

The Neutral Transport Analysis Based on Visible Light Measurement of Recycling and 3-Dimensional Simulation in GAMMA 10

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Neutral transport related to recycling phenomena on two limiters installed in the central-cell was studied in the GAMMA 10 tandem mirror plasmas. Dependence of iris limiter is investigated in terms of plasma diamagnetism and H_{α} -line intensity. It was found that a plasma diamagnetic signal was improved and H_{α} -line intensity near the iris limiter increased if the diameter of the iris limiter shrank to 340 mm. Fully 3-dimensional Monte-Carlo simulation (DEGAS) was executed with the recycling source on the limiters. The neutral sources on the limiters were consistently given so as to satisfy 2-dimensional (2-d) image obtained by a high-speed camera. The determined H_{α} -line intensity from DEGAS well explained the experimental result. The simulation result, in the 340 mm case, predicted the reduction in the peak value of H_{α} -line intensity on the central limiter and the enhancement on the iris limiter. It suggests that the reduction of the recycling on the central limiter makes it possible to lead the better plasma performance.

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1. Introduction

In magnetic confining fusion devices, particle balances are important issues for obtaining good plasma performances. Neutral particles induced by limiters, divertors, gas puffers and neutral beam injection (NBI) must be controlled on an appropriate quantity. Recycling phenomena on limiters have a more significant influence on plasma performance compared with those on the other vessel wall, since the limiters are located near the plasma boundary. The detailed analysis of neutral transport by the passive source such as limiters enables us to control the active neutral source such as gas puffers [1, 2].

In the GAMMA 10 central-cell, central limiter and iris limiter have been installed, the former is a fixed type of limiter and the latter is a radially variable type of limiter, respectively. Electron cyclotron resonance heating systems (ECRH) are installed on the central and plug/barrier cells. These are used for heating bulk electrons and producing plasma confinement potential [3].

In order to measure neutral particles, H_{α} -line detectors and high-speed camera have been installed [4, 5]. Axially and radially aligned H_{α} -line detectors take advantage of

the spatial distribution. The high-speed camera has been also mounted on the central mid-plane. It is sufficiently capable of measuring the light emission with a band of wavelength in visible ranges. Based on these measurements, the detailed neutral distribution is predicted by utilizing Monte-Carlo simulation code (DEGAS) [6, 7]. In the mesh-model for DEGAS, not only the vacuum vessel but also the inner structures including the central limiter and the iris limiter have been completely realized. The H_{α} emission on the each mesh is numerically solved using atomic and molecular hydrogen density.

Recently, the diameter of the iris limiter has been properly changed fitting the experimental objective, which has controlled the plasma condition. Especially, drastic improvements of the plasma performance were observed during ECRH in the central-cell (c-ECRH) by optimizing the diameter of the iris limiter. In this paper, axial H_{α} -line intensity and the plasma parameters are analyzed in terms of the iris limiter. Moreover, using DEGAS mesh-model, the H_{α} -line intensity distribution due to the recycling on the central limiter and the iris limiter is quantitatively estimated. Finally, appropriate recycling supplies for plasma by the neutral source are discussed.

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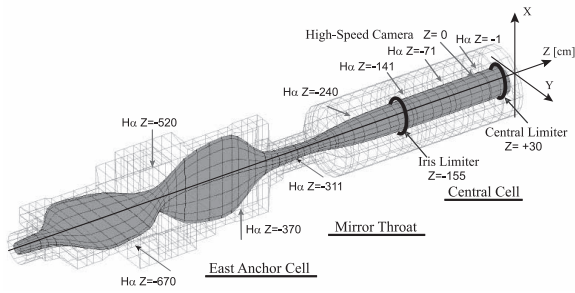


Fig. 1 The schematic view of Ha-line detectors and high-speed camera. The plasma and vacuum vessel structure and the limiters are illustrated.

2. Experimental Setup

The GAMMA10 tandem mirror is an open magnetic plasma-confining device with thermal barrier [8]. 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 side corresponds to plus and minus in Z -axis, respectively. Central-cell is the main region to confine plasma and is 6 m in length and the diameter of 1 m. Mirror-throat regions which exist on 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 built up by plasma guns located in both ends. Then plasma is sustained by gas puffing coupling with ion cyclotron heating. c-ECRH and neutral beam injection (NBI) [9] are additionally supplied for the plasma production and heating. A typical electron density reaches $4 \times 10^{12} \text{ cm}^{-3}$ in the central-cell.

