§3. Development of High Efficiency ECH System and Research of the ECH Physics in GAMMA10

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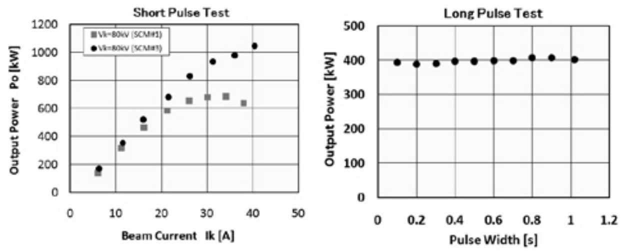
In the tandem mirror GAMMA 10 at Plasma Research Center (PRC) in University of Tsukuba, axial confinement potential formation which is the plug potential for ions and the thermal barrier for electrons are performed by Electron Cyclotron Heating (ECH) at both end mirror regions. In addition, electron 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 an 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. It is also important to contribute to the divertor simulation experiments with the ECRH upgrade.

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. Three 28 GHz 0.5 MW and two 28 GHz 0.2 MW gyrotrons are applying to GAMMA 10 plasma experiment now.

As the second step, a 28 GHz 1 MW gyrotron has been developed to upgrade the GAMMA 10 ECH systems. In the first test tube of 1 MW gyrotron evaluation test, the maximum power of 1.05 MW was obtained in 2009, which is in agreement with its design target value. In 2010, the long pulse test was performed by using the superconducting magnet (SCM) for NIFS 77 GHz #1 gyrotron. Before the long pulse test, operation parameters have adjusted in short pulse operation. Comparison of beam current dependences of the output power in 2009 test with using SCM #3 and in 2010 test with using SCM #1 are shown in Fig.1(a). The output power and the efficiency of the SCM #1 test were lower than those of the SCM #3 test. The output power has tendency to saturate with increasing the beam current I_k and decreased at $I_k > 35$A. From the simulation results of MIG calculation cord, the reason of output power saturation is considered to be the deterioration of the pitch factor α, the α spread and the laminar flow of the electron beam in front of the cathode caused by the slight difference of magnetic distribution at gun region between SCM #1 and #3. In the long pulse test, the pulse length extended to 1 sec. with 400 kW (V_k=75 kV, I_k=16 A). As seen from Fig.1(b), the output power was stable during 1 sec. The RF frequency was constant at 28.04 GHz too.

For performing high efficiency ECH, it is necessary to transmit the RF power with high transmission efficiency and high mode purity and to inject to plasma by suitable RF beam distribution and wave mode. Aiming at high efficiency 28GHz ECRH system establishment, the mode purity measurement of the wave guide propagation RF has started. The RF beam profiles launched from corrugated waveguide which was the 500 kW gyrotron output transmitted through the Matching Optics Unit (MOU) and three miter-vends , were measured at some different points. One of the measured RF beam profiles is shown in Fig.2. The RF beam was Gaussian-like beam which was approximately parallel for a wave guide axis and had good purity.

The scheme of the central ECH antenna system in 2009 and 2010 are shown in Fig.3(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. In 2010, the antenna system constituted of a corrugated waveguide launcher and an elliptical mirror was examined to increase the transmission efficiency, to reduce the stray RF and to broaden the absorption profile. However, the good heating performances couldn't be obtained because the wave polarization control (X mode / O mode) was so difficult by the cause which the RF beam launched for the mirror passed through the plasma. As shown in Fig.3(b), a new antenna which injects RF beam to the EC resonance directly has been designed and installed on GAMMA 10. The plasma experiment with new antenna will be performed in 2011.



(a) (b)

Fig. 1 (a) Comparison of beam current dependences of the gyrotron output power in 2009 test with using SCM #3 and in 2010 test with using SCM #1. (b) Pulse width dependence of output power.

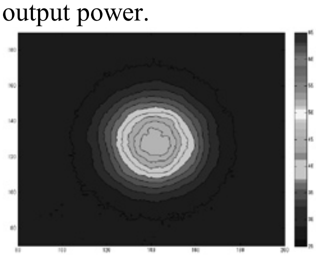
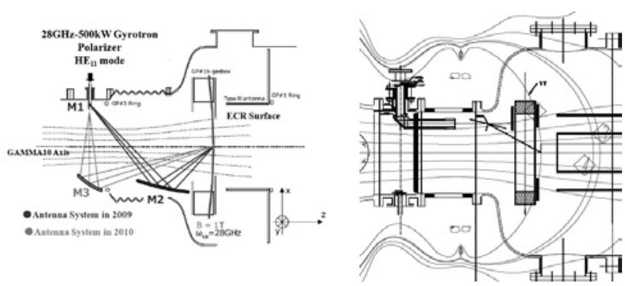


Fig.2 RF beam profile launched from corrugated waveguide



(a) (b)

Fig.3 Scheme of the central ECH antenna system
(a) in 2009 and 2010, (b) new design.