§37. Observation of Fast-Ion Losses Induced by Various MHD Modes

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In existing/future toroidal devices, fast ion-driven magnetohydrodynamic (MHD) instabilities such as toroidal-Alfvén-eigenmodes (TAEs)[1] and energetic-particle continuum modes (EPMs)[2] can potentially enhance radial transport of fast ions such as alpha particles. In the Large Helical Device (LHD), a new type of a scintillator based lost-ion probe (SLIP) has recently been installed on the outboard side of a horizontally elongated cross section to study the loss behaviors of co-going beam ions, which might interact strongly with these fast ion-driven MHD instabilities[3].

In LHD, the direction of the toroidal field is changed from clockwise (CW) to counter-clockwise (CCW) and vice versa, depending on the physics theme. There are three negative-ion-source-based neutral beam (N-NB) injectors whose acceleration energy is up to 180 keV. Two of the NBs are tangentially injected in the same direction, and another is injected in the opposite direction. In many cases, beam ions are super Alfvénic because of the high beam energy. Strong instabilities are often excited by these ions at relatively low B_t (< 1 T) conditions[4].

Lost fast ions were measured in co-injected N-NB heated plasmas in the CW/CCW direction of the toroidal field. In the CW case, no clear SLIP signal was observed. This fact can be explained by two following reasons. One is that fewer fast ions are present in this plasma compared with the CCW case, because only one N-NB injector produces co-going fast ions in the CW case. Fewer fast ions would not strongly destabilize TAEs. Accordingly, this would induce only a small number of fast-ion losses. Another reason for the lack of a clear signal in the CW case is that the SLIP is located 80 mm from the symmetric position for detecting lost fast ions in the CCW or CW case. Thus, fewer fast ions can be detected with the SLIP in the CW case.

Figure 1 shows time evolutions of (a) higher-frequency magnetic fluctuations filtered in the frequency range of 60 to 80 kHz, (b) lower-frequency fluctuations filtered in the frequency range of 1 to 15 kHz, and (c) fast-ion-loss rate detected by SLIP at the outboard side (Larmor radius/pitch angle is about 50 mm/35 degrees, which is confirmed by measurements using a C-MOS camera). These measurements were carried out in the configuration of R_{ax} = 3.6 m at B_t = 0.6 T (CCW). The higher-frequency mode shown in Fig. 1(a) is recognized as TAE. Its poloidal mode number m and toroidal one n, derived with magnetic probe array, are $m \sim 1$ and $n = 1$, respectively. Conversely, lower-frequency fluctuations are generated by a group of interchange modes with m/n = 1/1, 2/3, and 1/2, respectively. These modes of which rational surfaces reside in the plasma edge region are driven by the bulk plasma pressure gradient there in relatively low-Bt conditions[5]. Two types of sharp increases in SLIP signals are identified. A large increase corresponds to a TAE burst ($m \sim 1$, $n = 1$). Small increases are generated by interchange modes dominated by an $m = 1/n = 1$ mode structure, which will extend radially from the edge to more interior region.

An existing theory of energetic ion loss induced by MHD modes suggests that a radially extended MHD mode destabilized by background plasmas would enhance the radial transport of energetic beam ions[6]. A low-frequency mode with large amplitude could lead to a stochastic orbit of fast ions due to stochastic magnetic field, causing the confinement degradation of fast ions, even though the level of the stochastic field does not affect bulk plasma confinement[6, 7]. More simply, energetic ion orbits extended toward the plasma edge at low B_t conditions might easily fall into loss-cone orbits due to the large amplitude MHD mode excited near the edge. In fact, a significant decrease in the neutron emission rate was observed in DIII-D when tearing mode instabilities were present[7], suggesting that beam ions are anomalously lost. A similar result was also observed in ASDEX-U: lost fast ions correlate with neoclassical tearing modes[8]. The abovementioned increase in fast-ion loss rates associated with interchange modes in LHD is thought to be due to a similar loss mechanism observed in DIII-D and ASDEX-U. More detailed mechanism of the observed loss process is currently under investigation.

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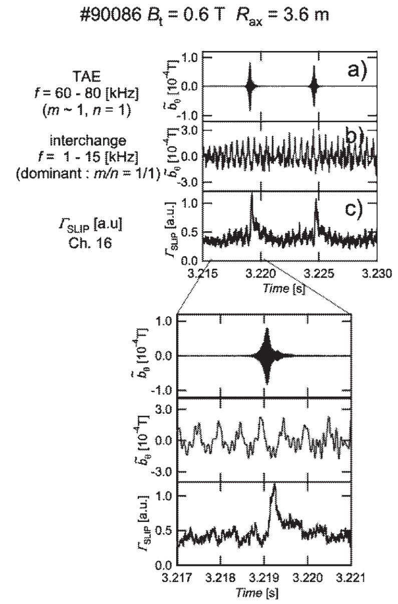

Fig. 1 Time evolutions of magnetic fluctuation amplitude $\tilde{b}_\theta$ and fast ion loss flux Γ_{SLIP} in an NBI heated plasma at B_t = -0.6T. (a) $m \sim 1$, $n = 1$ TAE fluctuation, (b) m/n = 1/1 interchange modes, and (c) SLIP signal measured with a PMT.