§4. Development of High Efficiency and High Power ECH System for GAMMA 10

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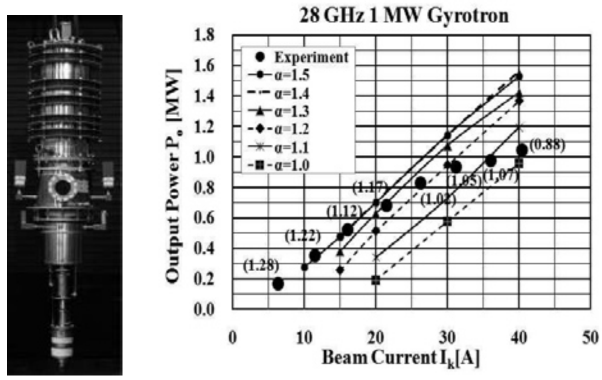
In the tandem mirror GAMMA10 at Plasma Research Center (PRC) in University of Tsukuba, axial confinement potential formation which is the plug potential for ions and the thermal barrier for electrons are performed by Electron Cyclotron Heating (ECH) at the both end mirror regions. In addition, electron heating by ECH at the central mirror region is carried out to reduce the electron drag to increase the stored energy of the hot ions. A gyrotron which is a electron tube to oscillate a high power microwave is a powerful and an essential tool for ECH. High power and long pulse operations of the gyrotron and the efficient transmission of its output are quite important to achieve better plasma performances.

As the first step of gyrotron development for tandem mirror GAMMA10, the 28 GHz gyrotron output power was increased from 0.2 MW to 0.5 MW for the higher potential and electron temperature.[1] Three 28 GHz 0.5 MW gyrotrons were applied to GAMMA 10 plasma. New record values of ion confining potential and electron temperature were obtained in 2006.[2] As the second step, the development of a 28 GHz, 1 MW, 1 sec. gyrotron is carrying out. The first test tube of 28 GHz 1 MW gyrotron has been designed and fabricated in 2008. And it has been tested in 2009. The initial experiment with the short pulse was performed in the RF test stand of PRC in University of Tsukuba by using the super conducting magnet (SCM) for 77 GHz gyrotron of NIFS LHD device. The picture and the comparison of beam current I_k dependences of the experimental output power and the calculated output power of 28 GHz 1 MW gyrotron are shown in Fig.1. The experimental output powers shown by closed circles increase with increasing I_k without saturation and the maximum power of 1.05 MW was obtained at I_k of 40 A, which is the result of achieving the design target value of 1 MW. The maximum output efficiency is 40% at I_k of 16 A. The calculations are adjusted to be the calculated window output power by the multiplied of the calculated cavity oscillation power with each pitch factor α of 1.0~1.5 and the calculated transmission efficiency of 94.7% from the mode converter to the window. In the comparison between the experimental and the calculation results, the electron beam may have α=1.4 in I_k<15 A. The value of α decreases with increase in I_k, and may become 1.0 around I_k=40 A. In Fig.1, the values of round brackets are the pitch factor α calculated by MIG simulation code with the experimental operation parameters. The I_k dependences of α decrease and α spread increase are seen by MIG calculation results. This tendency causes deterioration of efficiency or the out of optimization of operation parameter due to the anode current increase. This is one of the issues for the higher power and the higher efficiency gyrotron development.

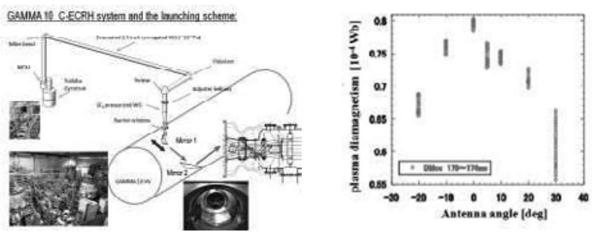
The scheme of the central ECH antenna system is shown in Fig.2(a). Linear polarized wave from Gyrotron is transmitted with corrugated waveguide as HE_{11} mode and launched from the higher magnetic field side and focused on the center of the EC resonance surface of 1 T through two reflecting mirrors. To obtain the high efficient heating performances, it is important to design transmission line and antenna capable to control wave polarization, transmission efficiency and absorption profile. The vertical movable antenna with the two elliptical mirrors was installed in GAMMA 10 and the vertical absorption position was optimized in 2008. In 2009, new horizontal movable (rotational) antenna was tested and the horizontal absorption position and wave polarization were optimized. The RF injection angle dependence of the plasma diamagnetism is shown in Fig.2(b). On axis injection (rotation antenna angle = 0deg) with X-mode ratio of 100 %, plasma diamagnetism and soft X-rays signal had better results.

In the plug ECH system, new structure to absorb the stray RF for stable gyrotron operation and measure its power was installed in the Matching Optics Unit (MOU) which is adjusted the profile and phase of gyrotron output RF beam to couple to a corrugated waveguide as HE_{11} mode. It was shown that the stray RF power increases by the reflection from plasma. This is one of issues for stable gyrotron operation.



(a) (b)

Fig. 1. (a) Picture and (b) comparison of beam current dependences of the experimental output power and the calculated output power of 28 GHz 1 MW gyrotron.



(a) (b)

Fig. 2. (a) Scheme of the central ECH antenna system and (b) the horizontal RF injection position dependence of plasma diamagnetism .

1) T. Kariya et al. : Trans. of Fusion Science and Tech., 51, 2T (2006) 397
2) T. Imai et al. : Trans. of Fusion Science and Tech., 51, 2T (2006) 208