IMPROVEMENT OF ECRH ELLIPTICAL MIRROR ANTENNA FOR GAMMA 10

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Horizontally steerable ECRH antenna system of central cell on GAMMA 10 is developed for efficient electron heating. The steering mirror antenna can shift horizontally absorption position at the resonance surface in the range of -7.3 ~ +7.3 mm from standard position without significant power reduction which is examined with both calculation and cold power test. As a result of the plasma experiments of the antenna position scan, it is found the horizontally optimized position for ECRH. The spilled RF from mirror(the stray RF) seems to deteriorate the hot ion confinement. The newly installed efficient antenna system which has higher transmission efficiency of ~90% has shown improved heating performance.

I. INTRODUCTION

The GAMMA 10 in University of Tsukuba is a tandem mirror device. The main plasma confined in the central cell of GAMMA 10 is heated by ion cyclotron resonance heating. Therefore, high ion temperature plasma of several keV is obtained. Since electron temperature is quite low (less than 100 eV), the heat transport from high temperature ions to electrons occurs and prevents from rising ion temperature. Therefore, efficient electron heating by Electron Cyclotron Resonance Heating (ECRH) is quite important to improve plasma performance.

The ECRH system for the central cell plasma consists of 28 GHz high power gyrotron, HE_{11} transmission line, and mirror antenna system. In ECRH, it is necessary to transmit microwave to the resonance surface by mirror antenna system. The antenna developments have been done to improve heating performance. The steering antenna having two mirrors has been tested with various conditions. From these studies of that two mirror antenna system, we have introduced the highly efficient antenna system having one mirror for better heating performance.

This paper is organized as follows. In next section, the two ECRH antenna systems for central cell of GAMMA 10 are explained. Section III gives the result of the cold test of the horizontally steerable mirror system which simulated GAMMA 10 ECH configuration, followed by the plasma experimental result in GAMMA 10. Finally, conclusion is given in section V.

II. ECRH ANTENNA SYSTEMS

The microwave propagates the corrugated waveguide line over 10m as HE_{11} mode, and is controlled by polarizer and twister and is injected to the ECRH resonance via elliptical mirror. The microwave is EC wave as X-mode and is absorbed at the fundamental resonance (1T).

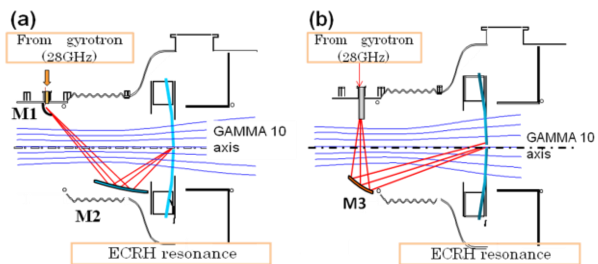

Fig. 1: Schematic view of ECRH antenna system in the central cell of GAMMA 10. (a) The steering two mirror (M1 and M2) antenna (b) The efficient one mirror (M3) antenna.

Fig. 2: The picture of M1 steering gear for horizontal motion. The center part is connected onto the GAMMA 10 installing port flange.

II.A. The steering antenna (two mirrors)

Figure 1(a) shows ECRH antenna system of two elliptical mirrors (M1 mirror attached to the waveguide aperture and M2 mirror placed on the vacuum chamber bottom). The M1 dimension is small as 50 × 100 mm^2 mirror surface and M2 is 280 ×300 mm^2. Microwave beam is directed to the center of ECRH resonance layer by this mirror antenna system. In the previous reports, [1-2] vertical movable elliptical mirror antennas had tested. In this paper, new antenna to enable horizontal motion has been developed and tested. ECRH antenna has been fixed to the vacuum chamber therefore we could not investigate the effects of movement of the injected position. However owing to adopted new antenna to enable horizontal motion, plasma performance could be optimized.

