§63. Studies of Energetic Particle Confinement

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In a magnetically confined nuclear fusion reactor, good particle confinement including fusion born alpha particles is strongly required for the sustainment of self-igniting plasma. The aim of our research is to clarify the physics and the improvement of both production and confinement of energetic ions toward the realization of Heliotron type nuclear fusion reactor. In LHD, we can consider the isotropic energetic ion confinement utilizing with many different kinds of heating system consisted of the perpendicular and tangential neutral beam injection (NBI) and ion cyclotron resonance heating (ICRF). Moreover, the existing diagnostics and newly developed ones including fast ion charge exchange spectroscopy (FICXS) and corrective Thomson scattering (CTS) which can measure the spatial and velocity space profile of ions can give us the information of classical energetic ion transport and anomalous transport of energetic ions in detail. These researches have been actively done by the physical group of energetic particles. Each outline is described below.

1-1. Dependence of ripple transport of energetic ion on magnetic configuration:

We have to investigate the energetic ion confinement, in particular, collision-less particle, in helical plasma which has complex and three-dimensional magnetic configuration. We experimentally show that good energetic particle confinement in the plasma of inward-shifted magnetic configuration utilized by the time behavior of neutral particle obtained from NPA in the experiment of the blip injection of neutral beam in LHD. It is also showed that the degradation of energetic ion confinement is depended on the magnetic field strength.

2-1. Observation of GAM in NBI-heated plasmas:

Two types of GAM excited by energetic ions are observed in counter-NB injected plasmas of LHD. One is the GAM, which can be controllable and sustainable, excited quasi-stationary in reversed magnetic shear plasmas by energetic particle. The other is GAM excited in NBI heated low-density plasmas. The former one is excited transiently (just after NBI switch on) in very low-density plasma. Magnetic probe signals indicate that the observed mode has a character of toroidal mode number n=0 and standing wave type with m=1 or 2 of observed mode. The latter one is accompanied by large electrostatic potential fluctuations. The amplitude of the magnetic fluctuation is roughly proportional to the electrostatic potential. The relation seems to agree with a theoretical prediction. Estimated power transfer from the GAM to bulk ions is not negligible. The GAM observed in low density plasmas, modes can be categorized into two type. The one has $Te^{0.5}$ dependence of its initial frequency and is considered as energetic particle induced GAM. The other has weak Te dependence of its frequency. The frequency is almost constant at around the orbital frequency of the NB-produced energetic ions. From the sensitivity analysis of Ti-profile to NPA measurement, the phenomena indicate the ion temperature increase in the central region. The phenomena might indicate the anomalous ion heating by n=0 energetic particle induced instability which may indicate that GAM channeling.

2-2. The measurement of spatial structure of Toroidicity-induced Alfven eigenmode and energetic ion loss caused by AE:

With regards to the TAE and their effect on energetic ion transport observed in LHD, We measured the spatial structure of TAE obtained from Hα excited by the energetic ion and the result is corresponding with the numerical result obtained from AE3D. A part of co-going fast ion is diffusively lost due to m/n=~1/1 TAE. The study is being done on various plasmas in order to investigate the effect of magnetic configuration on energetic ion loss. We reveal that magnetic axis shift induces the increase of lost fast ion. The loss process is changed from convective-type to stochastic orbit type orbit following simulation with TAE reproduced the changing of loss process. The steeper dependence is the result of the expansion of the energy and pitch angle region of energetic ions lost from the plasma.

3-1. Development of advanced energetic particle diagnostics: Fast ion charge exchange spectroscopy (FICXS):

The main purpose of FICXS is to investigate the dependence of passing fast ion densities on electron density fluctuations. Slowing down times observed by FICXS signal agree well with those calculated on the basis of the classical theory. For the high field cases (B_t= 2.2T, 2.85T), the reduction of fast ion density is strongly correlated with the amplitude of electron density fluctuation.

3-2. Development of advanced energetic particle diagnostics, Corrective Thomson scattering (CTS):

The main purpose of CTS is establishment of diagnostic method of bulk and fast ion velocity distribution by CTS. We have observed the time evolution of CTS spectra. The comparison of relative intensities between measured and simulated spectra has been carried out. For understanding the detail structure of CTS spectrum, high frequency resolution receiver system has been developed. It is possible to analyze excited CTS spectra have been measured from the new sightline for parallel velocity $v_{\parallel}$ component. (1.5L, $v_{\parallel}/v$~45deg.)