Studies on neutral beam ion confinement and excitation of beta-induced Alfvén acoustic eigenmodes in the HL-2A tokamak

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Abstract
Experiments with high-energy deuterium neutral beam (NB) injection were performed on the HL-2A tokamak. To obtain information on NB deposition and the slowing down of beam ions in HL-2A plasmas, very short-pulse deuterium NB injection, or the so-called ‘blip’ injection, was applied to MHD-quiescent ohmic deuterium plasmas. Analysis of neutron decay following the NB ‘blip’ injection indicates that tangentially injected beam ions are well confined, slowing down classically in the HL-2A tokamak. In contrast to the MHD-quiescent plasma, anomalous losses of beam ions were observed when a core-localized mode with a frequency up-chirping from 15 to 40 kHz appeared in the plasma. The core-localized mode was identified as a beta-induced Alfvén acoustic (BAAE) mode by its frequency sweeping behaviour and numerical calculation. Such a high energetic particle driven mode led to fast-ion loss, showing the strong influence of the core-localized fast-ion-driven BAAE mode on the fast-ion transport. Furthermore, a clear frequency splitting was first observed on the Alfvén-acoustic-type mode, and is found to be strongly linked to the effect of resonant wave–particle interaction, providing further insights into how frequency splitting structures are generated in the plasma.

1. Introduction
Confining energetic particles is one of the most important problems to be solved in fusion research. In recent years, significant progress has been made in the field of fusion energy development. Plasma parameters of tokamak devices are steadily approaching the reactor-relevant condition. It is well known that energetic alpha particles arising from d–t reactions in a future burning plasma play an essential role in sustaining the self-ignition condition. Once substantial loss of energetic alphas occurs for some reason, the self-ignited state will be terminated. Moreover, the localized heat load on the first wall due to impact of escaping alphas may seriously damage the device. For these reasons, considerable attention has been paid to physics issues related to energetic ions such as magnetic field ripple transport of energetic ions [1], anomalous transport and/or loss of energetic ions caused by fast-particle-driven modes [2].

Neutron diagnostics have played an important role in studying energetic-ion physics in deuterium neutral beam (NB) heated deuterium plasmas, providing information on the confinement property of energetic beam ions in toroidal fusion plasmas [3]. One effective method to check whether beam ions slow down classically or not is to measure the decay rate of neutron emission following deuterium NB injection and to compare the experimental decay rate with the decay rate predicted by the classical slowing-down theory. Experimental study based on an approach of short-pulse NB injection, or so-called NB ‘blip’ injection, whose duration is much shorter than the slowing-down time ($\tau_{s}$) of beam ions, has been carried out in DIII-D [4], CHS (Compact Helical System) [5] and other devices. One of the advantages of NB ‘blip’ injection is that the ‘blip’ injection does not have a great influence on plasma parameters. Another is that beam ions can be recognized as test particles having a narrow distribution in the velocity space.