

Modeling of MHD Stability Consistent to the Transport

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Introduction

Burning plasma contains complex physics produced by coupling of some physical-factors that are transport, MHD, wave-particle interaction, plasma-wall interaction and so on. These physical factors have widely different time scale (10^{-10} to 10^3 sec) and different spatial scales (10^{-6} to 10^2 m), and these are linked with each other. Especially, the tokamak burning plasma has an autonomous property due to the large fusion power against the additional heating power and due to the large bootstrap current against the total current. To predict and control the burning plasma, the simulation code including these complex factors is necessary. At the present, it is not realistic to simulate the whole burning plasma based on the first principle such as the particle simulation. Therefore, the modeling of the various physics in tokamak plasmas and the integration of the models are necessary. In this paper, the plan of the integrated modeling of the tokamak physics is described and the progress on the modeling of Edge Localized Mode (ELM) is presented.

Integrated modeling in JAERI

To simulate complex burning plasmas, the integration of the simulation codes based on the 1.5D transport code, TOPICS[1], is planned in JAERI. TOPICS code solves the 1D transport equation, the current diffusion equation and the 2D Grad-Shafranov equation for the real configuration. It is organized to integrate the physical factors which are the current drive, the impurity transport, edge pedestal model, divertor model, MHD and high energy behavior model (Fig.1). The heating and current drive source of NBI is obtained by the 1D or 2D Fokker-Planck codes, and the source of RF (ECCD/ECH)

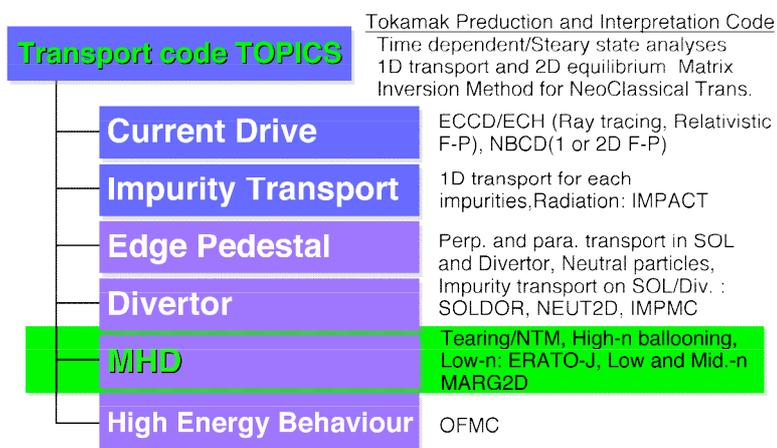


Fig.1 Burning Plasma Simulation Code Cluster in JAERI

is obtained by the ray tracing and the Fokker-Planck codes with the relativistic effect. Impurity behaviors are solved by 1D transport code IMPACT with TOPICS. Physics on the divertor is solved by the integration of the fluid model of SOL/Divertor, SOLDOR, and models of neutrals and impurities using Monte Carlo method, NEUT2D and IMPMC. MHD stability codes are coupled to the TOPICS code to obtain the MHD stability consistent to the transport for the analysis of beta limits, neo-classical tearing mode (NTM) and ELMs. Here, the ELM model by using the integrated code of the transport and MHD stability is presented.

Model of MHD stability consistent to the transport

ELMs are important from viewpoints of the heat load on the divertor plate, the plasma confinement and the plasma control for the steady state. The ELM phenomena are mainly considered to be induced by the high-n ballooning mode due to the large pressure gradient or by the medium-n peeling mode due to the large edge current and the pressure gradient. To evaluate the time-dependent effect of the ELM activity on the confinement of burning plasma, here we develop an integrated transport simulation model using both of TOPICS code and the linear MHD instability code MARG2D [2].

MARG2D code solves the eigen-value problem associated with the 2D Newcomb equation. MARG2D is applicable for medium-n modes stability analysis and its calculation time is very short. To simulate the ELMs, the MARG2D is solved on each time step of the transport code TOPICS. The thermal diffusivity is enhanced according to the radial profile of the eigen function when the mode becomes unstable.

