Improvement of ICRF Antenna Loading in the Minimum-B Configuration on GAMMA 10*)

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On GAMMA10, waves in Ion-Cyclotron Range of Frequency (ICRF) are used to produce initial plasmas, heat plasmas and keep magneto-hydrodynamic (MHD) stability. High performance plasmas in the minimum-B configuration supply MHD stability. In order to enhance plasma heating, we introduce an ICRF system for heating plasmas in the anchor cell and evaluate its antenna loading. Changing the antenna shape is expected to improve antenna loading. In the experiment, we confirm to increase the antenna loading by changing the antenna shape from simple bar-type to the double elliptic arc type.

Keywords: GAMMA10, ICRF heating, minimum-B field, ICRF antenna, wave transmission

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1. Introduction

On the GAMMA10 tandem mirror, high performance plasmas are achieved with magneto-hydrodynamic (MHD) stability attained by the high-B plasmas in the minimum-B anchor cells [1, 2]. On GAMMA10, waves in the Ion-Cyclotron Range of Frequency (ICRF) are used for ion heating in the minimum-B field. In the standard discharge, waves in ICRF are excited and propagate to the anchor cell from Type-III antenna in the both end of the central cell. It is difficult to control only the heating effects in the anchor cell, because these ICRF waves are also used for the plasma production in the central cell. In order to enhance anchor heating, an antenna is installed in the anchor cell. In this manuscript, we study the dependence of the antenna shape on the coupling with the facing plasmas by the experiment.

This paper is organized as follows. The experimental setup, including the antenna designed for the anchor cell, is shown in the next section. The experimental results are discussed in section 3, followed by a summary in section 4.

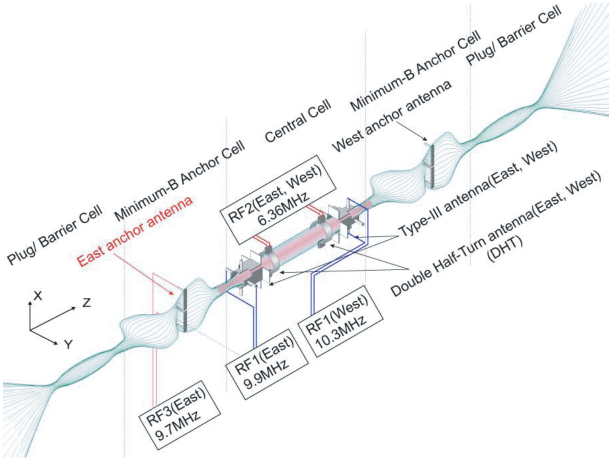

Fig. 1 Schematic drowing of magnetic lines ,and the five mirror configurations. Three ICRF systems are also indiceted.

2. Experimental Setup

GAMMA10, the largest tandem mirror device in the world, consists of five magnetic mirror configurations, which are a central cell, two minimum-B anchor cells connected on each sides of the central cell and a plug/barrier cell at each ends (Fig. 1). The central cell is 5.6 m in length with field strength of 0.4 T at the midplane. The anchor cells has non-axisymmetric minimum-B field configuration and is 1.6 m in length with the field strength of 0.6 T at the midplane. Figure 2 shows the axial profiles of the magnetic field and the values of $\omega/\Omega_{\mathrm{ci}}$ on GAMMA10, where ω is the applied frequency and Ω_{ci} is the cycltron-frequency at the axial location. The $\omega/\Omega_{\mathrm{ci}}$ values of waves at 6.36 MHz and near 10 MHz in the ICRF are shown on Fig. 2. Waves at 6.36 MHz have resonance layers in the central cell and waves of near 10 MHz have resonance layers at the end of the central cell and near the midplane of the minimum-B anchor cell. There are three ICRF sys-

