Investigation on Optimal Limiter Condition for Stable Sustainment of the Potential Confined Plasma in GAMMA 10

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In GAMMA 10, Electron Cyclotron Heating (ECH) is used for the formation of the axial confining potential (P-ECH) and for the bulk electron heating in central-cell (C-ECH). The paper describes the dependence of the diameter of the iris limiters on the plasma stored energy and the hydrogen recycling. In this experiment, it was observed that the plasma diamagnetism was degraded with the ECH injection and Hα emission was increased near the limiters at the same time. In the case that the diameter of the iris limiters shrunk to 350 mm, the plasma diamagnetism decreased with each ECH by the plasma-limiter interaction. On the other hand, in the case that the diameter of the iris limiters widened to 380 mm, the diamagnetism of the plasma increased with P-ECH, however the plasma collapsed with C-ECH. The above results indicated the close relationship between the iris limiters and the plasma stability. In this paper, we discuss the mechanism of the degradation of the plasma performance and the optimal limiter condition for effective operation of ECH.

Keywords: GAMMA 10, tandem mirror, limiter, hydrogen recycling, Hα, DEGAS, medium-speed camera, ECH

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1. Introduction

In magnetic confining fusion devices, particle balance is important issues for stable sustainment of the potential confined plasma. Control of the plasma diameter by the limiter causes the hydrogen recycling around the limiters. Recycling phenomena on the limiters have a more significant influence on the plasma performance compared with those on the other vessel wall, since the limiters are located near the plasma boundary.

In the GAMMA 10 central-cell, a central limiter and two iris limiters have been installed, the former is fixed type of limiter and the latter are capable of changing each diameter [1]. ECH systems are installed on the central-cell and plug/barrier-cells. These are used for heating bulk electron and the formation of the axial confining potentials [2].

In order to measure neutral particles, Hα emission detectors and medium-speed camera have been installed [1, 3]. Hα emission detectors are located near each limiter for observing the recycling source around the limiters.

The diameter of the iris limiters have been properly changed corresponding to the experimental objectives. The purpose of this experiment is to comprehend the mechanism of the degradation of the plasma performance, and to find the optimal limiter condition for effective operation of ECH. In this paper Hα emission intensity and the plasma parameters are analyzed in terms of the iris limiters. We examine the mechanism of the plasma collapse and the deterioration in the plasma performance from analytical results. In section 2, an experimental setup is described. In section 3, experimental results are shown. In section 4, simulation method to investigate the axial distribution of Hα emission intensity and results is explained. Finally, experimental results and simulation results are discussed in section 5.

2. Experimental Setup

The GAMMA 10 tandem mirror is open magnetic plasma-confining device with thermal barrier [4]. It consists of central-cell, anchor-cells, plug/barrier-cells, and end-cells. Mid-plane of the central-cell is $z = 0$ cm and west and east sides correspond to plus and minus in z-axis, respectively. Central-cell is the main region to confine plasma and 6 m in length and the diameter of 1 m. Mirror-throat regions which exist between the central-cell and each anchor-cell have the first mirror with strong magnetic field for the confining plasma in the central-cell. In standard hot-ion mode plasmas, initial plasma is build up by plasma guns located in both ends. Then plasma is sus-

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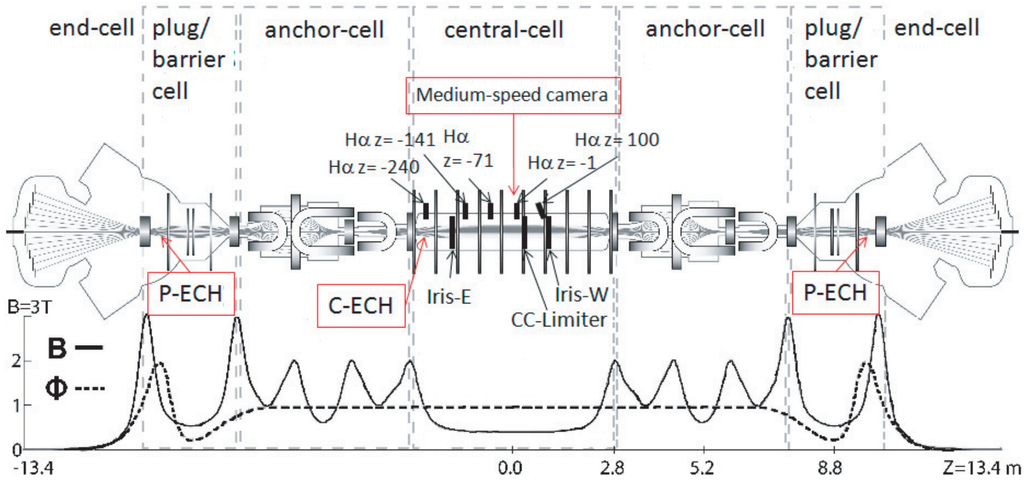