Simulation of ELMs

ELM activity is simulated for JT-60U like parameters as follows: $R_{\text{maj}}=3.4\text{m}$, $a=0.9\text{m}$, $\kappa\sim 1.5$, $\delta\sim 0.2$, $I_p=1.5\text{MA}$, $B_t=3.5\text{T}$ and $\beta_N\sim 0.5-0.8$. The heat and particle diffusivities are assumed as, $\chi_{i,e} = \chi_{neo,i} + \chi_{ano,i,e}$ where $\chi_{neo,i}$ denotes the neoclassical ion thermal diffusivities calculated by the matrix inversion method [3]. The anomalous diffusivities $\chi_{ano,i,e}$ are simply given as $\chi_{ano,i} = 0.18[m^2/s] \times (1 + 2\rho^3) \left(1 + \sqrt{\hat{P}_{NB}}\right)$ and $\chi_{ano,e} = \chi_{ano,i}/2$, where \hat{P}_{NB} is the normalized NB power [4]. To make the pedestal structure, the $\chi_{i,e}$ near the edge ($\rho > 0.9$) is set to the neo-classical level ($\chi_{ano,i,e} = 0$). Here, the density profile is fixed as $n_e = 0.33 \times 10^{20} [m] \times \left[0.7(1 - \rho^2)^{0.5} + 0.3\right]$. Z_{eff} is 2.8 near the center and gradually decrease

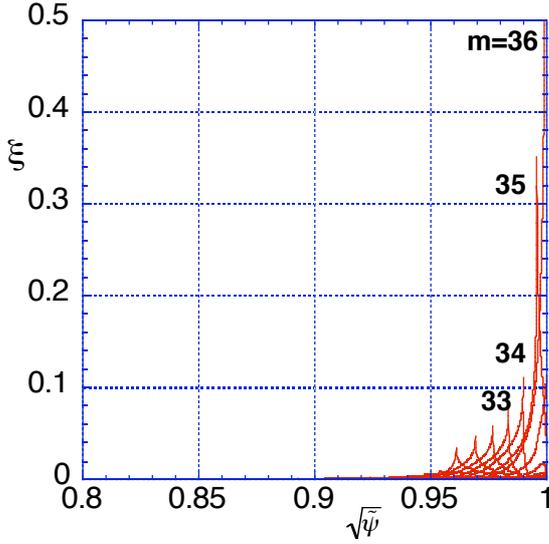


Fig.2 Eigen function of the $n=7$ unstable mode at 1.299s. The maximum is normalized to one.

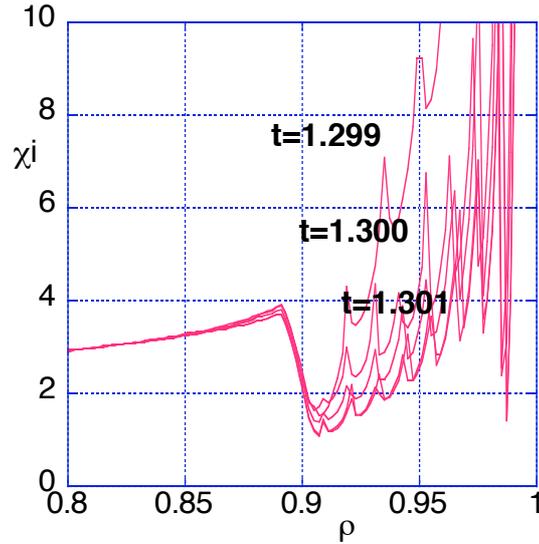


Fig.3 Enhancement of χ_i according to the most unstable eigen-function.

to 2.3 near the edge. Stabilities of several finite n modes, from $n=1$ to $n=10$, are examined in each time step.

The simulation starts on the nearly steady state and the reduction of χ edge begin at $t=1$ s. After the evolution of the pedestal, the $n=7$ mode becomes unstable at $t=1.299$ s. Here we note the n -infinity ballooning mode is stable in a whole plasma region. Figure 2 shows the radial component of the eigen function, $\bar{f}_{eig}(\rho)$, of the unstable mode at 1.299s, and the heat conductivity is enhanced as follows: $\chi_{i,e} = \chi_{neo,i} + \chi_{ano,i,e} + \chi_{ELM}$ and $\chi_{ELM} = 1000 \times \bar{f}_{eig}(\rho)^2$ (Fig.3). Since the unstable mode is localized near the edge, the collapse of the temperature profile at first occurs outside region ($r > 0.9$), and next the relaxation of the shoulder of the pedestal appears, as shown in Fig.4. During an ELM crash, the current density does not change very much (Fig.5) due to the longer current diffusion time without including a model of stochastic current diffusion. The most unstable mode changes to higher n modes. After the short period of the ELM crash, the finite- n MHD mode becomes stable and the evolution of the pedestal restart as shown in Fig.6. The pressure gradient locally increases as shown in Fig.7, but the finite- n and infinite n ballooning modes remain stable. The pressure gradient profile at $t=1.299$ s is shown for the comparison.

