

## §6. Cooperative ECH Study for High Density Plasma Heating using the 28GHz High Power CW Gyrotron System

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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. In the initial experiment with the short pulse, the maximum power of 1.05 MW was obtained, which is in agreement with its design target value. And the high efficiency of 40 % without collector potential depression (CPD) was obtained with 0.8 MW. 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. In the ECH system of QUEST, a 0.4 MW CW gyrotron is needed.

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 preliminary test of Tsukuba 28 GHz 1 MW gyrotron has been done for the purpose of adaption of this gyrotron to QUEST ECH system and the demonstration of plasma heating effect in QUEST. In considerations of these test results and the requirements for QUEST ECH system, the design improvement for the QUEST 28 GHz 400 kW CW gyrotron has been performed.

In 2012 research, the electron gun (MIG) and the output window of present 28 GHz 1 MW gyrotron were modified to improve the oscillation efficiency at high current region and to perform the 35 GHz oscillation test. This modification is considering the development of a 28 GHz 2 MW gyrotron for GAMMA10/PDX or NSTX in Princeton Plasma Physics Laboratory (PPPL) and a dual frequency gyrotron which can operate at the both frequencies of 28 GHz and 35 GHz for the Heliotron J in Kyoto University. The MIG of first tube had the same cathode structure with the NIFS 77 GHz 1.5 MW #3 gyrotron to get compatibility. The improvement point of MIG design is that the cathode angle has been made deeper for better laminar flow of electron beam in front of the cathode. The higher  $\alpha$  operation and the lower  $\alpha$  dispersion with good laminar flow leading to the higher oscillation efficiency at the higher beam current would be expected by this improvement.

The experimentally obtained beam current dependence of the output powers are shown in Fig.1. Figure 1(a) and Fig.1(b) are the results before and after the MIG modification, respectively. In the results, the saturation tendency of oscillation efficiency at the beam current  $I_k$  of 40~50 A was improved, and the output power of 1.25 MW was achieved at  $V_k=80$  kV,  $I_k=50$  A. Further, the preparation of applying 1 MW gyrotron to the

QUEST plasma experiment has been done. According to the requirement of QUEST ECH power supply system, the gyrotron performance test was carried out at the beam voltage of  $V_k=70$  kV. The stable operation of 600 kW 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.) These results satisfy the requirements of the preliminary plasma heating in QUEST. In the pre-test of 35 GHz oscillation with the improved 28 GHz 1 MW gyrotron, the output power of 1 MW level was confirmed which agrees well with the calculation.

The RF power transmission components were designed and fabricated. The schematic diagram of 28 GHz RF transmission system in QUEST is shown in Fig.2. The output RF beam form gyrotron is adjusted its profile and phase by Matching Optics Unit (MOU), and couples to a corrugated waveguide with its diameter of  $\phi 63.5$  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. At the injection port of QUEST, a vacuum window, an adjusting bellows, an insulation flange and a launcher are installed (Fig.3). The vacuum window is the structure that can be also used as the output window of 28 GHz 1MW gyrotron.

These RF power transmission components and 28GHz 1 MW gyrotron have been installed on QUEST, and will be applied to the ECH/EBW experiment in 2013.

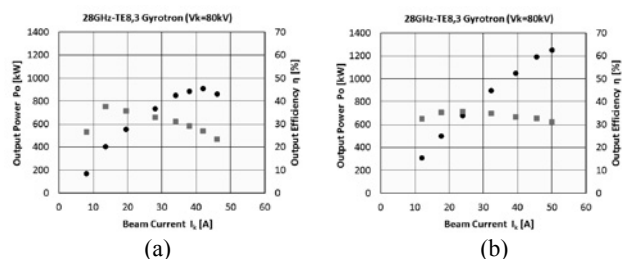


Fig.1 Beam current dependences of output power (a) before and (b) after the modification of MIG.

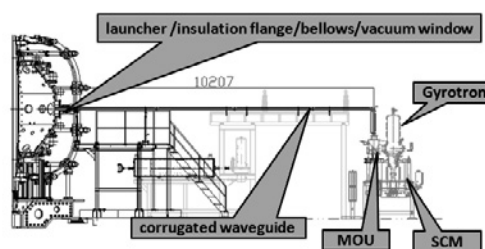


Fig.2 Schematic diagram of 28 GHz RF transmission system in QUEST.

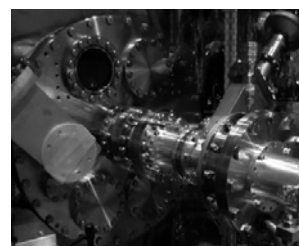


Fig.3 RF power transmission components installed at the injection port of QUEST