Figure 1 shows the schematic view of the axially aligned H_{α} -line detectors, the high-speed camera and the location of the central limiter ($Z = +30$ cm) and the iris limiter ($Z = -155$ cm) together with magnetic flux tube and the vacuum vessel. In the central-cell, magnetic flux tube is expanded in the mid-plane, and shrinks toward the both mirror-throat regions. The central limiter is the fixed type of limiter and 360 mm in diameter, while the iris limiter is radially variable type of limiter. Each axially aligned H_{α} -line detector in the central-cell has been located at $Z = -1, -71, -141, -240$ and -311 cm, respectively. A microwave for c-ECRH is launched in the mirror-throat region on the east side and the microwave power is absorbed near a fundamental harmonic region around $Z = -240$ cm.

3. Experimental Results

Figure 2 shows the temporal distribution of plasma parameters and H_{α}/NLcc which means the H_{α} -line intensities divided into electron line density measured in the central-cell (NLcc) in the cases that the diameters of the iris limiter are 400 mm and 340 mm. It is obvious that diamagnetic signal (DMcc) and NLcc immediately drop after c-ECRH

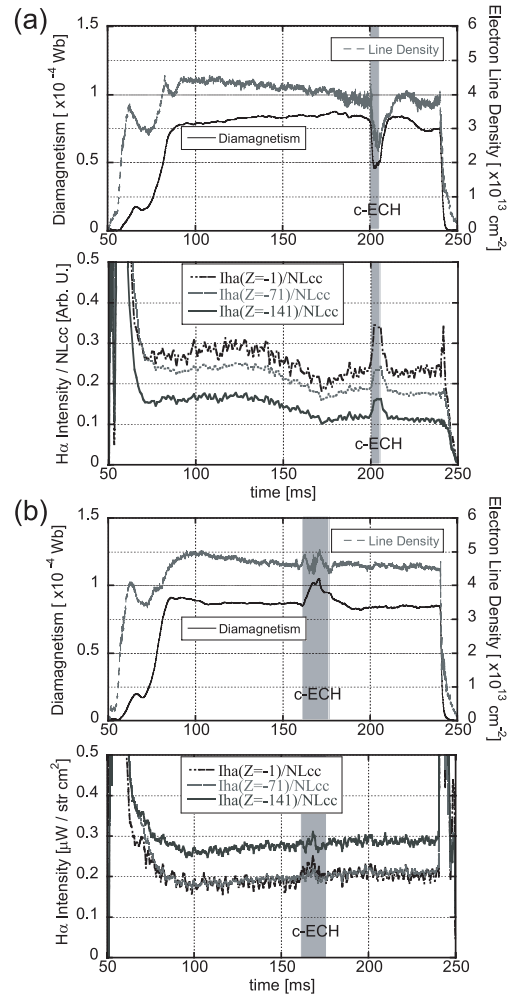


Fig. 2 The temporal distributions of plasma parameters and Ha-line intensity in the central-cell in the case of 400 mm (a) and 340 mm (b) in diameter of the iris limiter.

in the case of 400 mm. At the same time, H_{α}/NLcc remarkably increase, especially in $Z = -1$ cm where locate near the central limiter. In the whole plasma duration, H_{α}/NLcc in $Z = -1$ cm remains at the highest level, followed by $Z = -71$ cm and $Z = -141$ cm. In case that the diameter of iris limiter became 340 mm, on the other hand, DMcc gradually increases together with c-ECRH and then the H_{α} -line intensities hardly change during c-ECRH. It is found that H_{α}/NLcc in $Z = -141$ cm is kept in higher value than that in $Z = -1$ cm.

The relationship between the H_{α} -line intensity in $Z = -1$ cm and that in $Z = -141$ cm was examined in regard to the diameter of the iris limiter. In Fig. 3, the rate of the H_{α} -line intensity in $Z = -141$ cm to $Z = -1$ cm is plotted as a function of the diameter of the iris limiter. It is confirmed that this rate intends to increase according to the reduction of the diameter of the iris limiter.