Summary

The integrated calculation of MHD stability code MARG2D and the transport code TOPICS is realized for the simulation of ELMs. A collapse event like the ELM, such as the degradation and the evolution of the pedestal structure, is reproduced. The improvement of the model, i.e., the decay and recovery time and pedestal profile, by the comparison with the

experiment are remained as future works.

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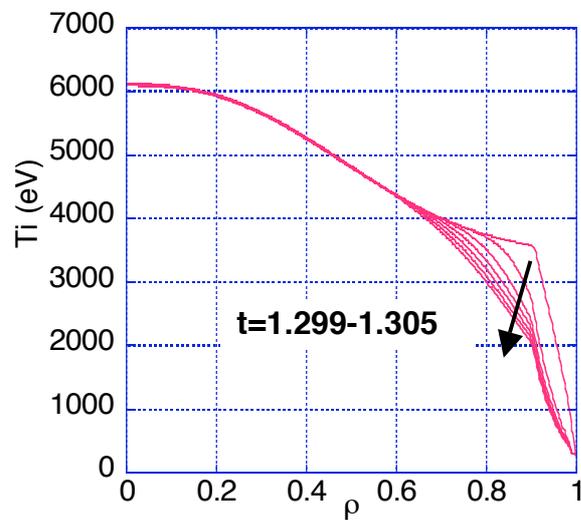


Fig.4 Degradation of the edge pedestal of the ion temperature

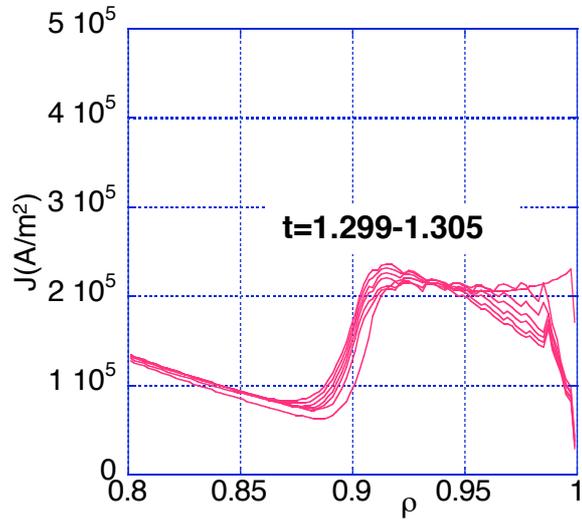


Fig.5 Change of the current density through the change of the pressure gradient

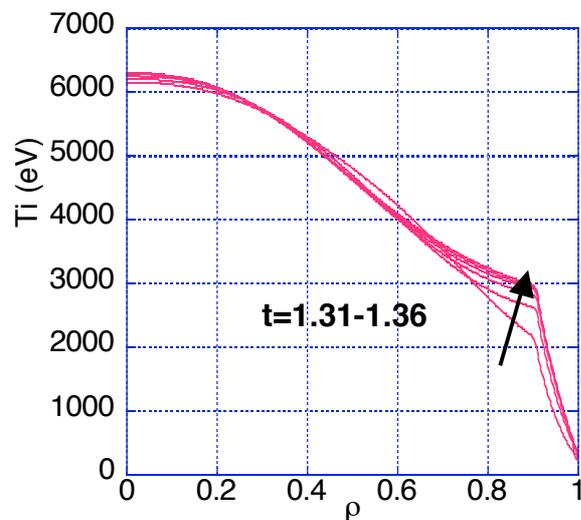


Fig.6 Re-buldup of the edge pedestal during an ELM

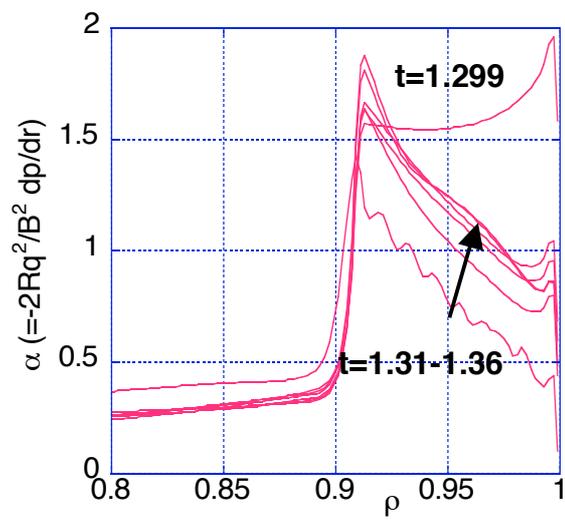


Fig.7 Increase of the normalized pressure gradient during an ELM.