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(Received - Aug.19, 1999 )

NIFS-610

Sep. 1999

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**RESEARCH REPORT**  
NIFS Series

# Core Localized Toroidal Alfvén Eigenmodes Destabilized by Energetic Ions in the CHS Heliotron/Torsatron

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Keywords: CHS, TAE, NBI, energetic particle, magnetic probe, soft X-ray, internal structure, continuum damping

## INTRODUCTION

In a fusion reactor, it is predicted that the toroidal Alfvén eigenmodes (TAE) destabilized by the pressure gradient of energetic alpha particles with super-Alfvénic velocity, could expel the alpha particles before thermalization [1]. In large tokamaks, therefore, the excitation of TAEs has been extensively studied by the use of energetic ions generated by neutral beam injection (NBI) and ion cyclotron heating and also by the use of alpha particles in a deuterium-tritium plasma. TAE research is also important for helical systems, with moderate or high magnetic shear, that is, a heliotron/torsatron device. In the CHS heliotron/torsatron, we investigate TAE excitation by energetic ions in NBI-heated plasma [2]. In CHS plasmas, the TAE frequency, estimated from the formula  $f_{TAE} = V_A / (4\pi Rq)$  where  $V_A$  is the Alfvén velocity, increases rapidly towards the plasma edge because  $q$  decreases towards the edge. As a result, the frequency of a TAE in the plasma core usually intersects the Alfvén continuum in the plasma edge where the magnetic shear is high, which can cause the corresponding TAE to be stabilized due to strong continuum damping. However, it is possible for TAEs to be destabilized in this configuration if the magnetic shear in the plasma core is appreciably reduced by net plasma current  $I_p$  or finite plasma

pressure. In this situation, TAEs localized in the plasma core region may be excited by energetic ions, as observed in a tokamak [3]

## EXCITATION OF TAE

In neutral-beam-heated plasmas in CHS, coherent magnetic fluctuations excited by energetic ions are detected (Fig.1), where the energetic beam-ion beta value is comparable to the bulk plasma beta ( $\langle\beta_{beam}\rangle \sim 0.1-0.3\%$ ). The observed frequency is

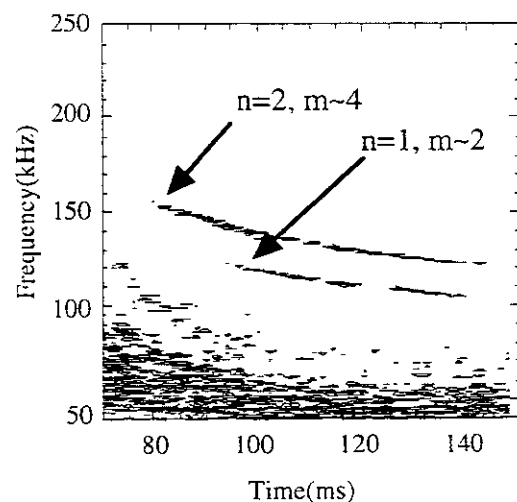


Fig. 1 Typical time evolution of magnetic fluctuations related to TAEs in NBI heated plasmas in CHS, where electron density is increased linearly in time. Toroidal and poloidal mode numbers are indicated in the figure.

proportional to the Alfvén frequency. Comparison of the observed frequencies and mode numbers to a simple TAE analysis based on a large-aspect ratio tokamak clearly indicates that the magnetic fluctuations are due to TAEs. The modes were excited only when the beam velocity exceeds about half the central Alfvén velocity and the net plasma current induced by co-injected neutral beams is in the required range. Figure 2 shows dependence of the net plasma current  $I_p$  required for TAE excitation on the toroidal magnetic field. This figure suggests that the reduced magnetic shear in the plasma core is necessary for excitation of TAEs in CHS. Note that data in the plasmas having the same beta value ( $\langle\beta_{\text{bulk}}\rangle\sim 0.2\%$ ) are plotted in Fig. 2, since the bulk plasma beta value also influences the magnetic shear in the plasma core region. The required lower bound of  $I_p$  increases with increase in  $B_t$ . The plasma current  $I_p$  in inward shifted plasmas (magnetic axis position  $R_{\text{ax}}=0.92\text{m}$ ) is larger than that in slightly outward shifted plasmas ( $R_{\text{ax}}=0.95\text{m}$ ). This tendency is interpreted that the rotational transform in the plasma core region of the inner shifted plasmas ( $R_{\text{ax}}=0.92\text{m}$ ) is smaller than that of the plasmas with  $R_{\text{ax}}=0.95\text{m}$ . On the other hand, the upper bound of  $I_p$  is determined by elimination of the relevant TAE gap. Figure 3 shows the radial profiles of the rotational transform for the plasmas obtained at various magnetic axis positions, the bulk plasma beta values and the toroidal magnetic fields. The solid curves in Fig. 3 indicate the rotational transforms without the net plasma current where TAEs are not observed. The broken curves indicate the rotational transform calculated taking account the lowest plasma current where TAEs are observed. The horizontal solid line in Fig. 3 indicates the rotational transform  $\iota=0.4$  where poloidal mode coupling between  $m=2$  and  $m=3$  harmonics takes place in the  $n=1$  TAE. When the plasma current is in the required range, the TAE gap position (for instance,  $\iota=0.4$ ) moves toward the plasma center and the magnetic

