Numerical study of EP driven TAE/EPM on EAST

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Abstract. Toroidal Alfvén Eigenmode (TAE) can be drvien by energetic particles (EPs) in tokamak plasmas, especially in strong auxiliary heating plasmas. With the equilibrium reconstructed by the EFIT code based on EAST (Experimental Advanced Superconducting Tokamak) experimental measurement, simulations of TAE driven by EPs are performed using MEGA code. It is found that the frequency, the dominant poloidal mode number and the radial location of the TAE modes from MEGA simulations are consistent with the results of the eigenvalue code AWEAC. The $n = -1$ TAE is generate by the coupling of $m = 1$ and $m = 2$ modes, which are induced by the resonance interaction of EP at $v_\parallel = -V_{A0}/3$ and $v_\parallel = -V_{A0}/5$ respectively. These benchmark simulations lay solid foundations for further study of MHD modes related to EPs investigated on EAST experiments with strong auxiliary heatings.

Keywords: TAE · tokamak · EAST · MEGA.

1 Introduction

Since the velocity of energetic particles (EPs) is close to the phase velocity of Alfvén eigenmodes (AEs), EPs generated by heatings and fusion reactions in tokamak plasmas may excite toriodal Alfvén eigenmodes (TAEs), which can influence the stability and confinement of plasmas in burning regimes. [1,2,3] EAST(Experimental Advanced Superconducting Tokamak) is a medium-size tokamak with fully superconducting TF (Toroidal Field) and PF(Poloidal Field) coils, which has similar configuration to ITER (International Tokamak Experimental Reactor). The main design parameters are as follows: major radius $R = 1.7 - 1.9$ m, minor radius $a = 0.4 - 0.45$ m, toroidal magnetic field $B_t = 3.5$ T and maximum plasma current $I_p = 1$ MA.

For EAST discharge #38300, Hu et al has studied the eigen feature of AEs for this discharge using the eigenvalue code GTAW[8]. Then Pei et al has also studied the same discharge with the kinetic-MHD code MEGA and M3D-K [9]. To further study the features of AEs on EAST, we perform an eigen-analysis of AEs using the code AWEAC (Alfvén Wave Eigen-Analysis Code) and simulation using the MEGA code on the same discharge.

It is found that the linear simulations with MEGA are consistent with the AWEAC eigen-analysis results. The TAE excited by EPs is located in the $r/a = 0 - 0.4$ area with frequency $f = 95.9$ kHz, which corresponds to the bottom side of the TAE gap induced by $m = 1$ and $m = 2$ components. It is also found that the varations of EP distribution function correspond to $m = 1$ mode in the $r/a = 0 - 0.2$ area and $m = 2$ mode in the $r/a = 0.2 - 0.4$ area, which is consistent with the 2D mode structure and Fourier analysis. The reonance number for EP with lagest δf is $l = 0$ and $l = 3$, which correspond to $v_{\|} = -V_{A0}/3$ and $v_{\|} = V_{A0}/3$ for $m = 1$ component.

2 Simulation and Eigen-analysis model

MEGA code, which solves the hybrid kinetic-MHD equations, is developed by professor Todo [4,5] and used for EP driven instabilities in both tokamak and stellarator[6]. In this hybrid kinetic-MHD model, the background plasma is modeled using full MHD equations and energetic particles are modeled by kinetic equations.

AWEAC can provied the spectrum of AEs and the radial mode structure by solving the ideal MHD eigenmode equations [8] with python. To render the Alfvén continua more clear, the slow sound approximation[7], which remove the sound continua while keeping the Alfvén continua nearly unchanged, is adopted.

3 Benchmark of MEGA simulation of TAE with eigen-analysis

The kinetic equilibrium is reconstructed using the EFIT code with experimental data from EAST discharge #38300 at 3.9 s [10,11]. The slowing down distribution is adopted for modeling the equilibrium distribution of the energetic ions from the deuterium neutral beam injection on EAST.

Under initial setting of $n = -1$, which n is the toroidal mode number, the system evolves with time. The EPs excite MHD mode, which initially grows linearly with time and then saturates. To identify the mode, the toroidal electric field in the cross-section at 1.9 ms of linear stage, which shows the 2D mode structure, is given in Fig. 1 (a). As one knows that the TAE is generated by the

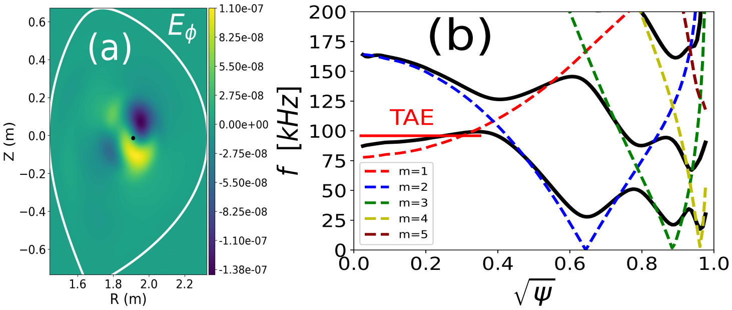

Fig. 1. (a) Contour plot of the toroidal electric field in the cross-section of tokamak. (b) Alfvén continuum generated by AWEAC, where the black solid lines are continua in toroidal geometry and dashed lines are ploidal components in cylindrical geometry. The red solid line is the EP driven TAE during MEGA simulation.

coupling of m and $m+1$ components, it is necessary to analyse the poloidal components of the mode. Though the FFT of the radial velocity of the fluid element, we plot out both the sin part and the cos part of the poloidal components for $m = 1 - 6$. It can be seen that the $m = 1$ component is dorminant in the radial region $r/a = 0 - 0.4$ and the $m = 2$ component is the second major component, which is the feature of TAE. It is also can be identified in the 2D mode structure that $m = 1, 2$ components coexsist and the $m = 1$ component is larger than the $m = 2$ component.

After checking the mode with the poloidal components and the radial location, we can also identify the mode with the frequency and the radial location by the continuum. With the FFT of energy evolution, one can obtain the mode frequency $f = 95.9$ kHz. The Alfvén continuum under slow sound approximation by using AWEAC is given in Fig. 1 (b), where the TAE information is extracted from MEGA simulation. It can be seen that the EP driven TAE mode is located at the bottom of the TAE gap, which is generated by the compling of $m = 1$ and $m = 2$ components. As we know that the even TAE induced by m and $m + 1$ components with same sign, located at the bottom end of the TAE gap and have the ballooning structure, which is consitent with the position of TAE in Fig. 1 (b) and the structure in Fig. 1 (a).

4 Conclusion

TAE has been excited by the NBI generated EPs in EAST tokamak with strong auxiliary heating. Simulation of TAE has been performed by using MEGA code. TAE features, such as the frequency, the dominant poloidal mode number and the radial location, are consistent with AWEAC eigen-analysis. Through the investigation of EP behavior in phase space, one can draw the conclusion that the TAE is mainly driven by the resonant particles and the mode features are closely related to the reonance behavior. These benchmark simulations are well understood and lay solid foundations for further study. In the future, we will study the mode transitions between TAE and EPM, as well as the long-time nonlinear behavior of these MHD modes.

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