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Studies of MHD-induced Fast-ion Loss By Means Of Faraday-cup-type Lost Fast-ion Probe in Heliotron J Plasmas

ヘリオトロンJプラズマにおけるファラデーカップ型
損失高速イオンプローブ計測を用いた
MHD不安定性起因の高速イオン損失の解析

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The objective of our study is to clarify the physical mechanism of interaction between fast-ion and fast-ion-driven magnetohydrodynamic (MHD) instabilities in Heliotron J plasmas. We developed a Faraday-cup-type lost fast-ion probe (FLIP) to detect the lost fast-ions induced by MHD instabilities. Information including both the energy and the pitch angle of the lost fast ions is obtained simultaneously by using the FLIP. The detected lost fast-ions have energy close to the injection energy of neutral beams (E_b), and pitch angles of 100° ~110° . Comparison between experimental results and full-orbit calculations indicates that the lost fast-ions come from the plasma edge region.

1. Introduction

In order to achieve a fusion reactor, the good confinement of alpha particles is required because the alpha particles must sustain the ignited plasma by itself. The confinement and loss of fast ions including alpha particles are being extensively studied in many tokamaks and helical systems. In our study, we focus on the effect of magnetohydrodynamic (MHD) instabilities, especially fast-ion-driven MHD instabilities, on the confinement and loss of fast ions. We developed and installed a Faraday-cup-type lost fast-ion probe (FLIP), which can directly measure the energy and the pitch angle of lost fast-ions with high time resolution, on Heliotron J. In this paper, FLIP system, experimental results and comparison with orbit calculations are described.

2. Experimental Setup

Figure 1 shows the position of FLIP together with the poloidal cross section of flux surfaces of Heliotron J plasma. FLIP can be inserted into the vacuum chamber of Heliotron J and adjusted to locate just outside the last closed flux surface (LCFS) of each magnetic configuration. The photograph and schematic drawing of inner structure of FLIP are shown in Figs. 2 (a) and (b), respectively. The FLIP has eight thin aluminum (Al) foils as electrodes to detect lost fast-ions covered with a molybdenum (Mo) box having double apertures to sort out ions, as shown in Fig. 2

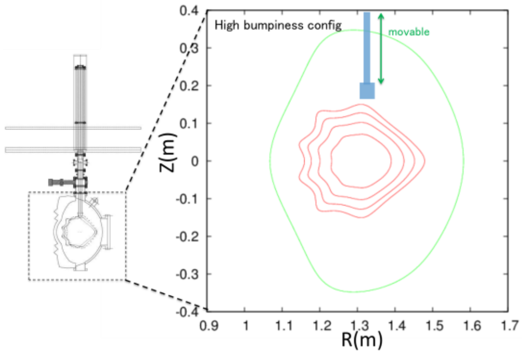

Fig.1. Schematic drawing of the FLIP position and flux surface in the poloidal cross section of Heliotron J plasmas. FLIP is located just outside of the last closed flux surface to effectively detect lost ions.

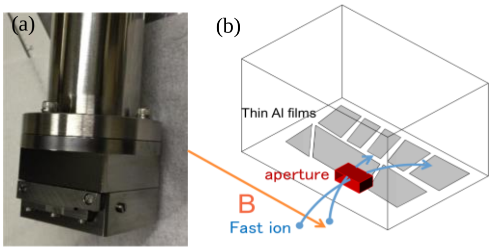

Fig.2. (a): Photograph of the FLIP head, (b): Schematic figure of FLIP structure.

(b). Fast ions enter the FLIP through the double apertures and hit the Al foils. The strike positions of lost fast-ions are determined by both the Larmor radius and the pitch angle. Each Al foil can collect fast ions having a certain range of energy and pitch angle simultaneously, and then we can get the information of lost fast-ions. The previous research shows that fast-ion-driven MHD instabilities with intense fluctuations are destabilized by co-going fast ions [1, 2]. Therefore, we focus on the detection of co-going fast-ions which can resonantly couple with shear Alfvén wave.

3. Experimental Results and Discussion

The lost fast-ions in the plasma which were initiated by electron cyclotron heating (ECH) and heated by both ECH and neutral beam injectors (NBIs) were measured. Figure 3 shows time evolution of magnetic fluctuations, power spectrum density of magnetic fluctuations, FLIP ch.B signal (the detectable range of energy is 20~55keV, the range of pitch angle is 100° ~110°), and FLIP ch.F signal (the detectable range of energy is about 4~20keV, the range of pitch angle is 90° ~110°). Two NBs whose energies respectively are 27keV and 24keV for co- and ctr.-injector are tangentially injected into ECH plasma. The increases of FLIP signals were observed just after co.-NBI turned on at 180ms. These increases of observed signals of FLIP ch.B and ch.F indicate the detection of direct orbit loss of trapped ions and re-entering passing ions. We also observed bursting magnetic fluctuations corresponding to the fast-ion-driven MHD instabilities during NBI heating. The timing of appearance of spiky signals in FLIP ch.B synchronizes with that of bursting MHD instabilities, as shown in Figs. 3 (b) and (c). FLIP ch.B could detect the lost fast-ions having the energy (E) in the range of 20~E~55 keV and pitch angle of 100° ~110° .

We calculated the full orbit of lost fast-ion which was detected by FLIP in vacuum for the purpose of the investigation of physical mechanism of lost fast-ions, as shown in Figure 4. Figure 4 shows the fast-ion orbit having the energy of 20keV, pitch angle of 110° in blue, flux surfaces in red and FLIP in blue. The full-orbit calculation indicates that the observed fast ions come from the plasma edge region. Moreover, the amount of lost fast-ion flux observed in FLIP ch.B scales with the amplitude of magnetic fluctuation of fast-ion-driven MHD instabilities. These experimental results indicate that pitch angle of fast ions was varied by the magnetic fluctuation of MHD instabilities and then fast ions went into loss cone at plasma edge region.

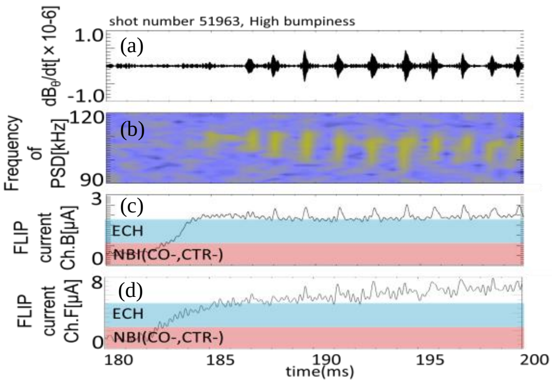

Fig.3. Time evolution of (a): magnetic fluctuation measured by magnetic probe, (b): power spectrum density of magnetic fluctuation, (c): FLIP signal ch.B, (d): FLIP signal ch.F.

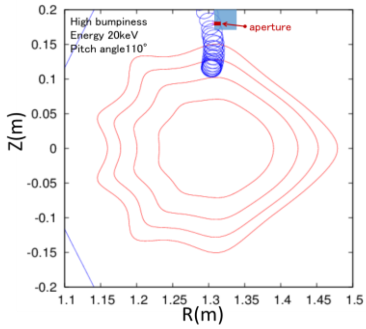

Fig.4. Orbit of the lost fast-ion in poloidal section. The orbit starts at the position of FLIP, and calculate time backward.

Acknowledgments

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References

[1] M. Isobe, *et al.*: Rev. Sci. Instrum. **77** (2006) 10F508.

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