§45. High-Energy-Particle Experiments on LHD in FY 2010

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Good confinement of energetic particles (EPs) in magnetically confined fusion plasmas is required to realize a fusion reactor, since fusion-born energetic alphas play an essential role as a primary heating source in future burning plasmas. With a burning plasma stage imminent, the physics of the interplay between EPs and EP-driven magnetohydrodynamic (MHD) instabilities such as Alfvén eigenmodes (AEs) and energetic-particle continuum modes (EPMs) have become more important in recent years. This is because those MHD modes can potentially lead to the anomalous loss of energetic alphas, resulting in the loss of a self-ignited condition. Alfvénic modes have been regularly observed in LHD with strong super-Alfvénic energetic ion tails [1] as well as in tokamaks [2]. In FY 2010, proposals of 24 were submitted to the EP physics theme group. Our efforts were primarily devoted to reveal 1) confinement property of energetic ions by use of beam blip technique [3], 2) effects of toroidicity-induced AEs (TAEs) and low frequency n=0 magnetic fluctuation on non-classical energetic-ion losses by means of a tangential E//B neutral particle analyzer and scintillator-based lost energetic-ion probe (SLIP) [4-6], 3) spatial profile of helicity-induced AEs, so-called HAE, 4) relation between presence of suprathermal electrons and bulk electron heating efficiency, and interaction between suprathermal electrons and EP-driven MHD modes, 5) characteristics of ion cyclotron emission (ICE) synchronized with the TAE. In addition to those physics experiments, advanced energetic-ion diagnostics are required to increase understanding of energetic-ion-related physics, providing spatial and velocity distribution function of energetic ions. For this reason, the development of fast-ion charge exchange spectroscopy (FICXS) [7-9] and collective Thomson scattering (CTS) [10,11] diagnostics has kept pace with the experimental cycle in our group. A few representative results are highlighted in this report.

Concerning the experimental subject #1, a beam blip were perpendicularly injected in various density regions, i.e. various slowing-down time regime at an inward shifted configuration with a vacuum magnetic axis position R_{ax} of 3.53 m. Subsequently, decay rates of charge-exchange fast neutral flux measured with a perpendicular solid state NPA following the beam blip were analyzed. Note that beam blips were already carried out at R_{ax} of 3.6 m, 3.75 m and 3.9 m by FY 2009 [3]. The analysis showed that the decay rates at R_{ax} of 3.53 m are obviously longer than those at outward shifted configurations. It also showed that the decay rate becomes longer as the plasma shifted inwardly even in the same slowing-down time regime. This fact tells us that the inward-shifted configuration provide better confinement property of helically trapped energetic ions.

As for the experimental subject #2 and 3, our efforts were made to revel dependence of TAE-induced beam-ion losses on magnetic axis position at finite β equilibria, R_{mag} and field strength, B_t. As discussed in Ref. 5, the normalized losses by beam-ion density are nearly in proportion to the TAE magnetic fluctuation amplitude, δB_{TAE} in plasmas with R_{mag} of 3.75 m. Increment of beam-ion losses due to TAE tends to be a quadratic dependence on δB_{TAE} in the case of larger R_{mag}(=3.85 m), and finally much stronger dependence in the largest case of R_{mag}=4.0 m. Magnetic fluctuations of which frequency (~250 kHz) is higher than the TAE gap frequency (~70 kHz) have been regularly observed together with beam-driven TAE. To identify the class of the high frequency fluctuation, we calculated 3D-shear Alfvén continua. Experimentally observed frequency matches that of the HAE gap frequency. In addition, the density fluctuation profile deduced from fast-response Hα light detector array was reproduced by that evaluated from the eigenfunction of HAE calculated by AE3D. We may, therefore, reasonably conclude that magnetic fluctuations with the frequency of 250 kHz are certainly classified into the HAE.

One of interesting observations was ICE while beam-driven TAEs were present. ICE is known to be applicable to fusion products diagnostic. It can be excited when the distribution function of ions increases with the perpendicular velocity, and its frequency is close to multiples of the ion cyclotron frequency at the excitation point. In FY 2010, two pairs of high-frequency magnetic probes were installed from upper diagnostic ports, and we successfully detected ICE at the plasma edge and beam-ion losses by the SLIP at the same time. The measurement shows that both signals are synchronized. The free energy source of this type of ICEs is, therefore, thought to be due to the beam ions radially transported by the TAE.

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