# AIC MODE IN MIRROR BASED VOLUMETRIC NEUTRON SOURCE (FEF-II)

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**Abstract**

The growth rate of AIC mode excited by the anisotropic distribution of the sloshing ions and the $\alpha$-particles in the mirror based plasma neutron source FEF-II has been studied. The distribution function of these fast ions are calculated by Fokker-Planck equations. The growth rate of AIC mode by the sloshing ions is very large compared with the growth rate by the $\alpha$-particles.

## 1. Introduction

The importance and necessity of the neutron sources with the energy of 14MeV for development of the fusion reactor materials and also for fusion nuclear engineering have been recognized by the fusion community. The conceptual design studies of plasma based neutron source with the name of FEF have been carried out since 1981, and recently, FEF-II (upgraded version of FEF) design studies have been started. FEF-II is two-component plasma system (the target plasma and fast ion of the sloshing ions) [1], [2]. The sloshing ions are formed by injection of neutral beam (NBI) into the target plasma confined in the mirror magnetic field. The $\alpha$-particles are produced by DT reaction in the two-component plasma. These high energy ions play important roles in mirror plasma. In the earlier papers [3], [4], we reported the results of the property of the fast ions by use of the Fokker-Planck simulation.

High energy particles in the mirror field excite the Alfven-ion-cyclotron (AIC) instability as a result of the anisotropic velocity distribution due to loss-cone. We have studied the AIC mode which is excited by the $\alpha$-particles in the mirror field [5].

In the present paper, we study the linear growth rate of AIC mode for the sloshing ions and the $\alpha$-particles. The distribution function of these particles are obtained by the Fokker-Planck equations. We also obtain the energy anisotropy, and discuss the relation between the growth rate and the energy anisotropy.

## 2. Growth Rate of AIC Mode

We assume that the target plasma which consists of electron and 50%-50% DT-ions. We restrict ourselves to parallel propagation ($k_\perp = 0$) of AIC mode, the condition of resonance between the fast particles and the Alfven wave is given by [5]

$$\omega - \Omega - kv_\parallel = 0 \tag{1}$$

where $\omega$ and $k$ are the frequency and the wave number of the wave, and $\Omega$ is the cyclotron frequency of the fast particles. Neglecting the small contribution of the fast ions, we have following dispersion relation of the Alfven wave for the frequency range $\omega \ll \omega_\mathrm{e}$ [5],

$$\left(\frac{kc_\mathrm{A}}{\Omega}\right)^2 = \left(\frac{\omega}{\Omega}\right)^2 \left\{\frac{2}{5}\left(1-\frac{\omega}{\Omega}\right)^{-1} + \frac{3}{5}\left(1-\frac{3}{2}\frac{\omega}{\Omega}\right)^{-1}\right\} \tag{2}$$

where $c_\mathrm{A}$ is the Alfven velocity. Taking into account the contribution of the fast ions to the imaginary part of $\omega$, we obtain the growth rate [5]

$$\begin{aligned} \frac{\gamma}{\Omega} &= \frac{\pi^2}{2}\frac{4\pi e_\mathrm{s}^2}{m}\frac{\omega}{c^2k^3}\int_0^{\zeta_\mathrm{c}} \mathrm{d}\zeta\, v_\zeta^2 \left(\frac{1-\zeta^2}{\zeta^2}\right) \\ &\times \left[\left\{1-\frac{\omega}{\Omega}(1-\zeta^2)\right\}\left(-\frac{\partial f}{\partial \zeta}\right)_{v=v_\zeta} + \frac{\omega}{k}\left(1-\frac{\omega}{\Omega}\right)\left(\frac{\partial f}{\partial v}\right)_{v=v_\zeta}\right] \end{aligned} \tag{3}$$