shear decreases there. As seen from Fig. 3, predicted profiles of the rotational transform for excitation of TAEs are very similar in the plasma core region.

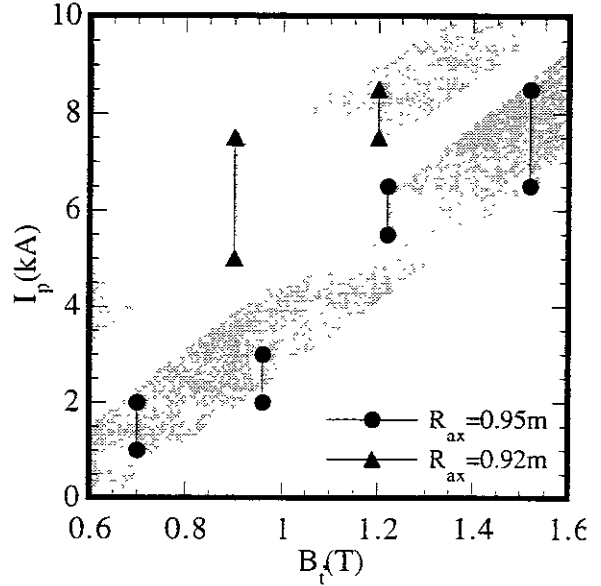


Fig. 2 Dependence of the net plasma current on the toroidal magnetic field where the TAEs are detected.

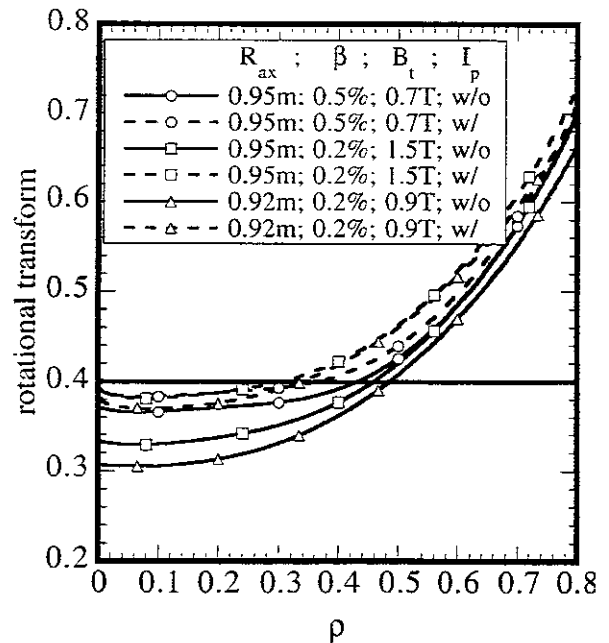


Fig. 3 .Comparison of the rotational transform profiles between the cases that TAEs are observed and those without TAEs.

