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Flute instabilities and associated radial transport in the divertor and dipole regions of the GAMMA10 A-divertor

GAMMA10 A-divertor におけるダイポール部を含めた系でのフルートモードと径方向輸送

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The numerical simulation on the flute instabilities was performed in the GAMMA10 A-divertor magnetic configuration. Here the dipole region is included in the calculations as well as the divertor region. The dipole region has been found to have an stabilizing effects on the flute instabilities in the GAMMA10 A-divertor.

1. Introduction

The GAMMA10 tandem mirror is planning to introduce an axisymmetric divertor mirror cell in it, where one of the anchor mirror cell is replaced by the divertor mirror as shown in Fig.1. The main purpose to containing the divertor is to perform such a simulation experiment as a divertor installed in big torus. The divertor mirror is an axisymmetric mirror stable to the flute mode, where the stability is due to the plasma compressibility[1]. The pressure radial profile of plasma has to be controlled in order to achieve the stable plasma in the divertor mirror such that $\nu(\psi)U^{\gamma}(\psi) = const$ radially, where γ the specific heat index, U the specific volume of a magnetic field line defined by[2],

$$U(\psi) = \int \frac{\hat{p}_{\perp}(\chi) + \hat{p}_{\parallel}(\chi)}{B^2} \mathrm{d}\chi$$

Here plasma pressure is assumed to be represented by a separation of variables $p(\psi, \chi) = \hat{p}(\chi)\nu(\psi)$ and $\boldsymbol{B} = \nabla\psi \times \nabla\theta = \nabla\chi$. The stability criterion of flute modes in a mirror is given by

$$\frac{\partial U(\psi)}{\partial \psi} = -\frac{1}{2} \int \frac{(\hat{p}_{\perp} + \hat{p}_{\parallel})\kappa_{\psi}}{B^2} \mathrm{d}\chi \leq 0$$

Here κ_{ψ} is the normal component of magnetic field line curvature $\boldsymbol{\kappa} = \kappa_{\psi}\nabla\psi + \kappa_{\theta}\nabla\theta$. The criterion $\partial U/\partial\psi \leq 0$ can be applied to a non-paraxial device such as a divertor as well as the GAMMA10 tandem mirror with a long thin magnetic field.

The divertor mirror has an x-point, where the magnitude of magnetic field is zero, so that there is a large classical radial transport across the separatrix. Here separatrix is a magnetic flux tube, the field lines on which pass through x-point. The stability condition $\nu U^{\gamma} = const$, therefore, is broken near the separatrix, and the flute modes become unstable. The flute instability and the associated radial transport in such a situation has been investigated[3,4]. The divertor simulations[3,4] and other divertor stability analysis such Ref.[1] assume the boundary condition $\tilde{\phi} = 0$ on the separatrix, where $\tilde{\phi}$ is the perturbed electrostatic potential. This boundary condition is used in all of the arti-

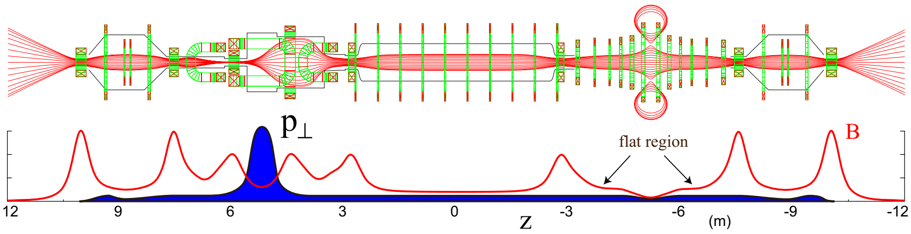

Figure 1: GAMMA10 A-divertor

cles on the divertor mirror to the first author's knowledge. The condition $\tilde{\phi} = 0$ on the separatrix results from the electron short circuit effects along the azimuthal magnetic null line at x-point. However, the resistivity can generate due to the chaotic orbits of particles[5], so that the boundary condition $\tilde{\phi} = 0$ at x-point may not be applicable. Therefore, it is necessary to carry out the simulation on the flute instabilities without the boundary condition of $\tilde{\phi} = 0$ at x-point.

2. Simulation Results

In order not to use the boundary condition $\tilde{\phi} = 0$ at x-point, we include the dipole region as well as the divertor region.

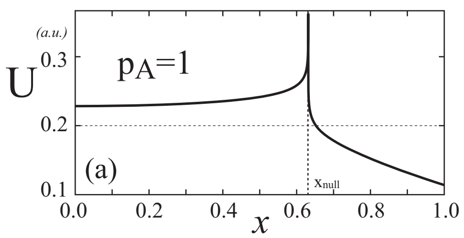

Figure 2: Radial profile of specific volume.

Figure 2 plots the radial profile of the specific volume of the GAMMA10 A-divertor. There is the x-point around $x \simeq 0.63$, where the dipole region is $x \gtrsim 0.63$ and the divertor region is $x \lesssim 0.63$. Therefore the boundary condition $\tilde{\phi} = 0$ at $x \simeq 0.63$ is not used in the simulation here.

The basic equations are the reduced MHD equations which are described in Refs.[3,4]. The boundary condition is that $\tilde{\phi} = 0$ at $x = 1$, where is near the inner coils inside the dipole region. In the simulation the plasma pressure in the anchor mirror cell was made the same as that in the central cell and the divertor mirror cell, so that the system is unstable to the flute modes.

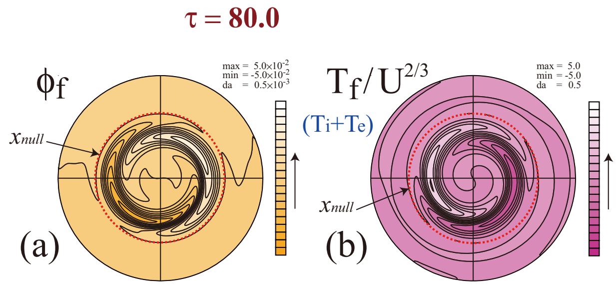

Figure 3: Contour plots of $\tilde{\phi}$ and $\widetilde{T}_i + \widetilde{T}_e$.

The flute instability grew in the linear phase and then entered into the non-linear saturation phase. Figure 3 plots $\tilde{\phi}$ and $\widetilde{T}_i + \widetilde{T}_e$ at the end of linear phase of normalized time $\tau = 80$. It is found that the flute modes are localized just inside x-point (x_{null}). The remarkable feature is that $\tilde{\phi} \simeq 0$ in the dipole region because the magnetic field lines in the dipole region have a good curvature for the divertor region as seen in Fig.2.

3. Conclusion

We carried out the numerical simulation of flute instability in the GAMMA10 A-divertor including the dipole region. It has been found that $\tilde{\phi} \simeq 0$ in the dipole region even if the flute modes are unstable. Therefore it is concluded that $\tilde{\phi} = 0$ at x-point can be used as a boundary condition in the divertor[6].

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