where $v_\zeta = (\Omega - \omega)/k\zeta$ is the velocity of the resonant particles and $f$ is the velocity distribution of the fast ions, $\zeta$ is the cosine of the pitch angle. The distribution of the sloshing ions and the $\alpha$-particles are obtained by use of each Fokker-Planck equation, simultaneously. The production terms for the sloshing ions and the $\alpha$-particles are represented as [3], [4], [6]

$$S = \frac{I}{4\pi^2 e\,\Delta v\, v_0^2\,\Delta\zeta\, V}\exp\left[-\left(\frac{v-v_0}{\Delta v}\right)^2 - \left(\frac{\zeta-\zeta_0}{\Delta\zeta}\right)^2\right] \tag{4}$$

$$S_\alpha = \left[n_\mathrm{D} n_\mathrm{T} \langle\sigma v\rangle_\mathrm{DT} + n_\mathrm{s} n_\mathrm{T}\langle\sigma v'\rangle_\mathrm{DT}\right] h(v)\phi(\zeta) \tag{5}$$

respectively, where $I$ is NBI trapped current, $V$ is the plasma volume, $v_0$ is the velocity of injected particles, $\zeta_0$ is the cosine of the injection angle. $h(v)$ and $\phi(\zeta)$ are the velocity and angular distributions, respectively, of the produce $\alpha$-particles as follows [6]:

$$h(v) = \frac{1}{4\pi v_\alpha^2}\left(\frac{a_0}{\pi}\right)^{1/2}\frac{1}{v}\left[\mathrm{e}^{-a_0(v-v_\alpha)^2/v_\alpha^2} - \mathrm{e}^{-a_0(v+v_\alpha)^2/v_\alpha^2}\right] \tag{6}$$

$$\phi(\zeta) = \begin{cases} 1 & (\,\zeta < \zeta_\mathrm{c}\,) \\ 0 & (\,\zeta \ge \zeta_\mathrm{c}\,) \end{cases} \tag{7}$$

We assume that the target plasma is isotropic and Maxwellian. The target plasma parameters are assumed to be constant throughout the simulation.

## 3. Results and Conclusions

We have investigated AIC instability in FEF-II. The parameters for the calculation are listed in Table 1. We obtain the maximum growth rate for AIC mode in steady state. The distribution

| | |
|---|---|
| Target plasma density [$cm^{-3}$] | $4 \times 10^{14}$ |
| Ion temperature [keV] | 20 |
| Electron temperature [keV] | 1 |
| Plasma volume [$cm^3$] | $9.4 \times 10^4$ |
| Plasma radius [cm] | 10 |
| Mirror ratio | 3.4 |
| Mirror to mirror distance [m] | 3.3 |
| Magnetic field at midplane [T] | 4.7 |
| Injection energy of NBI [keV] | 100 |
| Injection angle of NBI | $45^o$ |
| Injection current of NBI [A] | 100 |

**Table 1.** Tentative parameters of FEF-II.

function of the sloshing ions and the $\alpha$-particles are calculated by the Fokker-Planck equations. The density of the sloshing ions and the $\alpha$-particles are $1.91 \times 10^{13}$ $cm^{-3}$ and $5.28 \times 10^{10}$ $cm^{-3}$ in steady state, respectively. The growth rate of Alfven wave versus $\omega/\Omega$ is shown in Fig. 1(a) and (b), respectively. It is shown that $(\gamma_s/\Omega)_{max} = 4.20 \times 10^{-2}$ at $\omega/\Omega = 0.43$ for the sloshing ions and $(\gamma_\alpha/\Omega)_{max} = 8.02 \times 10^{-5}$ at $\omega/\Omega = 0.22$ for the $\alpha$-particles. We conclude that the excitation of AIC mode by the sloshing ions is very large compared with the excitation by the $\alpha$-particles. We also obtained the energy anisotropy of the fast ions which is defined by $\lambda = T_\perp/T_\parallel$. The results are $\lambda = 0.70$ for the sloshing ions and $\lambda = 2.0$ for the $\alpha$-particles in steady state.

