§12. Cooperative 28 GHz ECH Study for High Density Plasma Heating and Development of 14 GHz and 28 GHz/35 GHz Gyrotron

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A 28 GHz 1 MW 1 s gyrotron with $TE_{8,3}$ cavity has been developed to upgrade the ECH systems of GAMMA 10/PDX. In the short pulse, the maximum power of 1.25 MW was obtained at the beam voltage $V_k = 80$ kV and the beam current $I_k = 50$ A. The stable operation of 0.6 MW 2 s was obtained at $V_k = 70$ kV, $I_k = 23.9$ A. The output power and pulse width were limited by the power supply and the water dummy load. In the recent studies for the advanced heating, 28 GHz range gyrotrons are required in various plasma experimental devices like QUEST of Kyushu University, Heliotron J of Kyoto University and so forth.

The final purpose of this NIFS collaborative program is the progress of the electron heating study such as the electron Bernstein wave (EBW) heating in super dense core (SDC) plasma. For the first step of this study, the Tsukuba 28 GHz 1 MW gyrotron is adapted to QUEST ECH system and the plasma heating effect in QUEST is demonstrated.

In 2013 studies, the super conducting magnet (SCM) and Tsukuba 28 GHz gyrotron were installed first in the QUEST ECH system that was remodeled for triode-gyrotron operation in 2012. The SCM was installed on the oil tank and cooled down. The setting position of SCM was adjusted so that the magnetic axis of SCM accorded with gyrotron axis. The gyrotron and matching optics unit (MOU) were installed. The plumbing of the coolant were attached. The high power test of gyrotron was carried out, while the malfunctions of the combination drives of the power supply and the gyrotron were settled. The RF power was measured by a water dummy load at the MOU output and the coupling waveguide output attached at MOU. The gyrotron output power was confirmed until 370 kW. The output RF beam profile and phase form the gyrotron are adjusted by Matching Optics Unit (MOU), and the RF beam is coupled to a corrugated waveguide with its diameter of 63.5 mm as HE_{11} mode. The RF power coupled to the waveguide mode transmits 0.85 m to the vertical direction. And it transmits about 10 m to the horizontal direction after being bent 90 degrees by the miter bend. RF transmission line is evacuated in a vacuum. A picture of gyrotron and transmission wave guide installed at QUEST is shown in Fig.1. Adjustment of the gyrotron operating parameter and the pulse width extension were carried out, while RF power was injected to QUEST plasma. The successful results were obtained that the over dense plasma production more than 1×10^{18} m^{-3} which was higher than cut-off density at 8.2 GHz and EC-driven plasma current of 60 kA in QUEST plasma experiment. The electron temperature was 80 eV.

On the other hand, the design study of a dual-frequency gyrotron which can operate with oscillation power of 1.5～2 MW at 28 GHz and 35 GHz was progressed for GAMMA10/PDX, QUEST, NSTX in Princeton Plasma Physics Laboratory (PPPL) and Heliotron J. The beam current I_k dependences of cavity oscillation powers P_o obtained by calculation are shown in Fig.2. For both 28 GHz $TE_{8,5}$ mode and 34.8 GHz $TE_{10,8}$ mode, over 2 MW can oscillate with same cavity resonator.

In addition, the design study of 14 GHz gyrotron for GAMMA10/PDX and QUEST has been started. The cavity oscillation mode was decided to $TE_{4,2}$ mode, based on the design results of cavity resonator, magnetron injection gun (MIG), radiator and electron beam trajectory. Beam current dependences of cavity oscillation powers obtained by calculation are shown in Fig.3. For 14 GHz $TE_{4,2}$ mode, oscillate power of over 1 MW was obtained.

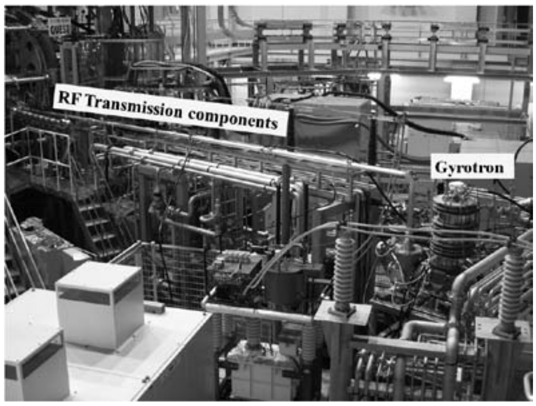
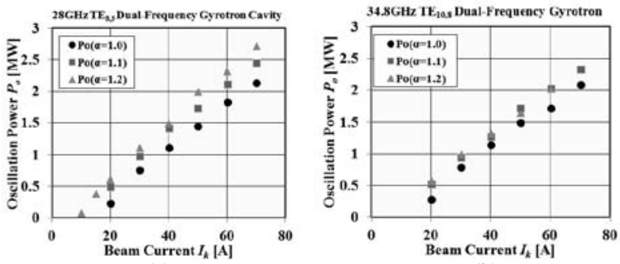


Fig.1 Picture of the gyrotron and transmission wave guide installed at QUEST



(a) (b)

Fig.2 Beam current dependences of cavity oscillation power of dual-frequency gyrotron with each electron beam pitch factor α (a) 28 GHz $TE_{8,5}$ mode (b) 34.8 GHz $TE_{10,8}$ mode.

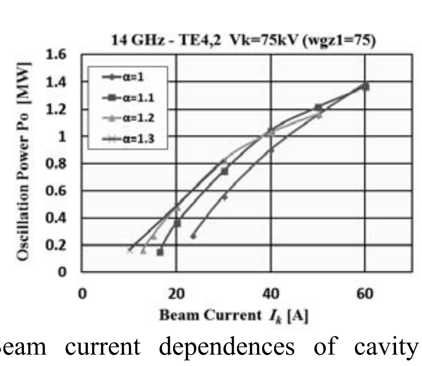


Fig.3 Beam current dependences of cavity oscillation power of 14 GHz gyrotron.