## INTERNAL STRUCTURE OF TAEs

The internal structure of TAEs was measured with a soft X-ray detector (SX) array. The soft X-ray fluctuation level for TAEs is too low to obtain the radial profile of the fluctuation intensity because of fairly low electron temperature ( $T_{e0} \leq 0.3\text{keV}$ ). For this reason, the coherence between the soft X-ray signal of each channel and the magnetic probe signal was calculated in the TAE frequency range. The solid circles in Fig. 4 (a) shows the radial profiles of coherence for the TAE observed in the plasma with  $R_{ax} = 0.92\text{ m}$ . This figure suggests that the high coherence region is localized within  $\rho \approx 0.6$ , where the coherence of noise is  $\sim 0.3$ . This figure shows mode localization at  $\rho \approx 0.2-0.6$ . Note that the high coherence near the plasma center is due to path-integral effect of soft X-ray signal. Moreover, plasma potential fluctuations due to TAEs measured by heavy ion beam probe (HIBP) are also localized in  $\rho \approx 0.2-0.6$  [2]. Therefore, the TAEs are estimated to be localized in the region  $\rho \approx 0.2-0.6$ . In order to compare the radial profile of TAE fluctuations to other MHD activity, we shows the radial profiles of the coherence for the fishbone-like burst modes (FBs)  $m=2/n=1$  observed together with TAEs [4] in Fig. 4(b), when the frequencies of TAEs and FBs are  $\sim 100\text{kHz}$  and  $\sim 30\text{kHz}$ , respectively. FBs are destabilized by the presence of energetic ions such as TAEs. In contrast to TAEs, the fluctuations of FB are localized in more outer region  $\rho \approx 0.4-0.7$ . Results in Fig. 4 clearly shows that TAEs observed in CHS have a character of the core localized mode.

## CONCLUSION

In CHS, core-localized TAEs are detected when the plasma current induced by co-injected NBI is in the required range depending on the toroidal magnetic field and the magnetic axis position. The parallel velocity of beam ions is also required for

excitation of the TAEs to be large than half of the central Alfvén velocity. The TAE localized in the plasma core region was supported by the radial profiles of TAE fluctuations measured by the SX-array and HIBP. The observed fluctuation frequencies are near the lower boundary of the predicted TAE gap [2]. The observed TAEs exhibit ballooning nature, as can be seen in Fig.4(a). These results seem to be consist with the core localized TAEs. So far enhanced loss of energetic ions due to TAEs was not observed.

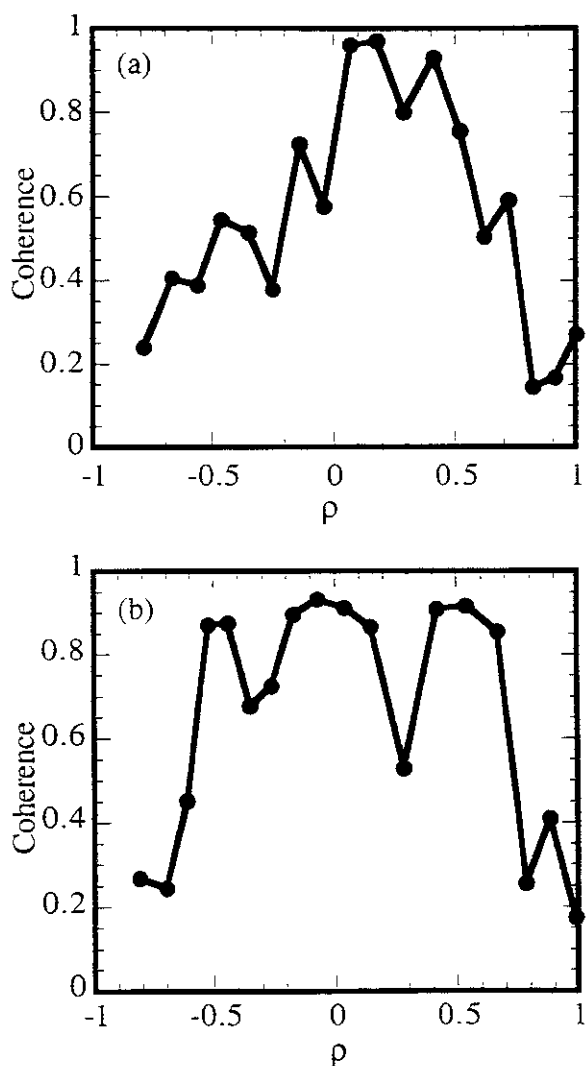


Fig. 4. (a) Radial profiles of the coherence of TAEs between the soft X-ray signal of each channel and the magnetic probe signal (b) Radial profiles of the coherence for fishbone-like burst mode other than TAEs.  $\rho > 0$  means the outboard side of the plasma.

Detailed numerical analysis in the three-dimensional configuration is necessary to understand the TAE excitation in heliotron/torsatron configuration more clearly.

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