Transition to helical RFP state and associated change in magnetic stochasticity in a low-aspect-ratio RFP

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Recent progress in RFP research has demonstrated that an RFP state where a single helical mode dominates the plasma dynamics can lead to improved confinement, as Quasi-Single Helicity (QSH) or Single Helical Axis (SHAx) state in RFX. The confinement improvement is attributed to the recovery of magnetic flux surfaces (magnetic chaos healing) in otherwise stochastic core region. In fact, it has been shown that the electron temperature profile has much steep gradient in the core region in QSH or SHAx RFP states in RFX. Similar steeper temperature gradient has also been observed in MST RFP where improved confinement has been achieved by current profile control using the pulsed poloidal current drive (PPCD) for tearing mode stabilization and subsequent suppression of magnetic chaos in the core region.

In a small low-aspect-ratio RFP machine RELAX (R/a = 0.5m/0.25m, I_p <100kA)[1], we have observed easier transition of the magnetic configuration to QSH whose duration might depend on the characteristic time of dissipation in standard low-A RFP plasmas[2]. Moreover, it has been shown that the dependence of the m=1 magnetic fluctuation amplitudes increases as the field reversal parameter F approaches toward 0 (non-reversed discharge), where F ($=B_\varphi(a)/\langle B_\varphi \rangle$) is the ratio of the edge toroidal field to the average toroidal field. More interestingly, the amplitudes grow largely when the RFP discharge is operated near the boundary of the field reversal, F~0.

In high amplitude region, radial profile measurements of the magnetic fields (B_r, B_θ, B_φ) with an array of magnetic probes inserted to the magnetic axis has revealed transition to helical RFP state[3]; The profiles of both the axisymmetric and m=1 asymmetric (fluctuating) components have shown good agreement with those predicted by the Helical Ohmic Equilibrium state, where m=1 helical RFP configuration can be sustained Ohmically without magnetic stochasticity. High-speed camera diagnostic has revealed a toroidally rotating simple helicat structure with helicity of m=1/n=-4 (core resonant). In addition, an imaging diagnostic with soft-X ray (SXR) pin-hole camera has shown that the similar helical structure can be identified in the SXR wavelength region. Another SXR diagnostic of multi-chord SXR emissivity measurement using AXUV detector arrays together with thin-foil aluminum absorber has revealed time evolution of asymmetric SXR emissivity profile, an indication of rotating asymmetrix structure. The SXR emissivity profile has a substantial gradient, which may be an indication of avoidance of magnetic chaos in the helical RFP state in RELAX.

In RELAX, however, the amplitudes of the neighboring modes are not negligible in the observed helical RFP state. It is therefore quite important to investigate magnetic stochasticity both in QSH and helical RFP state using the measured spectrum of magnetic fluctuations. It is also important to study magnetic chaos in standard deep reversal discharges, where the edge magnetic fluctuation level can be reduced to ~1%. Investigation on magnetic stochasticity has been initiated by running a numerical code for field line tracing using the measured mode spectrum. The complexity in low-*A* RFP configuration can be attributed to two aspects, one is the necessity of 3-D equilibrium profile, and the other is related to reconstruction of eigenfunctions of the tearing modes in 3-D magnetic geometry. The resistive wall boundary condition in RELAX may bring about additional difficulty.

Magnetic field line trace using ORBIT code has provided some preliminary results; In deep-reversal discharges in RELAX, magnetic surfaces remain undestroyed in the core region ($r/a<0.2$) for the experimentally observed magnetic fluctuation amplitudes, mainly because of the equilibrium profile of deep-recersal RFP. In deep-reversal case, the innermost resonant surface is $q=0.2$ at $r/a\sim0.4$, resonance to dominant $m=1/n=4$ mode being avoided. In helical RFP configurations, a bean-shaped magnetic island-like structure has been identified.

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[2] R. Ikezoe et al., Plasma and Fusion Research **3**, 029 (2008).

[3] K. Oki et al., J. Phys. Soc. Jpn. **77**, 075005 (2008).