4. Simulation Method

Monte Carlo simulation code (DEGAS) has been

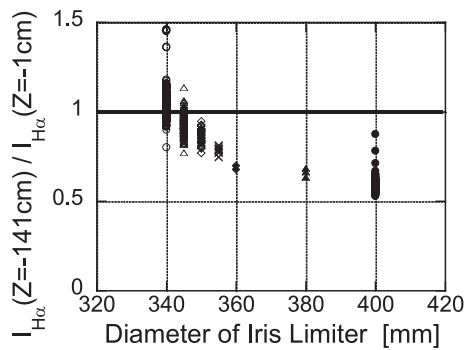


Fig. 3 The rate of H_{α} -line intensity in $Z = -141$ cm and $Z = -1$ cm versus the diameter of the iris limiter.

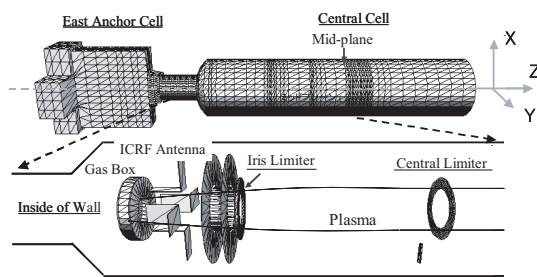


Fig. 4 The fully 3-dimensional DEGAS mesh-model.

used in order to numerically calculate the neutral density coupling with the measurement of H_{α} -line detectors and photographs by high-speed camera. Fully 3-dimensional mesh-model for DEGAS has been applied shown in Fig. 4. In this model of the central-cell, the limiters, antennas of ion-cyclotron radio frequency (ICRF) and gas puffers are precisely implemented in realistic configuration. Test particles defined as neutral hydrogen is randomly passing through the plasma or SOL in consideration of physical process. After that, atomic and molecular hydrogen densities are resolved at the each mesh. For the granular simulation of the recycling on the limiters, the iris limiter was newly added and the mesh of the central limiter separated in the large number.

5. Comparison Between Experiment and Simulation

Based on the 2-d images captured near the central limiter by using the high-speed camera, it was determined how to give test particles of the Monte-Carlo simulation on the limiters. The test particles defined as neutral hydrogen is initially given on the mesh of limiters to satisfy the 2-d image obtained by high-speed camera. As shown in Fig. 5 (a) and (b), the 2-d image of H_{α} -line intensity calculated by DEGAS is consistent with that by the high-speed camera.

The simulation was carried out in two cases that the diameter of the iris limiter is 400 mm and 340 mm. The neutral source was given in the central limiter and the iris limiter. Figure 6 shows the axial distribution of the H_{α} -

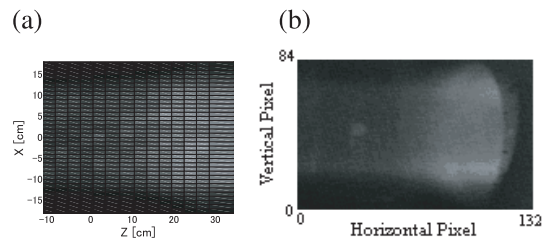


Fig. 5 2-d images by H_{α} calculation in the DEGAS simulation (a) and by high-speed camera (b) around the central limiter.

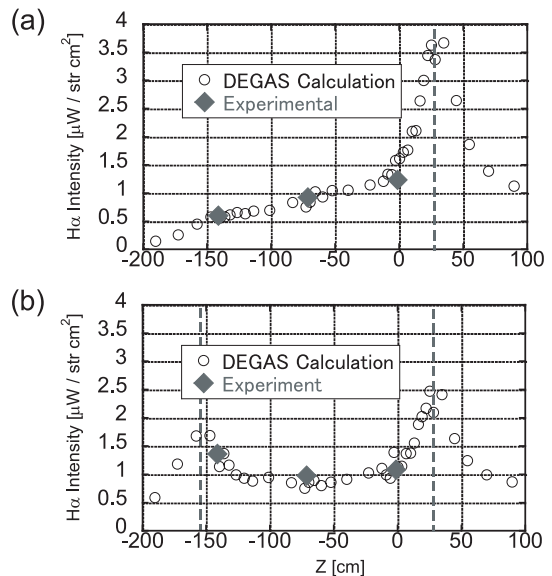


Fig. 6 The H_{α} -line intensity of the DEGAS simulation and the experiment in the case of 400 mm (a) and 340 mm (b) in diameter of the iris limiter.