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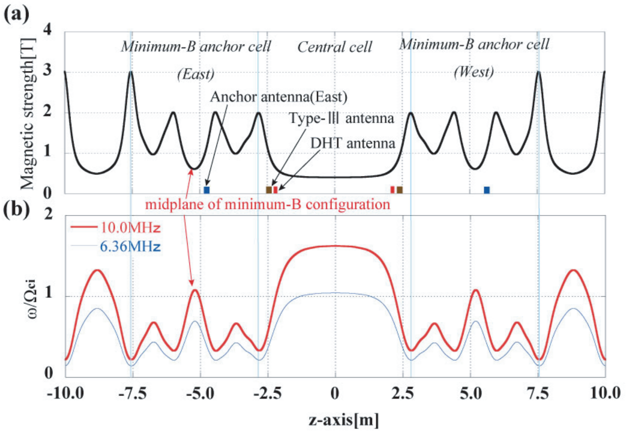

Fig. 2 Axial profile of (a) magnetic field and (b) value of $\omega/\Omega_{\mathrm{ci}}$ and locations of ICRF antennas in the central cell and the minimum-B anchor cells on GAMMA10.

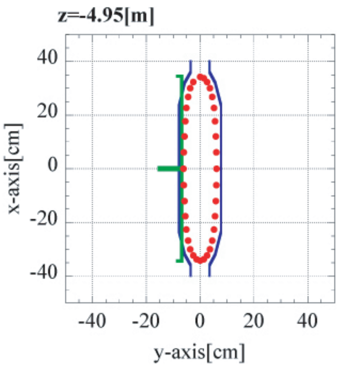

Fig. 3 Positions of the bar-type antenna and the newly designed antenna. Points are magnetic field lines at $z = -4.95$ [m] on the x-y layer.

tems. RF1 with the Type-III antennas in the both ends of the central cell excite 9.9 MHz wave at the east side and 10.3 MHz wave at the west side. RF2 systems with Double Half Turn (DHT) antennas in the both side of the central cell excite 6.36 MHz waves. In order to enhance anchor heating, the direct ion-heating in the minimum-B anchor cell is performed. RF3 system with the anchor antenna excites 9.7 MHz waves. RF1 system is also used for the plasma production in the central cell. Then, RF3 system can heat anchor plasmas independently.

Experiments with straight bar-type antenna have been performed and the stabilization effect of the whole plasma has been confirmed [3]. In the experiment, the loading of the bar-type antenna has been observed to be small. To improve the antenna loading, a three-dimensional full wave numerical code, which is developed by one of the authors (A. Fukuyama), is used for designing the antenna shape. According to the numerical simulation, it is shown that the antenna loading resistance is improved by changing the shape from straight to elliptic arc for surrounding plasmas as shown in Fig. 3 [3].

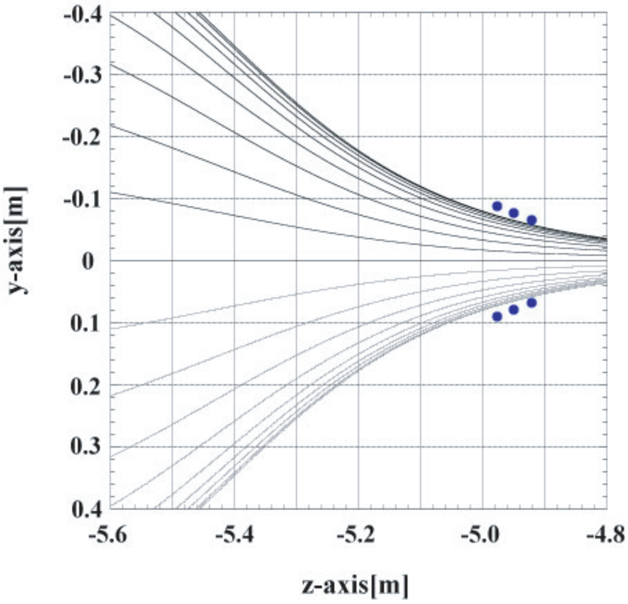

Fig. 4 Out most magnetic field lines beginning at $r = 20$ cm at the midplane of the central cell ($z = 0$ cm) and location of antennas installed in the east minimum-B anchor cell are presented on the y-z layer.