At this stage, we considered that M1 mirror is steered rotating around a waveguide. Figure 2 shows the picture of the steering gear for horizontal motion. We give the angle adjusting by turning the outside handle. The microwave transmission ratio is obtained by calculation of microwave electromagnetic field irradiated waveguide. The electromagnetic code for ECRH antenna design is calculated using Induced Current law.[2] With this code, the radiated pattern at the resonance surface is solved. The adjustable working range of M1 angle is -30 ~ +30 degree which corresponds the -9 ~ +9 mm beam shift at the resonance surface by the calculation.

II.B. The efficient M3 mirror antenna

The transmission ratio from waveguide to EC resonance surface of the two mirrors system is smaller than about 70 % in the last review.[2] The stray RF of about 30 % could badly influence plasma performance. The antenna having high transmission ratio would give better plasma performance.

Figure 1(b) shows ECRH antenna system of an elliptical mirror which placed on the vacuum chamber bottom just below the waveguide mouth. The mirror (M3) dimension is 180 × 188 mm^2. In this antenna system, the transmission efficiency from a waveguide to resonance surface is a high as 90 %, and the stray RF is roughly 1/3 of that of the steering antenna. Therefore it is to get improvement of plasma performance broader than two mirror system.

III. COLD POWER TEST

The cold power test of the steering performance is performed simulating actual beam propagation of the ECRH experiment using a 1W low power oscillator at 28 GHz. The microwave radiated from a HE_{11} waveguide is reflected by M1 and M2. Then, it is absorbed the absorber corresponding to resonance surface in GAMMA 10. The power distribution is changed into temperature increment on the microwave absorber, and the temperture particle were mesured by infrared camera.

Figure 3 shows peak position at the resonance surface by the changing M1 angle. The microwave is radiated the center position at the resonance surface when M1 angle is 0degree. As a result, the horizontal peak position shifts of 7.3mm with 20 degree and 9mm with 30 degree. And the tested beam positions agreed with those from electromagnetic field calculation code within 10 % error. As for the vertical movement, it is -4 to +4mm in the range of -20 ~+20 degree.

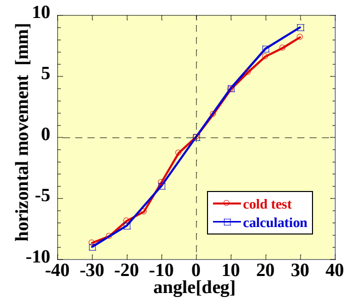

Fig. 3: Figure 3 shows peak position at the EC resonance by the changing M1 angle. When M1 angle is 10degree, the movable distance is 4 mm horizontally direction. At 20degree, it is 7.3 mm off. At 30 degree, it is 9 mm off.

IV. PLASMA EXPERIMENT

By these antenna systems, we carried out EC heating experiment in GAMMA 10 to study the heating performance.

IV.A. the experiment using the steering antenna

The steering antenna to plasma heating performance has been studied. The microwave injected from gyrotoron is output power of 100 kW at 28 GHz. The dependence of diamagnetism (DM) representing stored energy of plasma and soft X-ray intensity (SX) on peak absorption position was measured. Figure 4 shows the DM measurement. It is obtained the injection to the center of the ECRH resonance layer (M1 angle is 0 degree) is the most efficient, as expected. We define difference of $\Delta DM=DM_E - DM_0$,where DM_E and DM_0 are DM with ECRH and without. In case of 4 mm off center beam injection (M1 angle is 10 degree), ΔDM is almost 0 and ΔDM is negative in case of 9 mm off (M1 angle is 30 degree). In case of the injection to the center, $\Delta DM/DM_0$ is +5%. Figure 5 shows the SX measurement. The graph is symmetry, range of -20 ~+20 degree, therefore it is considered that center of symmetry is the best absorption position. In case of 9mm off, the large decrease is observed. From these studies it is found that optimized horizontal region is the designed center position.

