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Heating experiment with phase-controlled antennas on GAMMA10

GAMMA10における位相制御アンテナによる加熱実験

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Production of high β plasmas in anchor-cell is necessary for MHD stabilization in the tandem mirror GAMMA10. Plasma heating in anchor-cell has been carried out by ICRF system(RF1) with both east and west type-Ⅲ antennas installed in the central-cell. By using an additional ICRF system (RF3) with a bar-type antenna installed in the east anchor-cell, more effective anchor heating have been confirmed. East type-Ⅲ and the bar-type antennas are driven with the same frequency and phase difference between two antennas can be controlled in the experiment. Plasma parameters depend on the phase difference between both antennas. Increase of the line density and the soft X-ray signal are observed in the opposite phase. Stable plasma production with only east RF1 and east RF3 is also confirmed.

1. Introduction

By producing high β plasmas in the anchor-cell we can control MHD stability on the tandem mirror GAMMA10. It is planned to modify the west anchor-cell to the axisymmetric mirror field with a diverter configuration in near future [1]. Higher β plasma production in the east anchor-cell is needed to keep MHD stabilization of whole plasmas in GAMMA10. By using phase-controlled antennas, we have tried effective plasma heating in the anchor-cell.

2. Experimental Set-up

Figure 1 shows the schematic drawing of the GAMMA10 tandem mirror. Central-cell is a main plasma confinement region. Anchor-cell has a minimum-B field and keeps MHD stabilization. Plasma production and heating are mainly carried out by ICRF waves on GAMMA10. There are 3 RF systems; RF1, RF2 and RF3. Locations of ICRF antennas are indicated in Fig. 1. RF1 with type-Ⅲ antennas installed in the central-cell produces plasmas and heats ions in the anchor-cell. RF2 system with double half turn antennas installed in the central-cell heats ions in the central-cell. In the typical discharge, anchor heating is carried out by only RF1, of which frequencies are 9.9MHz (East) and 10.3MHz (West), respectively. In this study, RF3 is used for the anchor heating with the same frequency as East RF1 of 9.9MHz by using the same signal-generator (SG). By using phase-shifter (PS), phase differences between two antennas are controlled.

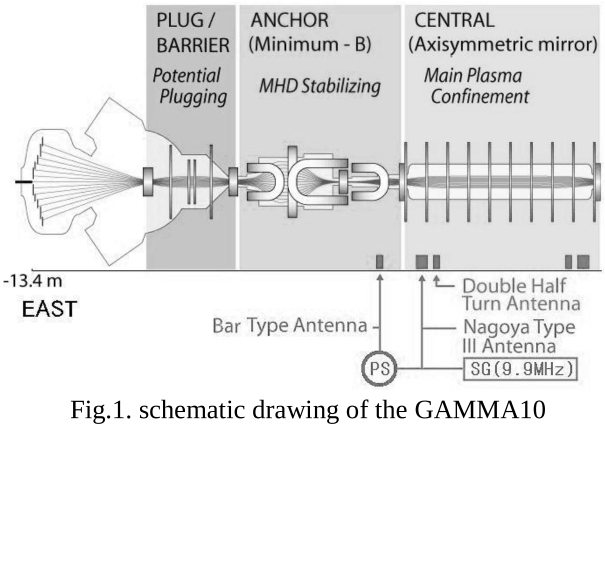

Fig.1. schematic drawing of the GAMMA10

Waves exited with same frequency interfere with each other. Then wave propagations are affected from the phase difference. Anchor resonance layer exists in the east side of RF3 antenna. Powers propagating to the east side of both antennas, P_E, and to the west side, P_W, are expressed as follows:

$$P_E/P_0 = 1 + \cos(\delta - k_z d)$$
$$P_W/P_0 = 1 + \cos(\delta + k_z d)$$

Here, P_0 is the power when only one antenna is exited. k_z is parallel wave number determined with a dispersion relation. d is the axial distance between two antennas. δ is the phase difference between two antennas. Standing wave is formed between two antennas. Wave propagations can be estimated by using antenna loading resistances. Main diagnostic systems used in this study are diamagnetic loops for measuring plasma pressure, microwave interferometers for measuring electron line density and soft X-ray detector for the information of the electron temperature.

3. Experimental Result

Firstly, RF3 is superposed to typical discharges and dependence of the phase difference on plasma parameters is measured. Secondly, the plasma sustainment with only east RF1 and RF3 is tried.