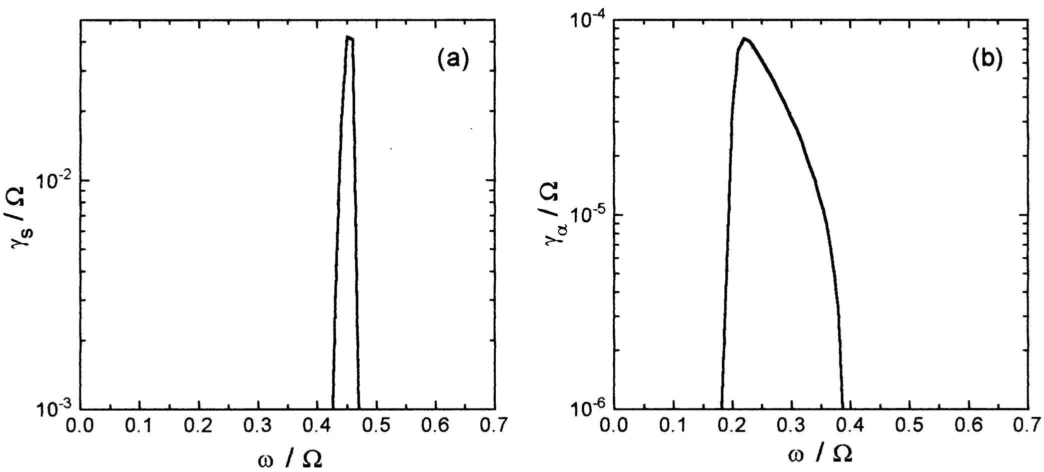


**Figure 1.** Growth rate of AIC mode by sloshing ions (a) and $\alpha$-particles (b) in steady state.

Fig. 2(a),(b),(c) show the density of the sloshing ions, $\lambda$ and the maximum growth rate dependence on $\zeta_0$ in steady state, respectively. It is shown that the growth rate of AIC mode is large at $\zeta_0 = 0.4 \sim 0.5$ ($\theta_0 = 60° \sim 66°$).

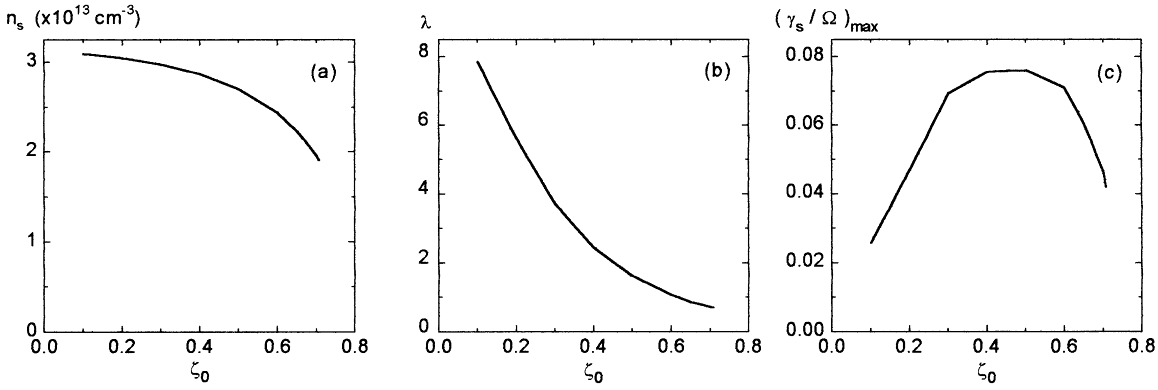


**Figure 2.** Dependencies of sloshing ions density (a), $\lambda(= T^{\perp}/T_{\|})$ for sloshing ions (b), and the maximum growth rate of AIC mode by sloshing ions (c) on $\zeta_0$ in steady state.

## References


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