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Discharge optimization of micro-Tokamak device using Electron-cyclotron heating

電子サイクロトロン加熱を用いた超小型トカマクにおける放電調整

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It is known that the loop voltage of a superconducting tokamak device is limited. In small tokamak devices, error field, short connection length and misalignment of coils generally all lead to an increase of required loop voltage. In order to elaborate a quantitative picture related to the equilibrium formation, an electromagnetic theory-based model was developed. We have performed the detail comparison of the numerical results with magnetic measurements. In addition, an influence of ECH that strongly modify the kinetic processes is presented in the poster.

1. Introduction

In many large tokamaks, reduction of the breakdown loop voltage has been investigated using ECH preionization and the electric field of 0.15Vm^{-1} achieved in DIII-D is the lowest documented record for plasma breakdown under an externally applied loop voltage[1,2]. We have performed reduction of the required loop voltage in micro-Tokamak device[3]. As a result of our previous research, the ionization assists of the glow discharge and the thermal electron emitter are not able to be used for the method of preionization because of its high utilizable gas pressure (0.9~10Pa) and its produced error field. Since plasma current ramp-up could not occur in simple calculation of the breakdown, we need to elaborate the comprehensive models. Therefore, we have performed the model computation and introduced ECH preionization to micro-Tokamak device. We will present the detail comparison of its numerical results with magnetic measurements and the influence of ECH for the breakdown loop voltage.

2. Overview of micro-Tokamak device

Micro-Tokamak device has been developed for a device processing, such as a semiconductor manufacturing process, and designed with the equilibrium code TOSCA. The device parameters are shown in Table 1[4] and Fig.1 shows the top view photo of the device. The device has toroidal field coil (TF, 12 segments), the center solenoid coil (ohmic heating coil: F, 56 turns) and 3 types of poloidal field coils (vertical coil: V, 14 turns, horizontal coil: H, 4 turns and divertor coil: D, 2 turns). Fig.2 shows the alignment of confinement field coils.

Table 1. Micro-Tokamak device parameter

Major radius R_0	0.06 m
Minor radisu a	0.02 m
Plasma current I_p	~100A
Toroidal Field B_t	0.05T

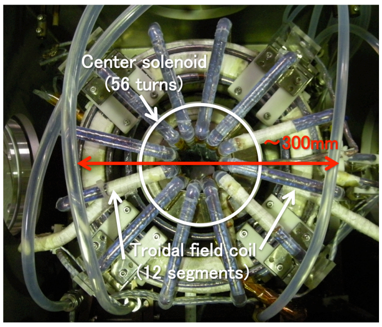

Fig. 1 Top view photo of the device

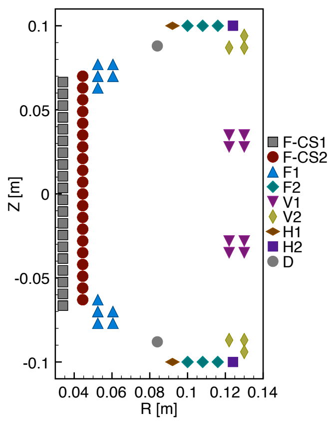

Fig.2 The alignment of confinement field coils

3. Numerical results of vaccum magnetic and electric field

In order to design the current waveform and estimate the misalignment of coils, we carried out the model computation of poloidal magnetic field and toroidal electric field in a poloidal cross section. A poloidal flux based on the Green's function for a toroidal current source is given by[5]:

$$\Psi(R,Z)=\frac{\mu_0 I}{k}\sqrt{R_c R}\left[\left(2-k^2\right)K\left(k^2\right)-2E\left(k^2\right)\right] \quad (1)$$

$$k^2=4RR_c\Big/\left(R+R_c\right)^2+\left(Z-Z_c\right)^2$$

where Ψ is poloidal flux, I is coil current, (R_c,Z_c) is the coil position, μ_0 is the magnetic permeability and K and E are the elliptic integral of the first kind and the second kind respectively. The magnetic field calculation is based on its partial derivative with respect to the coordinates (R,Z). And the electric field calculation is based on its partial derivative with respect to time. Thus, the electric field is given by:

$$E_\phi=-\frac{\partial A_\phi}{\partial t}=\frac{1}{2\pi R}\frac{\partial \Psi}{\partial t} \quad (2)$$

The numerical results of magnetic field indicated the existence of the current condition of minimum poloidal field. The perpendicular magnetic field at that condition is shown in Fig.3 (a). It shows the wide area of small poloidal field (< 0.2mT).

