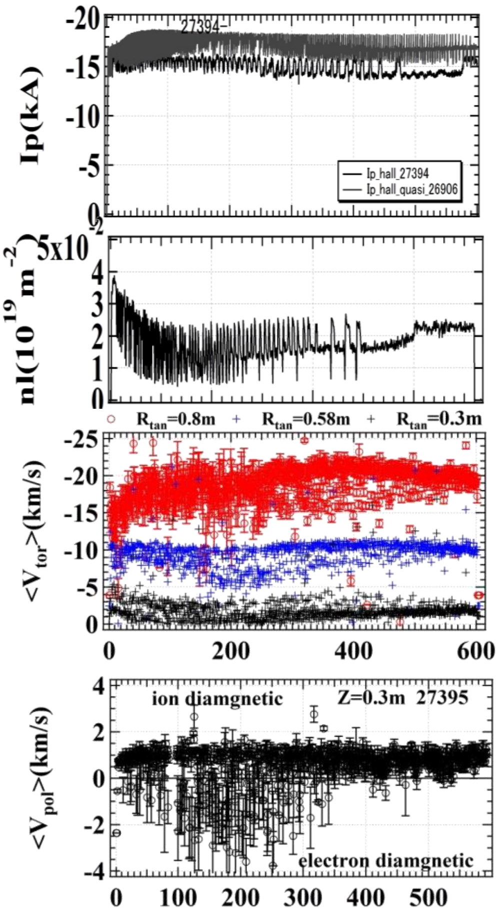

Fig. 5 Top-bottom Ip,nl,$V_{toroidal}$,$V_{poloidal}$ in steady state plasma. Ip and nl are modulated by series of puff.

References

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