# §3. Fast-Ion Loss due to Externally Applied Magnetic Perturbation in Large Helical Device

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One of the issues in the fusion device is controlling a heat load to a first wall or a divertor to the acceptable level. Reduction of divertor heat load due to edge localize modes (ELMs) has been demonstrated by application of externally applied static magnetic perturbations (MPs) in tokamaks and helical/stellarator [1-2]. Such MPs may increase a local heat load of fast ion to the first wall because they break the symmetry of a magnetic field.

Three-tangentially injected high-energy (up to 180 keV) neutral beam injections (NBIs) are equipped with LHD. Those high-power NBIs generate the fast ions in the LHD plasmas. Externally applied static MPs are generated by ten pairs of so called local island divertor coils equipped outside the vacuum vessel of LHD. We use a scintillator-based lost-fast ion probe (SLIP) to measure fast-ion losses in these experiments. A SLIP works as a magnetic spectrometer providing energy ($E$) and pitch angle ($\chi$) of lost-fast ion, simultaneously. Illumination images are captured with an image-intensified (I.I.) CMOS camera and detected a 4x4 photomultiplier tube (PMT) array.

Experiments are performed in the magnetic configuration with toroidal magnetic field strength ($Bt$) of 0.9 T and the preset magnetic axis position ($Rax$) of 3.60 m. Figure 1 shows time evolutions of absorbed power of NB ($P_{\mathrm{NBabs}}$), $T_{\mathrm{e}}$ at the plasma center ($T_{\mathrm{e0}}$), volume averaged plasma beta ($<\beta_{\mathrm{dia}}>$) and $<n_{\mathrm{e}}>$ in discharge with static MPs (Fig. 1 a) and without static MPs (Fig. 1 b). Note that there is no significant difference on global parameters ($T_{\mathrm{e0}}$, $<\beta_{\mathrm{dia}}>$ and $<n_{\mathrm{e}}>$) of a plasma in these discharges because the amplitude of an MP is not large enough to affect global confinement of plasma; radial field strength of static MP on the magnetic axis position is about $10^{-3}$ T. No static MP is applied in a shot number of 102960 whereas in a shot number of 102963, static MP having the constant amplitude is applied through the discharge. Figure 2 shows the time evolution of fast-ion loss measured with a PMT. With static MP, fast-ion-loss signal measured by the SLIP having $E/\chi$ of 70~180 keV/55~70 degrees increases by a one hundred percent, whereas fast-ions-loss-rate to the SLIP having energy/pitch angle range of 70~180 keV/20~40 degrees increases by fifty percent with MP.

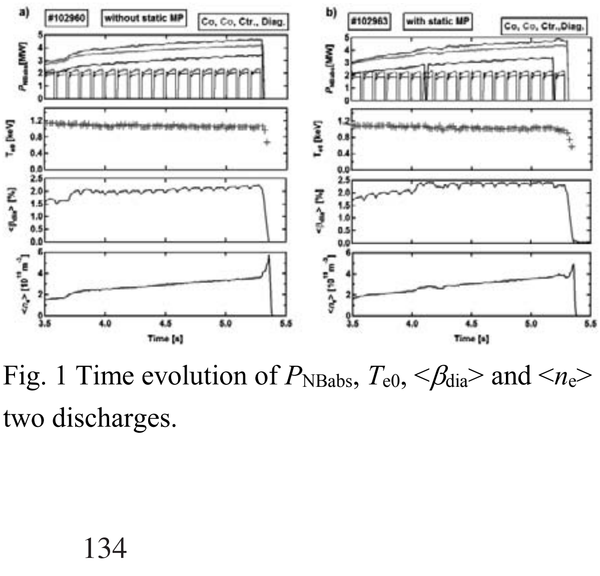


Fig. 1 Time evolution of $P_{\mathrm{NBabs}}$, $T_{\mathrm{e0}}$, $<\beta_{\mathrm{dia}}>$ and $<n_{\mathrm{e}}>$ in two discharges.

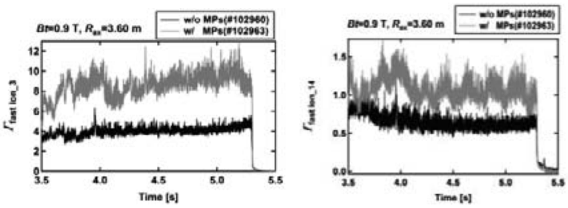


Fig. 2 Time evolution of fast-ion-loss signal measured by SLIP.

To understand how such a small-static MP affects a fast-ion orbit, the Lorentz orbit of fast ions is compared under condition of with and without the static MPs. In this calculation, the Lorentz force equation for a charged particle's motion is solved using 6th-order-Runge-Kutta methods in the LHD magnetic field in the Cartesian coordinates. According to experimental observation $E/\chi$ of 80 keV/25 degrees and 80 keV/60 degrees are chosen. The Poincare plot of the Lorentz orbits shown in Fig. 3. Due to MP, the orbit of a co-going and transition ion moves to the larger-minor-radius region of plasma. Here, width of Poincaré plot corresponds to a Larmor diameter (~12 cm) in without static MP case, however, in with a static MP case, width of Poincaré plot is larger than Larmor diameter. It means that the orbit becomes stochastic due to static MP. For transition ion, new bounce positions are appearing due to static MP. These effects potentially enhance the transport or loss of fast ion, so fast-ion-loss measured by SLIP can be increased by such a small-static MP.

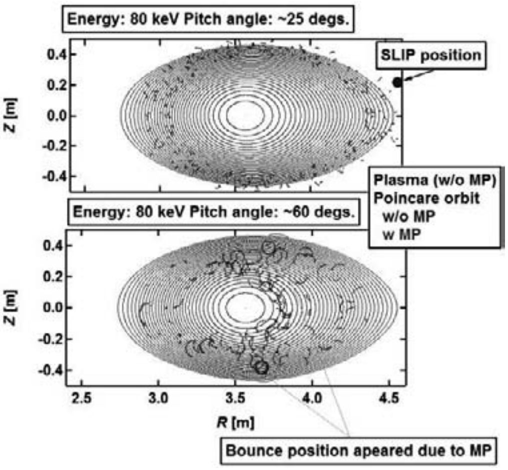


Fig.3 Poincaré plots of Lorentz orbit of a fast ion with and without MPs

1) Evans, T. et al.: Phys. Rev. Lett. **92** (2004) 235003.
2) Toi K., et al.: Nucl. Fusion **54** (2014) 033001.