Fig. 1 The overall of the GAMMA 10. The plasma and vacuum vessel structure and the limiters are illustrated.

tained by gas puffing coupling with ion cyclotron heating. C-ECH and neutral beam injection (NBI) are additionally supplied for the plasma production and heating. The power of ECH used in this experiment is comparatively high. The power of P-ECH is 380 kW, and that of C-ECH is 150 kW. C-ECH is installed at central-cell and P-ECH is installed at plug/barrier-cell. A typical electron line integrated density reaches 4×10^{13} cm^{-2} in the central-cell.

Figure 1 shows the schematic view of GAMMA 10 and axial profile of magnetic field strength and electric static potential. Locations of axially aligned Hα emission detectors and the medium-speed camera are also shown in the figure. The central limiter is located at $z = +30$ cm, the west and east limiters are located at $z = 100$ cm and $z = -155$ cm, respectively. The central limiter is the fixed type of limiter and 400 mm in diameters, while the iris limiter is radially variable type of limiter. The diameter of the limiter can be changed within 340 mm to 400 mm. In the cases of usual limiter position, the diameter of the iris limiters is 360 mm ($d = {}^{\phi}360$ cm). Each aligned Hα emission detector in the central-cell has been located at $z = 100$, -1, -71, -141, and -240 cm, respectively. Medium-speed camera has located at $z = 0$ cm. A microwave for C-ECH is launched in the mirror-throat region on the east side and the microwave power is absorbed near a fundamental harmonic region around $z = -245$ cm.

3. Experimental Results

Figure 2 shows the temporal behavior of the plasma parameters and Hα emission intensity in the two different cases of the diameter of the iris limiters. In the case of $d = {}^{\phi}350$ mm, as shown in Fig. 2 (a), the diamagnetic signal (DMcc) is degraded with both P-ECH and C-ECH. The Hα emission intensity increases near the limiters in each ECH period. The electron line integrated density (NLcc) measured at the central-cell increases in P-ECH period however, in the case of C-ECH, NLcc decreases just after the start of the ECH pulse. In another shot, in extremely bad condition, the plasma collapses with P-ECH on the same sequence of the plasma production/heating systems. The Hα emission intensity also remarkably increases near the limiters at the same time. The two-dimensional visible image of the central-cell plasma captured by the medium-speed camera at the time just before collapsing is shown in Fig. 3. This strong emission suggests that a large amount of the hydrogen recycling is produced from the limiters.

On the other hand, in the case of $d = {}^{\phi}380$ mm, as shown in Fig. 2 (b), the plasma performance improves with P-ECH. However the plasma collapses with C-ECH. Hα emission is not significantly changed during P-ECH compared with the case of the diameter 350 mm. Additionally, Hα emission intensity gradually decreases with the passage of time. The interaction between the plasma and the limiter is small in the case of $d = {}^{\phi}380$ mm.

In Fig. 4 (a), NLcc and DMcc are plotted as a function of the diameter of the iris limiters. In this case, the diameters of both iris limiters are kept at the same diameter. It is confirmed that NLcc tends to increase according to the reduction of the diameter of the iris limiters. On the contrary, DMcc tends to decrease according to the reduction of the diameter of the iris limiters. In Fig. 4 (b), Hα intensity decreases with the limiter diameter, which indicates that the hydrogen recycling is enhanced due to the reduction of the limiter diameter. The dependence of Hα intensity in the west iris limiter is stronger than that in the east, since the position of the Hα emission detector is much closer to the west iris limiter.

4. Neutral Transport Simulation Near the East Iris Limiter

Monte-Carlo simulation code (DEGAS [5]) has been used in order to numerically calculate the neutral density coupling with the measurement of Hα emission detector in GAMMA 10 [6–8].