3.1 *Phase control experiment*

Figure 2 shows temporal evolution of electron line density. RF3 is superposed on typical discharges from 120msec to 240msec and the phase differences between both east RF1 and RF3 are changed. When phase difference is 0.23radian, electron line density rise from 4×10^{13}cm^{-2} to 6×10^{13}cm $^{-2}$ during RF3 pulse. The electron density in the core region increases and the radial profile is almost same as the case without RF3. On the other hand, when phase difference is -2.76radian, electron line integral density seems no change from typical plasmas. Figure 3 shows temporal evolution of soft X-ray signal. When phase difference is 0.23radian, soft X-ray signal decrease during RF3 pulse. On the other hand, soft X-ray signal increases nearly 3times that before RF3 pulse, when phase difference is -2.76radian. According to measurement of Thomson scattering system, electron temperature increases from 34eV to 70eV on this phase difference. These indicate that plasma parameters vary depending on phase difference. According to measurement of the antenna loading resistances, wave propagation is estimated as follows. When phase difference is 0.23radian, wave propagates toward east-side of RF3 antenna and west-side of east RF1 antenna. On the other hand, standing wave is formed between two antennas, when phase difference is -2.76radian.

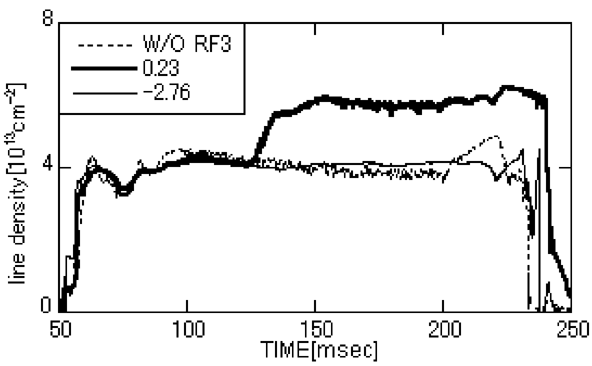

Fig.2. Time development of line density

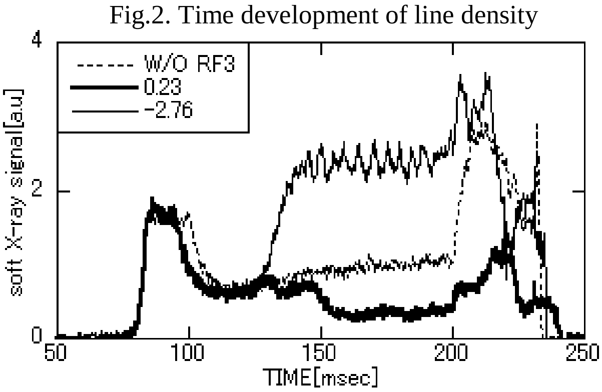

Fig.3. Time development of SX signal

3.2 *Experiment with only east RF1 and east RF3*

As a simulation of the operation without west anchor cell experiments with only east RF1 and RF3 are carried out. By controlling the phase difference between both antennas, we have achieved the production of the stable plasmas as shown in Fig. 4. Electron line density reaches to 4×10^{13}cm^{-2} and diamagnetism reaches to 6×10^{-5}Wb. They are almost same as plasma parameters of typical discharges on GAMMA10.

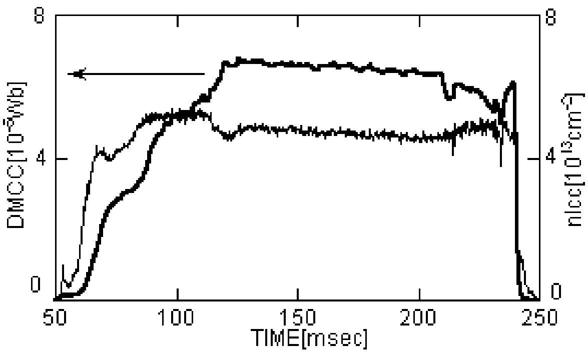

Fig.4. W/O west RF1 experiment

4. Summary

By using RF3 with the same frequency as the east RF1, we found following results. On the typical plasmas when wave propagates toward east-side of RF3 antennas and west-side of RF1 antennas, electron density rise and when standing wave is formed between two antennas, electron temperature rises. Even if only east RF1 and RF3 was used we can produce same plasmas as typical one by optimizing phase difference.

Acknowledgments

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References

[1] Y. Nakashima, et al: Fusion Sci. Technol. 59 (2011) 61-66.