§3. Fokker-Planck Simulation of Alpha-particle-driven Toroidicity-induced Alfvén Eigenmode

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Alpha-particle-driven Toroidicity-induced Alfvén eigenmodes (TAEs) were first observed in the Tokamak Fusion Test Reactor (TFTR) [1]. It should be noted that the estimated amplitudes of the TAEs were very small $\delta B / B \approx 10^{-5}$, and they persisted much longer than the typical damping time. We carried out five dimensional Fokker-Planck simulation of the alpha-particle-driven TAE in TFTR.

A perturbative model [2] is adopted to investigate time evolution of the n=4 TAE, where the TAE is described by a linear eigenmode structure and by amplitudes of the sine part and the cosine part. We use coordinates, major radius R, vertical coordinate z, toroidal angle φ, total velocity v, and the pitch-angle variable $\xi = v_{\parallel} / v$. We consider concentric circular magnetic surfaces as the equilibrium magnetic field for simplicity. Electromagnetic field is a superposition of this equilibrium field and the TAE field.

We simulate the n=4 mode observed at TFTR shot #103101. We take an approximate q-profile which is shown in Fig. 1. The eigenmode equations (e.g. Eqs. (3) and (4) of Ref. [3]) for two poloidal harmonics m=6 and m=7 are solved to obtain n=4 TAE structure. The plasma density is taken to be uniform for simplicity and the boundary condition that we imposed for this eigenvalue problem is zero amplitude at $r>0.45a$ to avoid an intersection with the Alfvén continuum spectrum in this simplified model. The mode structure is shown in Fig. 1 with the q-profile.

The parameters are taken to be consistent with the experiment; $R_0=2.52$ [m], $a=0.90$ [m], $B_0 = 5$ [T], and the mode frequency $\omega/2\pi=214$ [kHz]. We take an alpha distribution simplified from Eq. (51) of Ref. [4]. The central alpha pressure is $\beta_\alpha(0) = 6\times 10^{-4}$.

The algorithm to advance amplitude and phase of the TAE mode is that developed in Ref. [2]. We take the plasma number density $n = 3.5\times 10^{19}$ [m^{-3}] with the effective mass of 2.04 for the calculated eigen frequency to be consistent with the observed TAE frequency. It is in good agreement with the experimental electron number density around $r=0.3a$ where the TAE localizes spatially.

The simulation was carried out with realistic collisional rates, the pitch-angle scattering rate ν_d= 1.0 [1/s] and the slowing-down rate ν= 2.8 [1/s]. The mode damping rate is chosen $\gamma_d = 5\times 10^{-3}\omega$. The amplitude evolution is shown in Fig. 2.

We would like to discuss the linear behavior before moving on to the nonlinear stage. Linear alpha drive is estimated $\gamma_L = 9.9\times 10^{-3}\omega$ from the linear growth rate and the damping rate. This linear alpha drive is in good agreement with the NOVA-K analysis result $\gamma_L = 8\times 10^{-3}\omega$ [5].

It is interesting to investigate the detail of the alpha-TAE resonance, since the cut-off velocity is lower than the Alfvén velocity. It is known that the particles with velocity lower than the Alfvén velocity can resonate with TAE at $v = v_A / 3$. We confirmed the distribution function is consistent with the resonance condition at $v_{\parallel} = -v_A / 3$ and $v_{\parallel} = v_A / 3$.

Let us turn to the nonlinear behavior. It can be seen in Fig. 2 that the amplitude decreases monotonically after saturation. The TAE never stays at steady amplitude. This is inconsistent with the experimental results. Convergence check in number of grid points is required, but it has not been done due to computational restriction. It needs more effort to resolve this discrepancy.

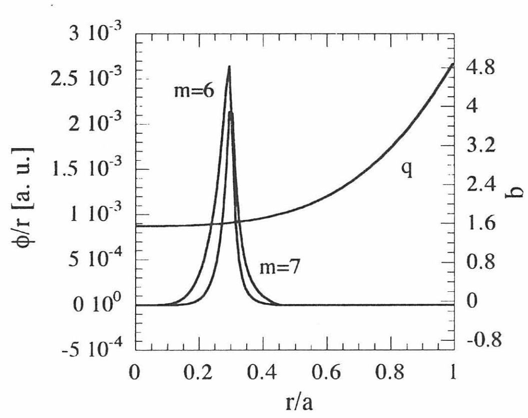

FIG. 1. The q-profile and the m=6 and m=7 poloidal harmonics of the n=4 TAE.

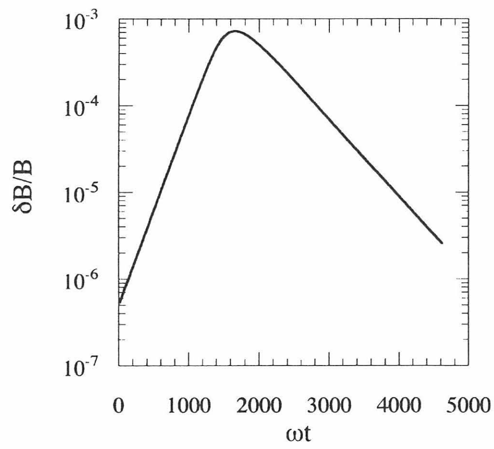

FIG. 2. Amplitude evolution of the n=4 TAE with the realistic pitch-angle scattering rate and $\gamma_d / \gamma_L = 0.5$.

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