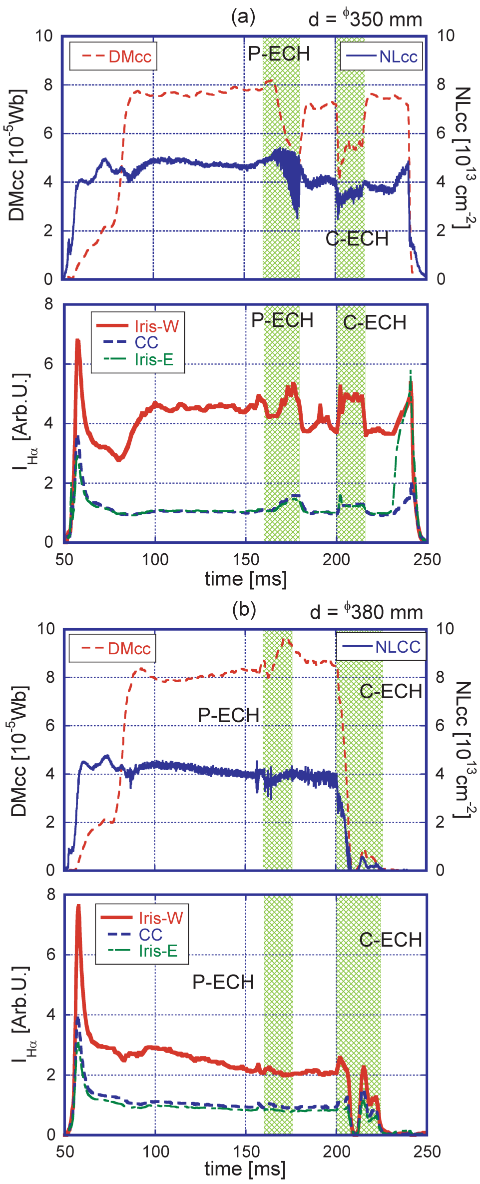

Fig. 2 The temporal behavior of plasma parameters and Hα emission intensity in the central-cell in the case of d = ϕ350 mm (a) and d = ϕ380 mm (b).

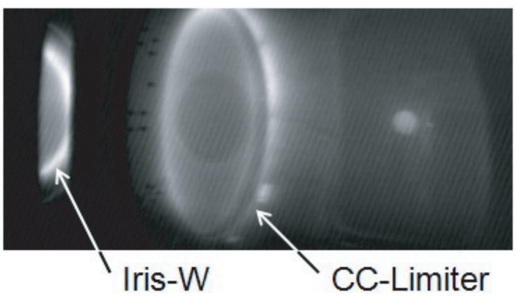

Fig. 3 2-D image of plasma near the west iris limiter and central-cell limiter taken by the medium-speed camera at the time just before collapsing. d = ϕ350 mm.

Fully three-dimensional mesh-model for DEGAS has been applied to the central-cell as shown in Fig. 5. In

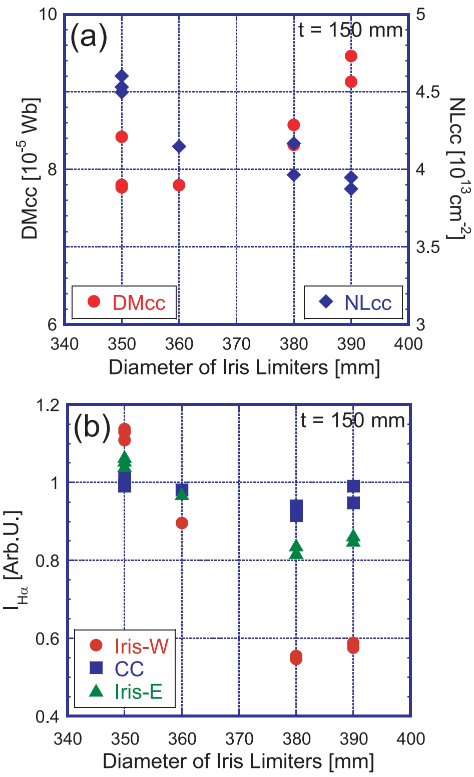

Fig. 4 NLcc (a) and Hα emission intensity on each limiter (b) versus the diameter of the iris limiters. The diameter of each iris limiter is the same diameter.

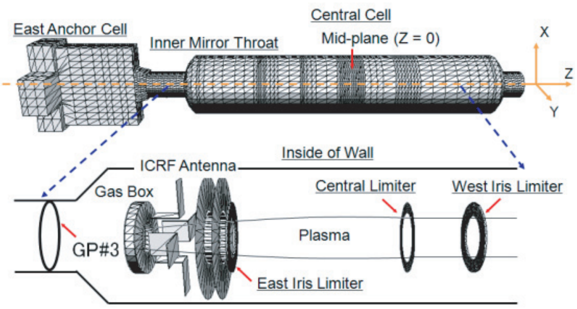

Fig. 5 The fully 3-dimensional DEGAS mesh-model.

this model the limiters, antenna of ion cyclotron radio frequency (ICRF) and gas puffer are precisely implemented in realistic configuration. The background plasma parameters (T_e, T_i, etc) were given based on the experimental data to each mesh. The neutral source is given at the gas puffer in the east mirror throat (GP#3) and on the east iris limiter. The Hα emission intensity is investigated for the influence of the hydrogen recycling on the plasma.