Figure 3 shows the cross-section of plasmas on the x-y plane at $z = -4.95$ [m]. The points are magnetic field lines which are started from $r = 20$ cm at the midplane of the central cell ($z = 0$ cm). The straightline of the left side of the plasmas indicates the shape of the bar-type antenna and elliptical lines are the shape of the modefied antenna. Plasma at the location of antenna is in the form of an ellipse. It is clear from Fig. 3 that the shape of the new antenna fits for the shape of the plasmas better than that of the bar-type antenna, and the area in contact with the antenna and the plasma is increased.

Figure 4 shows the out most magnetic field lines beginning at $r = 20$ cm at the midplane of the central cell and the locations of the anchor antenna by points in the minimum-B anchor cell. The new antennas are installed on either sides of the plasma.

3. Experimental Result

We performed heating experiments in the minimum-B anchor with two types of anchor antenna. In these experiments, ICRF waves of 9.7 MHz are excited with RF3. Figure 5 shows the results of the experiments with both antennas. The diamagnetism and the line-integrated density in the central cell are plotted on the upper graphs of Figs. 5 (a) and (b). RF3 is applied from 200 msec to 240 msec. The input and radiated powers are indicated on the middle graphs. The radiated power is defined as the input power minus the absorbed power by the circuit.

It is clear that the radiated power is very small when the bar-type antenna is used. The antenna loading is defined as the ratio of the radiated power to the input power as

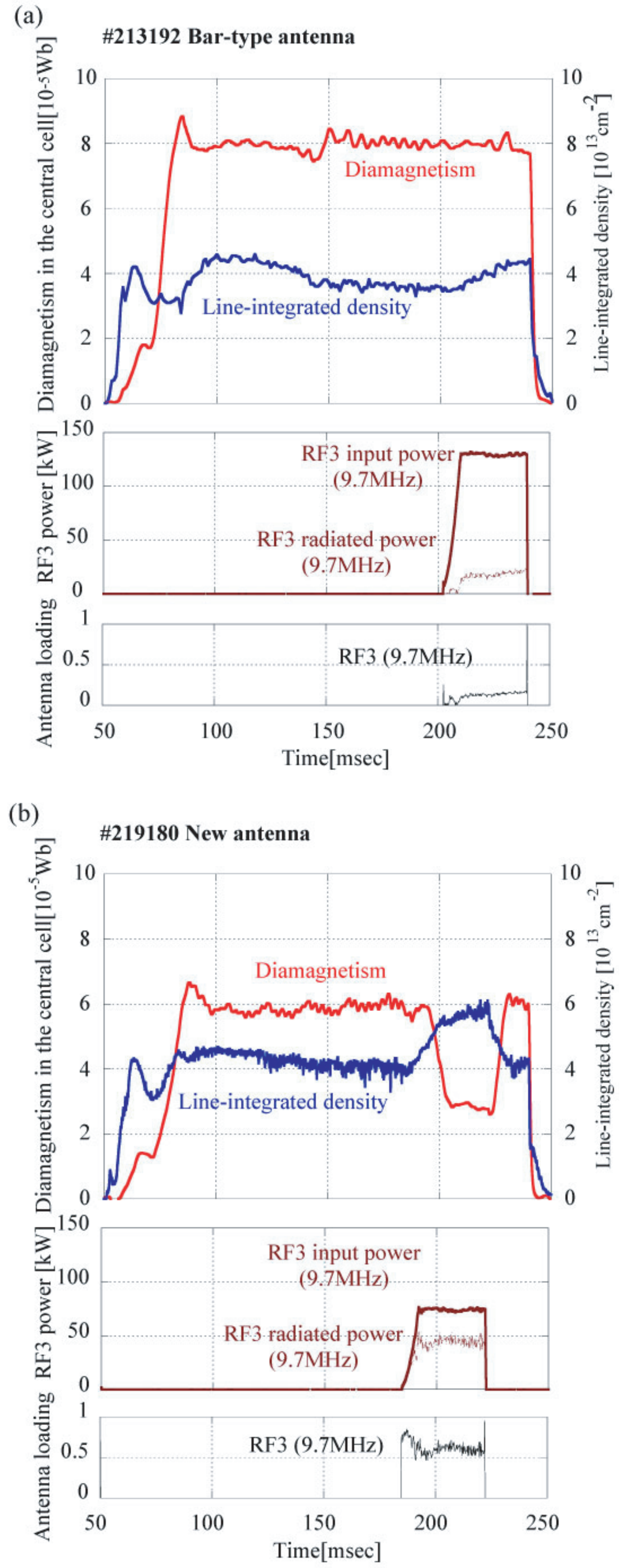

Fig. 5 ICRF heating experiment excited 9.7 Mhz waves by (a) the bar-type antenna and (b) the new installed antenna in the minimum-B anchor configuration.

