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

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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 was adapted to QUEST of Kyushu University and the plasma heating effect was demonstrated. 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.

In 2014 studies, the design of a dual-frequency gyrotron which can operate at 28 GHz and 35 GHz has been completed. In the recent studies for the electron cyclotron heating and current drive (ECH and ECCD), Ka-band gyrotrons are required in various plasma experimental devices. This dual-frequency gyrotron is developed for GAMMA10/PDX, QUEST, NSTX of Princeton Plasma Physics Laboratory (PPPL) and Heliotron J of Kyoto University. The design targets of dual-frequency gyrotron are listed in table 1. The targets for a 28 GHz operation are 2 MW 3 s and 0.4 MW CW, while that for a 35 GHz operation is 1 MW 3 s. The design of the triode MIG is the same as in 28 GHz 1 MW gyrotron. 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. The mode convertor and mirror system have good performance for both the 28 GHz $TE_{8,5}$ and 34.8 GHz $TE_{10,6}$ modes. The total calculated RF transmission efficiencies at the output window are 98.5% at 28 GHz and 97.9% at 34.8 GHz. The output window is a sapphire double-disk window that is cooled with a fluorocarbon coolant. By changing the gap length of the coolant flowing between the two sapphire disks, it is possible to match the reflected power coefficient with precision at both the frequencies of 28 GHz and 34.8 GHz. Figure 1 shows the calculated temperature of the cooled surface of the sapphire window. Where it indicates that 2 MW 3 s and 0.4 MW CW operations are possible at 28 GHz and 1 MW 3 s operation is possible at 34.8 GHz. The axial distributions of average deposition power density on the collector at 28 GHz and 34.8 GHz operation are shown in Fig.2. Peak average deposition power densities for each operation are less than 0.6 kW/cm^2 with spent beam powers of 2.8 MW. These results imply that the collector can operate at CW. The structural cross-section for 28 and 35 GHz dual-frequency gyrotron is shown in Fig.3. Fabrication of some of parts has already been started based on the results of this design study. We hope that the construction of this 28 GHz 2 MW dual-frequency gyrotron contributes in great measure to the collaborative studies of the ECH plasma experiment of QUEST, NSTX-U and Heliotron J.

In addition, the design study of 14 GHz gyrotron for GAMMA10/PDX and QUEST has been continued. The magnetron injection gun (MIG) design was completed.

Table 1. Set of required parameters of 28 and 34.8 GHz dual-frequency gyrotron.

28 GHz 2 MW Dual-frequency Gyrotron			
Frequency	28 GHz		34.77 GHz
Output Power	2 MW	0.4 MW	1 MW
Pulse Width	3 s	CW	3 s
Output Efficiency	50% (with CPD)		
Beam Voltage	80 kV	70 kV	80 kV
Beam Current	70 A	20 A	40 A
MIG		triode	
Cavity mode	$TE_{8,5}$		$TE_{10,6}$
Output mode	Gaussian like		
Output Window	Sapphire Double Disk		
Collector	Depressed Collector Sweeping coils		

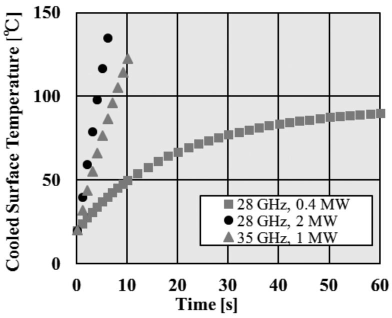

Fig.1 Temperature raise of double disk window.

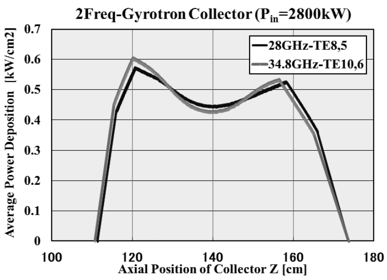

Fig.2 Axial distribution of the collector power deposition

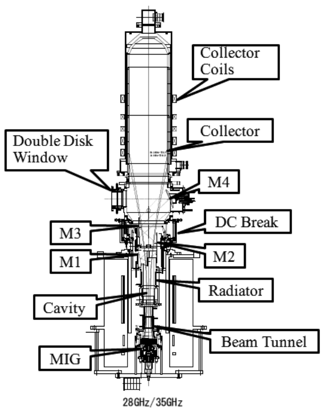

Fig.3 Structural cross-section of dual-frequency gyrotron.