Figure 6 shows the axial distribution of the Hα emission intensity from the east mirror throat ($z = -310$ cm) toward the central-midplane ($z = 100$ cm) obtained from the DEGAS simulation. The Hα line intensity calculated by DEGAS simulation is normalized at the measured points ($z = -310$, -240 and -141 cm). The amount of the hydrogen recycling on the east iris limiter is calculated in

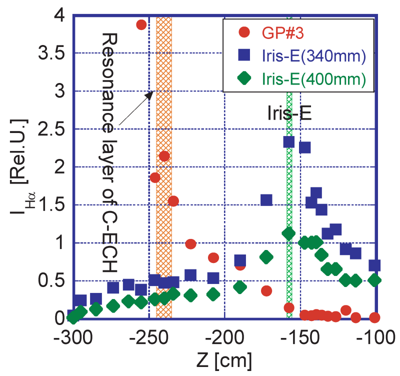

Fig. 6 The Hα emission intensity of the DEGAS simulation.

the two different cases of the diameter of the iris limiters. As shown in the figure, it is found that the neutral particle from GP#3 is dominant in the mirror throat region ($z = -300 \sim -250$ cm) and that the neutral particle from the east iris limiter becomes dominant near the iris limiter, since the influence of the particle of GP#3 becomes weak.

5. Discussion

From the experimental results, the deterioration of the plasma performance with ECH depends on the state of plasma before the ECH injection. In the case of $d = {}^{\Phi}350$ mm, a large amount of the hydrogen recycling from the iris limiters is observed. This observation indicates a possibility of the plasma collapse due to the rapid gas cooling. In this case, the plasma-limiter interaction becomes stronger by the P-ECH injection. In addition, the electric field induced by P-ECH causes off-axis rotation under the condition of non-axis symmetric heating [1], which enhanced the plasma limiter interaction. On the other hand, in the case of C-ECH, the radial transport may be caused by excessive power irradiation of microwave for electron heating. In both ECH cases, the plasma performance is degraded.

In the case of $d = {}^{\Phi}380$ mm, the degree of the hydrogen recycling on the limiters is observed to be low. NLcc is also lower than the cases of the usual limiter position. In addition, NLcc and the Hα emission intensity gradually decrease with the progress of time as shown in Fig. 2 (b). It is considered that this state is easy to exhaust of plasma particle. If ECH is injected to the plasma in this state, the condition of confinement is improved by the axial confining potential with P-ECH, which leads to an increase of DMcc. On the other hand, in the case of the C-ECH injection, radial transport by electron heating enhances exhaust of plasma particle, which leads to the plasma collapse.

In the cases of the usual limiter position, the plasma dose not collapse with C-ECH. It suggests that recycling gas of the iris limiter is ionized by C-ECH and the ionized particle is supplied to the plasma, and finally the plasma sustains. From the results of the simulation, the amount of the hydrogen recycling in the resonance layer of C-ECH is about 20 percent of the total amount of gas in this region. It has been ascertained that increasing the flowing quantity of GP#3 by about 10% has a good influence for the duration of plasma [1]. The simulation was consistent with a result of the experiment of additional gas puffing from the east mirror throat.

From the above results, if the limiter diameter is expanded in order to avoid a strong plasma-limiter interaction and compensation of loss particles is properly made, the operation of effective ECH becomes possible.

6. Summary

Optimal limiter condition for effective operation of ECH was investigated. From the experimental results, in the case of narrowed diameter, the plasma performance was degraded in both ECH cases. On the other hand, in the case of widened diameter, the plasma collapsed in C-ECH. Although optimal limiter condition for effective operation of all ECHs was not confirmed in these experiments, a profitable finding of the plasma duration was obtained.

In future, we will conduct the experiment to aim to prevent the exhaust of plasma particle during the C-ECH period by using an active particle supply. We will continue to improve the mesh model of the central-cell west side that more faithfully reproduces the experimental condition. The influence of the hydrogen recycling on the plasma will be investigated in both experiments and simulations.

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