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Simulation of the incident energy dependence on the effect of NBI in GAMMA 10

GAMMA 10におけるNBI効果の入射エネルギー依存性シミュレーション

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Neutral Beam Injection (NBI) have been installed at the central-cell and anchor-cell for plasma heating and particle fueling in GAMMA 10. The central-NBI is injected into ICRF-heated “high density mode” and “hot ion mode” plasmas. The increase in diamagnetism and electron line density was observed experimentally. A numerical simulation model using particles and energy balance equations was developed to investigate these modes and the effect of NBI heating in central-cell. This code is developed to evaluate as a neutron source towards the neutron irradiation of the fusion materials. For DT fusion condition energy dependence of NBI and high electron temperature for ECH is investigated

1. Introduction

It is an important to subject to increase the plasma temperature and density in magnetic confinement plasma devices, such as tokomak and helical and tandem mirror devices. Neutral Beam Injection (NBI) is a successful method for plasma heating and particle fueling [1-5].

The central-cell in GAMMA 10 is a simple axisymmetric mirror whose length is 6m. Neutral beam injection systems have been installed at the plug/barrier, anchor and the central regions as shown Fig.1. The central-cell NBI (NBI-c) system is used for main plasma heating and particle fueling.

In order to investigate the reactor materials, a neutron irradiation experiment is required as reactor engineering. We have the technique and experience of generation of high density and temperature plasmas using the tandem mirror device. It is necessary to perform the simulation which neutron flux expected in the present devices.

High-density-mode is one of the operation modes in GAMMA 10.This operation has high plasma density and low ion temperature. In order to raise the plasma parameter as the neutron source device, improvement in the NBI effect by high-density plasma production is required. The objective of this study is to estimate a plasma parameter required for nuclear fusion conditions according to the energy effect of NBI at high density operation.

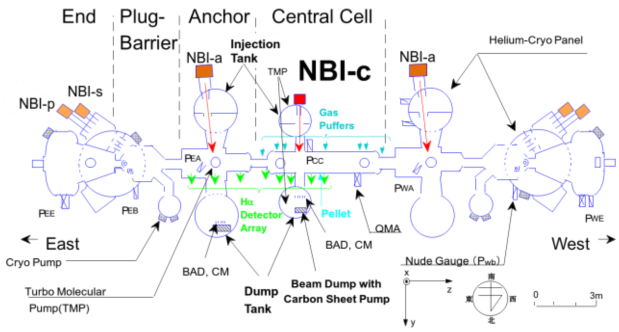

Fig. 1 Schematic illustration of the GAMMA 10

2. Simulation model

In order to explain the above experiment results, a numerical simulation model was developed. The model is composed of five differential equations based on the efflux and influx of particles and energy in the central cell. The equations are spatially zero dimensional and are solved numerically to simulate the time evolution of plasma parameters in the central cell [1]. Each equation as follows,

$$
\begin{aligned}
\frac{dn_0(t)}{dt} = {} & (\gamma-1)n_0(t)\{\delta(t)\alpha_h n_h(t)\langle\sigma v\rangle_{cx} + \alpha_w n_w(t)\langle\sigma v\rangle_{cx}\} \\
& + \delta(t)\gamma\frac{2r_p I(t)}{qV_p v_b}\{n_w(t)+n_h(t)\}\langle\sigma v\rangle_{cx} \\
& + \gamma\beta\frac{I(t)}{qV_{CC}} + S_{is} + S_{bg} + \frac{n_w(t)+n_h(t)}{\tau_{loss}} \\
& - n_0(t)[\{\alpha_h n_h(t) + \alpha_w n_w(t)\}\langle\sigma v\rangle_{pi} \\
& + \alpha_e\{n_w(t)+n_h(t)\}\langle\sigma v\rangle_{ei}] - \frac{n_0(t)}{\tau_{pump}} \qquad (1)
\end{aligned}
$$

for neutral particle density n_0,

$$\frac{dn_w(t)}{dt} = n_0(t)[\alpha_h n_h(t)\{\langle\sigma v\rangle_{pi} + \langle\sigma v\rangle_{cx}\} + \alpha_w n_w(t)\langle\sigma v\rangle_{pi} + \alpha_e\{n_w(t) + n_h(t)\}\langle\sigma v\rangle_{ei}] + \frac{n_h(t)}{\tau_{sd}} + S_{bg} - n_w(t)\frac{2r_p I(t)}{qV_p v_b}\langle\sigma v\rangle_{cx} - \frac{n_w(t)}{\tau_{Mw}} - \frac{n_w(t)}{\tau_{loss}} \qquad (2)$$

for warm ion density n_w,

$$\frac{dn_h(t)}{dt} = \frac{2r_p I(t)}{qV_p v_b}[\{n_w(t) + n_h(t)\}\{\langle\sigma v\rangle_{pi} + \langle\sigma v\rangle_{ei}\} + n_w(t)\langle\sigma v\rangle_{cx}] - \alpha_h n_0(t) n_h(t)\langle\sigma v\rangle_{cx} - \frac{n_{h(t)}}{\tau_{sd}} - \frac{n_{h(t)}}{\tau_{Mh}} - \frac{n_{h(t)}}{\tau_{loss}} \qquad (3)$$