line intensity obtained by the experiment and predicted from the DEGAS simulation. In cases that the diameter of iris limiter is 400 mm (Fig. 6 (a)), the simulation results are appropriately corresponding with the measurement if the neutral source is given only from the central limiter in the simulation. On the other hand, in the case of 340 mm (Fig. 6 (b)), both the central limiter and the iris limiter are defined as neutral source, which leads to the proper H_{α} -line intensity in axial distribution. Therefore, the H_{α} -line intensity profiles by DEGAS have two peaks on the central limiter and the iris limiter. Each peak shows a lower value than the one peak on the central limiter in the case of 400 mm.

6. Discussion

From the experimental and simulation results, it suggests that the iris limiter and the central limiter have much influence on the plasma condition and the neutral transport. It is certain that the iris limiter become a large number of neutral sources, as the diameter of the iris limiter is getting smaller. As the result, another peak of H_{α} -line intensity

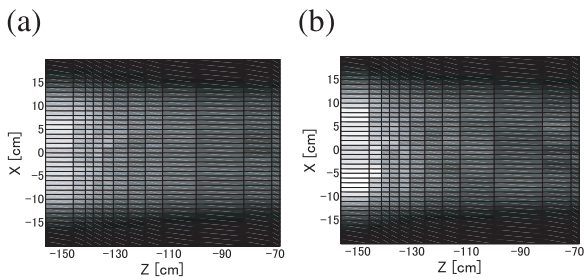


Fig. 7 2-d images by DEGAS around the iris limiter in the cases of 380 mm (a) and 340 mm (b).

distribution is formed around the iris limiter except around the central limiter. And then, it notes that the measurements of H_{α} /NLcc in $Z = -1$ cm are reduced and the peak around the central limiter of the simulation obviously decreases, if the iris limiter shrink from 400 mm to 340 mm in diameter.

The plasma in the central mid-plane has been sustained with high density and high energy compared to other positions. From the analysis of the high speed camera, rotations and vibrations of the plasma column during c-ECRH have been confirmed. Therefore, the excessive recycling source on the central limiter, especially during c-ECRH, maybe causes the degradation of the plasma performance. Consequently, it must be important for the plasma performance to decrease the recycling source on the central limiter such as in the case of 340 mm.

In order to estimate the effect of the iris limiter on the neutral transport, the localization of the H_{α} -line intensity related to the recycling source on the iris limiter was examined. This simulation was executed in the case of 380 mm and 340 mm in diameter of the iris limiter. Figure 7 shows the 2-d images of the calculated H_{α} -line intensity around the iris limiter in the both cases. The image in the 340 mm case is more enhanced at the near position of the iris limiter and reduced at distant locations compared with the 380 mm case. It is clarified that H_{α} -line intensity is much localized near the iris limiter if the diameter becomes narrower.

From the above results, it is expected that the local-

ization of the H_{α} -line intensity distribution on the limiters should be concerned with neutral transport. In future, in order to estimate the more detailed behavior of neutral particles around the limiters, the visible light measurements will be required in the nearer position of limiters.

7. Summary

Neutral transport related to the recycling phenomena on the limiters in the central-cell was analyzed. From the experiment, it was observed that the plasma diamagnetic signal increased in cases that the diameter of the iris limiter is 340 mm. The rate between H_{α} -line intensity in $Z = -141$ cm and that in $Z = -1$ cm proved to increase along with the reduction of the diameter size of the iris limiter.

The Monte-Carlo simulation was executed for the calculation of neutral transport due to recycling source on the limiters. In the case of 340 mm, the H_{α} -line intensity distribution by DEGAS has two peaks on the central and the iris limiter. Each peak takes a lower value than that of the central limiter on the condition of 400 mm. It suggests that the reduction of the recycling on the central limiter results in the improvement of the plasma performances.

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