(a) (b)

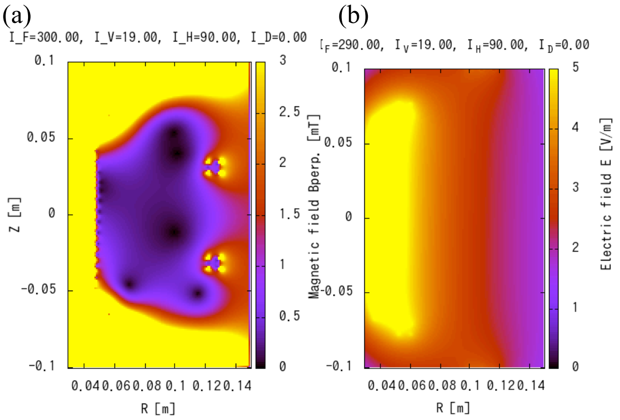

Fig.3 Numerical results of magnetic (a) and electric field(b)

The electric field numerical result at dI_F/dt = -1.0kA/ms in this current condition is shown in Fig.3 (b). It shows the toroidal electric field is about 3 ~ 4 V/m at $R=R_0$. The waveform used in the model computation is shown in Fig. 5.

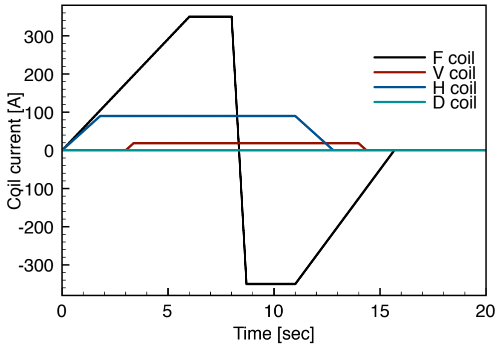

Fig.4 Current waveform of the operation

4. Comparing both results of model computation and measurement

In order to introduce ECH in the device and estimate the model, we measured the toroidal field and compare the value of measurement with the calculated result of toroidal field(shown in Fig.5)[6]. Fig.6 indicates that the measurement result(0.04T at $R=R_0$) is smaller than designed value(0.05T at $R=R_0$).

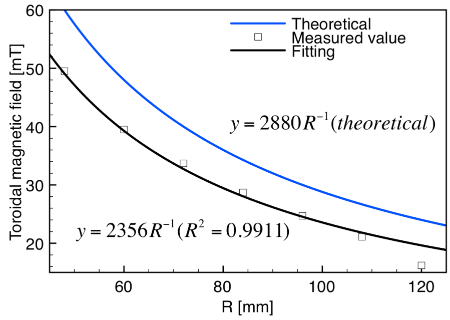

Fig.5 Comparison result about toroidal field

In addition, by comparing numerical results with magnetic measurements, we have verified the validity of the numerical model. Fig.6 shows the comparison result of poloidal field B_Z at mid plane in the minimum poloidal field condition.

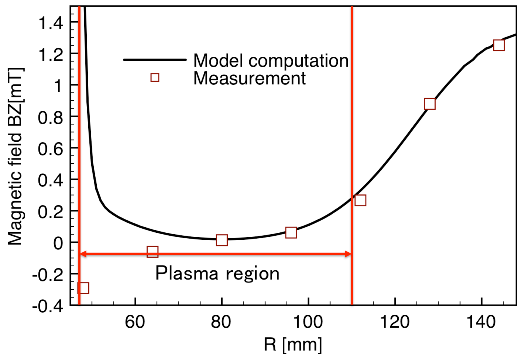

Fig.6 model validation about B_Z at midplane(Z=0)

It indicates large differences exist between the numerical result and the measured value for R<70mm. In 70mm < R < 140mm region, the model computation could describes the characteristic of B_Z. Moreover, It would be need to compare the other current set and search better condition in relating to the poloidal magnetic field.

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