for hot ion density n_h,

$$\frac{dW_w(t)}{dt} = \frac{\frac{3}{2}T_w(t)n_h(t)}{\tau_{sd}} + \frac{n_h(t)\left\{E_b - \frac{3}{2}T_w(t)\right\}}{\tau_{id}} + Q_{bg}^w - \alpha_w W_w(t) n_0(t)\langle\sigma v\rangle_{cx} - \frac{\frac{3}{2}n_w(t)\{T_w(t) - T_e(t)\}}{\tau_{ed}^{warm}} - \frac{W_w(t)2r_p I(t)}{qV_p v_b}\langle\sigma v\rangle_{cx} - \frac{W_w(t)}{\tau_E^{warm}} - \frac{W_w(t)}{\tau_{loss}} \qquad (4)$$

for warm ion energy density W_w,

$$\frac{dW_e(t)}{dt} = \frac{m_e}{m_p + m_e}\frac{2r_p I(t)}{qV_p v_b}\{n_w(t) + n_h(t)\}\{\langle\sigma v\rangle_{pi} + \langle\sigma v\rangle_{ei}\}E_b + \frac{n_h(t)\left\{E_b - \frac{3}{2}T_e(t)\right\}}{\tau_{ed}^{hot}} + \frac{\frac{3}{2}n_w(t)\{T_w - T_e(t)\}}{\tau_{ed}^{warm}} - \frac{\kappa W_e(t)}{\tau_E^{electron}} - \frac{W_e(t)}{\tau_{loss}^{electron}} \qquad (5)$$

for electron energy density W_e,

3. Simulation result

Fig. 2 and 3 shows and example of the comparison between hot ion and high density mode. Although DM_{CC} fall in hot ion mode, DM_{CC} rises during NBI in high density mode. The simulation of the high energy NBI was shown in Fig. 4 on the basis of high density mode. In this simulation, initial ion density n_w is decided to be $2.5 \times 10^{19}\,m^{-3}$ and energy is changed from 20 to 500eV. As shown in a figure, when energy was raised, it turned out that DM_{CC} continues going up during NBI for 10 to 20 ms.

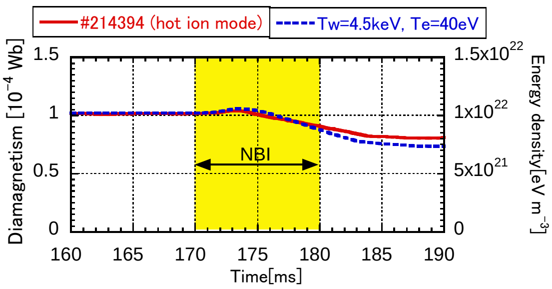

Fig. 2 Comparison between experiment and simulation in hot ion mode

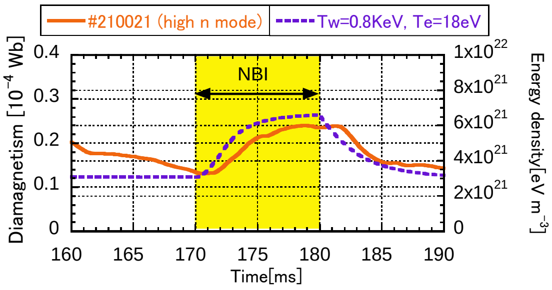

Fig. 3 Comparison between experiment and simulation in high density mode

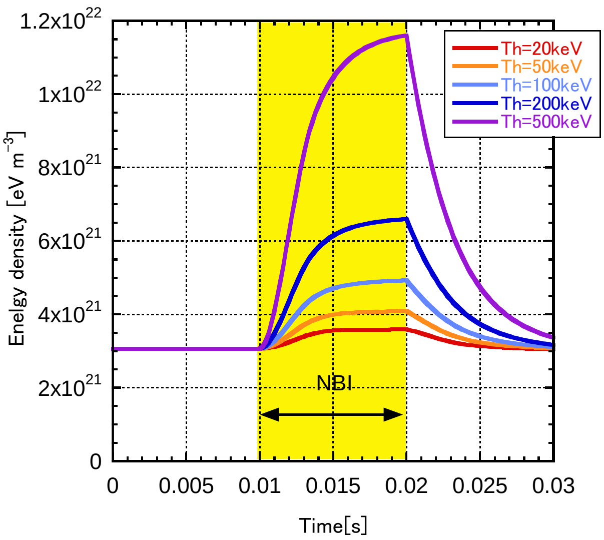

Fig. 4 Energy dependence on the effect of C-NBI

4. Summary and future plan

In this development of the simulation code, the effect of C-NBI in GAMMA 10 is fairly reproducible. As the energy of NBI increases, it turned out that DM_{CC} rises significantly.

In the future, fuel spices are changed into deuterium and the spices of the neutral beam is changed into deuterium or tritium, and it evaluated how much neutron flux can be generated in GAMMA 10.

References

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