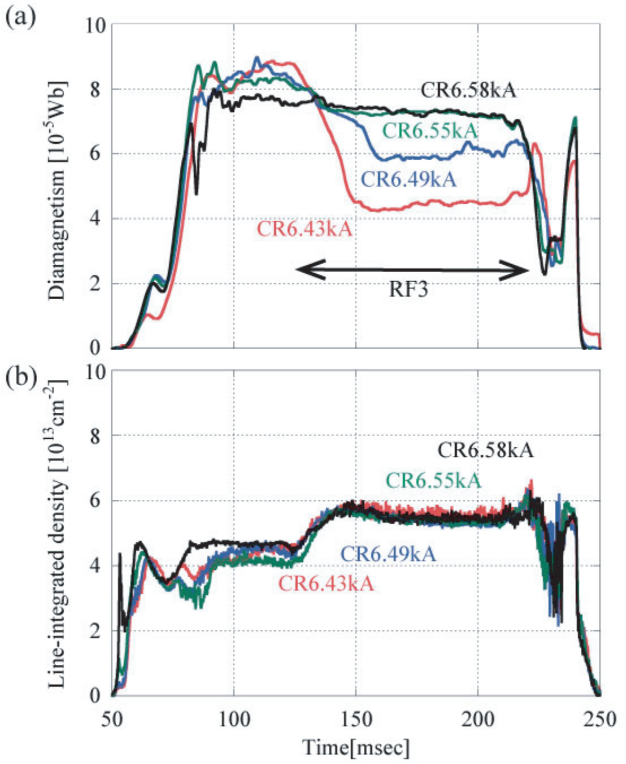

Fig. 6 Signal strength of (a) Diamagnetism and (b) line-integrated density in the central cell in the case of decreasing diamagnetism with changing coil current.

shown in the lower graphs in Figs. 5 (a) and (b). As clearly shown in Fig. 5, the plasma parameters such as the diamagnetism and line-integrated density change drastically when double-arc type antenna is used. For the bar-type antenna, antenna loading is ~ 0.2, so approximately 20% of the RF power is radiated to the plasma. In other words, the antenna coupling to plasmas is weak. On the contrary, antenna loading becomes large when the new double-arc type antenna is used. The loading is increased more than three times as indicated by the simulation. Although the input power is smaller than the bar-type antenna is used, stronger effects on the plasma parameters are observed. The line–integrated density increases, however, the drop of the diamagnetic signal is observed as shown in Fig. 5 (b). In GAMMA10, the diamagnetic signal in the central cell is determined by RF2, which is used for the ion heating in the central cell. When the line-integrated density is increased and the diamagnetic signal is decreased by RF3, the loading of the RF2 antenna is still constant. This means the coupling between RF antenna and plasmas in the central cell does not change.

To investigate the decrease in the diamagnetic signal, experiments with different magnetic field strengths were performed as shown in Fig. 6. When the magnetic field strength is increased slightly, the drop in the diamagnetic signal disappeared. In these experiments, the increase in the line-integrated density was maintained during the RF3. This means the location of the resonance layer in the central cell affects the ion heating. The decrease in the diamagnetic signal when RF3 is used is expected to result from complex mechanisms. The reason is not yet clear.

4. Summary

In order to heat plasmas in the minimum-B anchor cell effectively, experiments with two type of antenna, which are the bar-type antenna and a newly designed antenna, are performed. The experiments confirmed that the new double-arc type antenna increases the loading by more than three times compared to the bar-type antenna by coinciding with the plasma shape and increasing the area of the antenna in contact with the plasma. We have observed that the plasma in the central cell is more strongly affected by ICRF waves from the double-arc type antenna

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