In the case of 30 degree, it is found that the heating performance deteriorates largely from DM and SX measurements and is as different from other angle case. One of these causes is as follows. In case of M1 angle with 30 degree, substantial part of the power is uncovered with M2. Then the power injected to M2, hence, the resonance surface decreases. Conversely the spilled RF gives in the around, in consequence of increment of stray RF, the microwave is absorbed in an unexpected region e.g. the edge of resonance surface in fundamental and second harmonics which makes the non-axis symmetric heating hence the non-axis symmetric radial potential profile. This asymmetry could increase the neoclassical diffusion of hot ion and some ions loss due to the plasma shift, which was also observed in case of O-mode injection.[3] The plasma shift could also induce out gas mechanism due to the interaction with a vacuum wall which brings about charge-exchange of hot ion with neutral particles.

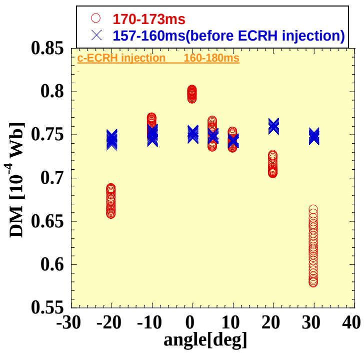

Fig. 3: Diamagnetism evolutions show the M1 angle dependence. The circles indicate C-ECRH injection time and the crosses indicate no C-ECRH injection.

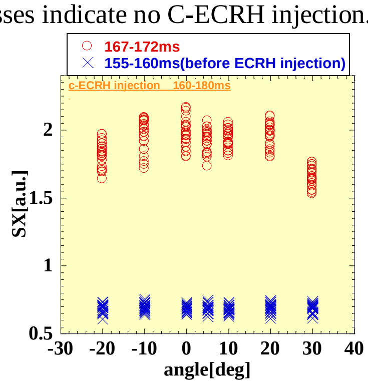

Fig. 4: Soft X-ray intensity evolutions show the M1 angle dependence. The circles indicate C-ECRH injection time and the crosses indicate no C-ECRH injection.

IV.B. the experiment using the efficient antenna

To study the effect of the stray RF, we have introduced the M3 antenna system shown in Fig. 1(b), which has higher transmission efficiency to resonance surface compared with steering antenna. It reduces the stray RF to 1/3 and we could expect high power higher efficiency experiment.

Figure 5 shows the time evolution of the DM and SX measurement. The last experiment (M1 and M2) got a small rise of DM (~5%). The rise of DM of >10% has been obtained with M3 antenna, which is better heating performance than the previous of ~5 % (100kW). The microwave injected from gyrotoron is output power of 150 kW. Other parameters are similar to experiment steering antenna.

In the M3 system, the microwave propagates vertically to the magnetic field from the waveguide to the mirror. The O and X modes passing in plasma vary the phase corresponding to each refractive index and there is possibility to change polarization from the optimized condition. The control of the phase shift will give progress of heating performance by ECRH.

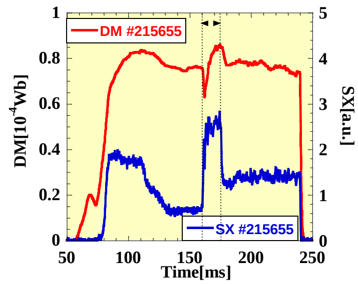

Fig. 5: Result using efficient antenna with DM and SX measurement. At the time injecting C-ECRH, it improved with DM and SX measurement.

V. CONCLUSIONS

We have developed the ECRH steering antenna in horizontal direction and carried out heating experiment in GAMMA 10. The adjustable range of M1 angle was -20 ~ +20 degree which corresponds the -7.3 ~ +7.3 mm beam shift. The cold test results agreed with calculation result. As a result of the plasma experiment, the injection to the center of the ECRH resonance surface is the most efficient from the SX and DM increment. We could determine the optimized position in the horizontal direction. It is found that the reduction of the stray RF is quite important for the efficient heating. From this result, the M3 antenna system with the low stray RF is installed and the tested heating performance indicates to be better.

ACKNOWLEDGMENTS

The authors thank the members of GAMMA 10 group of the University of Tsukuba for valuable discussions and their helps during this study. This work is partially supported by NIFS Collaborative program (NIFS09KUGM032 and NIFS04KUGM009)

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