

## Transition of Toroidal Alfvén Eigenmode to Global Alfvén Eigenmode in CHS Heliotron/Torsatron Plasmas Heated by Neutral Beam Injection

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A transition of a core localized type toroidal Alfvén eigenmode with  $n = 1$  toroidal mode number to two  $n = 1$  global Alfvén eigenmodes was observed in NBI-heated plasmas in the Compact Helical System (CHS) heliotron/torsatron. This transition phenomenon is interpreted based on the temporal evolution of the rotational transform near the plasma center caused by the increase in the beam-driven current.

### Keywords:

toroidal Alfvén eigenmode, global Alfvén eigenmode, eigenmode transition, rotational transform, helical plasma, tokamak plasma

In major tokamak and helical devices, Alfvén eigenmodes driven by energetic ions such as the toroidal Alfvén eigenmodes (TAEs) [1] and global Alfvén eigenmodes (GAEs) are currently under extensive study because they have the potential to expel energetic particles before thermalization, and which lead to the quenching of ignition and damage of the first wall. TAEs are often observed in tokamak and helical configurations with finite magnetic shear [2-4]. On the other hand, energetic ion driven GAEs were first observed in the W7-AS stellarator, which has almost no magnetic shear [5]. Particularly energetic ion driven GAEs with  $n = 0$  ( $n$ : toroidal mode number) were observed in the JET tokamak and CHS heliotron/torsatron [4,6].

In CHS, the configuration of which has finite and negative magnetic shear, we observed an interesting novel phenomenon; an eigenmode transition from TAEs to GAEs occurred in a plasma heated by co-neutral beam injection (NBI). The time evolution of a hydrogen

discharge where the eigenmode transition took place is shown in Fig. 1, where the magnetic axis position is  $R_{ax} = 0.949$  m at the toroidal magnetic field  $B_t = 0.9$  T. In this discharge, two types of TAEs  $n = 2$  and  $n = 1$ , respectively were observed. The former  $n = 2$  TAE appears from  $\sim 60$  ms and splits into multiple peaks with the same  $n$  [4]. This mode-splitting is caused by nonlinear effects and is similar to that observed in JET [7]. The latter  $n = 1$  TAE is destabilized from  $t \sim 35$  ms and suppressed at  $t \sim 65$  ms. The TAE gap is formed by  $m = 2$  and  $m = 3$  mode coupling. Consequently, two  $n = 1$  modes appear from  $t \sim 90$  ms, in the frequency ranges of  $f \sim 140$  kHz and  $f \sim 100$ – $70$  kHz, respectively. These frequencies tend to deviate from the trend of TAE frequency.

The  $n = 1$  TAE gap structure at  $t = 50$  ms of the plasma in Fig. 1 is shown in Fig. 2(a), where the Alfvén spectra are calculated by a simple dispersion relation on a large-aspect-ratio tokamak approximation [1]. In the calculation, the radial profiles of the rotational transform

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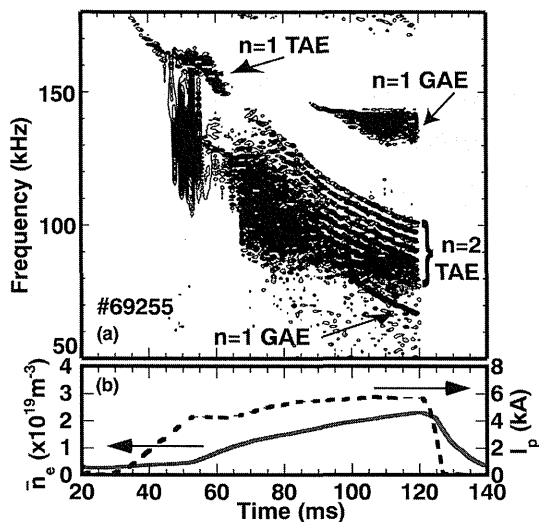


Fig. 1 Time evolutions of magnetic fluctuation spectra (a) and line-averaged electron density and the co-flowing plasma current (b) observed in a hydrogen plasma of  $R_{\text{ax}} = 0.949$  m and  $B_t = 0.9$  T. The solid curve in Fig. 1(a) indicates the calculated TAE frequency.

$1/q$  and the electron density shown in Fig. 2(c) are employed. As seen in Fig. 2(a), the observed frequency of the  $n = 1$  mode (indicated by the horizontal line) lies just above the lower bound of the  $m = 2/3$  TAE gap. This mode has the characteristic of core-localized TAE [3,4]. On the other hand, after the transition, the  $n = 1$  TAE gap in the range of  $f = 60$ – $170$  kHz no longer forms in the plasma core region ( $\rho < 0.5$ ), as shown in Fig. 2(b). The higher frequency of the  $n = 1$  mode observed at  $t = 120$  ms lies just below the minimum of the  $m = 3$  Alfvén continuum, and the lower frequency lies just above the maximum of the  $m = 2$  continuum. These two  $n = 1$  modes are thought to be GAEs generated by the transition of  $n = 1$  TAE, which is caused by the temporal evolution of  $1/q$ . That is, these  $n = 1$  modes with  $f \sim 140$  kHz and  $f \sim 100$ – $70$  kHz observed in the phase from 90 to 120 ms are  $n = 1/m = 3$  and  $n = 1/m = 2$  GAEs, respectively. The Alfvén spectra shown in Fig. 2(b) suggest that the  $n = 1/m = 3$  GAE would not suffer from strong continuum damping, whereas the  $n = 1/m = 2$  GAE would. The change in the Alfvén spectra shown in Fig. 2 is a result of the slight increase in  $1/q$  near the center caused by a co-flowing plasma current beyond  $1/q(0) = 0.4$ , which value corresponds to that at the  $n = 1, m = 2/3$  TAE gap. Thus, the GAE gap at  $t = 120$  ms is formed in the range of  $f \sim 60$ – $170$  kHz, as shown in Fig. 2 (b). Two GAE frequencies evolve with the temporal change of  $1/q$  near

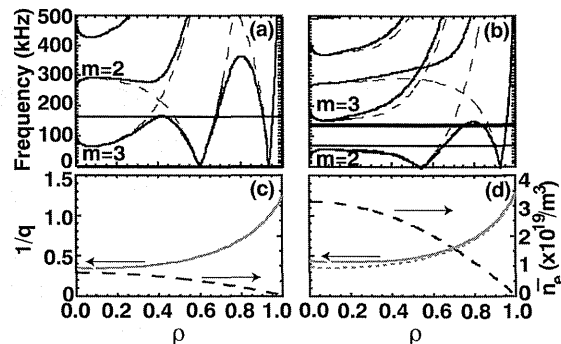


Fig. 2 The  $n = 1$  shear Alfvén spectra of the discharge shown in Fig. 1, which is calculated based on the large-aspect-ratio tokamak approximation [1] for  $t = 50$  ms (a) and for  $t = 120$  ms (b). (c) and (d) Radial profiles of the electron density and the rotational transform employed for the calculations for the Alfvén spectra (a) and (b). The horizontal lines in Figs. 2(a) and (b) stand for the observed frequencies. The dotted line in Fig. 2(d) denotes the rotational transform at 50 ms.

the plasma center. This transition between TAE and GAE observed in a heliotron/torsatron plasma is very similar to that predicted by numerical analysis for model  $q$ -profiles of a negative shear tokamak [8]. Recently, similar phenomena have been observed in the JT-60U [9] and the Large Helical Device LHD [10]. This eigenmode transition can be employed as a useful diagnostic tool for measurement of the central rotational transform in tokamak and helical plasmas.

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