§8. Cooperation Study of SDC-plasma ECH Using the 28GHz High Power CW Gyrotron System

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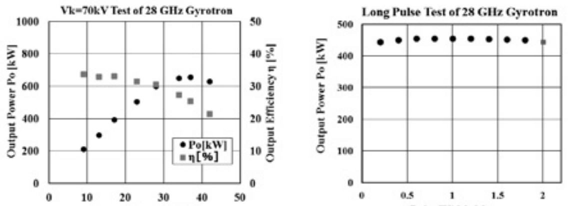
A 28 GHz 1 MW 1 s gyrotron with $TE_{8,3}$ cavity has been developed to upgrade the ECH systems of GAMMA 10. In the initial experiment with the short pulse, the maximum power of 1.05 MW was obtained, which is in agreement with its design target value. And the high efficiency of 40 % without collector potential depression (CPD) was obtained with 0.8 MW. 28 GHz range gyrotrons are required in some recent plasma experimental devices, like QUEST in Kyushu University where a 0.4 MW CW gyrotron is needed.

As the mutual collaborative program, the joint study with Kyushu University has started. The final purpose of this collaborative program is the contribution to 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 to investigate plasma heating effect in QUEST. In considerations of the test results and the requirements for QUEST ECH system, the design improvement for the QUEST 28 GHz 400 kW CW gyrotron has been performed.

Because of the requirement of QUEST ECH power supply system, gyrotron performance test was carried out at the beam voltage of V_k = 70 kV. The beam current I_k dependences of the output power and the output efficiency are shown in Fig.1(a). The output power over 450 kW is obtained at I_k = 20 A. As shown in Fig.1(b), the pulse width of 2 s with 450 kW oscillates stably. (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 considerations of the GAMMA10, 1 MW, 1 s gyrotron (first tube) test results, the design improvement for the QUEST 400kW CW gyrotron (second tube) is being performed. The first tube MIG has the same cathode structure with the NIFS 77 GHz 1.5 MW #3 gyrotron to get compatibility. Therefore the laminar flow of the electron beam in front of the cathode was not adequately optimized. The improvement point of MIG design is that the cathode angle has been made deeper for laminar flow of electron beam in front of the cathode. A good anode voltage dependences of the electron beam parameter is obtained by MIG simulation, that is the pitch factor α is 1.1~1.2 with small α spread (<5%). The higher α operation with the lower α dispersion leading to the higher oscillation efficiency at the higher beam current will be expected by these improvements. In the cavity calculation results of the first tube, an oscillation power of 1.44 MW with the oscillation efficiency of 45.1% was obtained at beam voltage V_k=80 kV, beam current I_k=40 A and α=1.2. In the improved design tube, the cavity design is the same as the first tube cavity, because oscillation power is not saturating at I_k=40 A and higher power will be obtained at the higher I_k by MIG improvement.

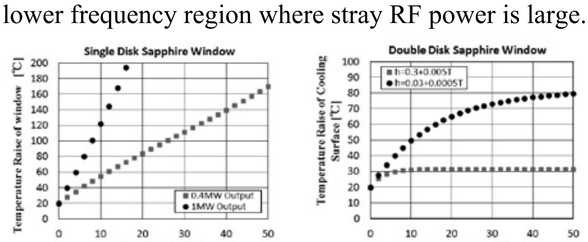


(a) (b)

Fig.1 (a) Beam current dependences of output power with V_k = 70 kV. (b) Long pulse operation of 450 kW 2 s.

The $TE_{8,3}$ mode RF wave is converted to a Gaussian-like beam by a built-in quasi-optical mode converter, and the RF beam is transmitted by four pieces of mirror system to the outside of the tube through a output window. The output RF beam is adjusted its profile and phase by MOU, and couples to a corrugated waveguide as HE_{11} mode. The target of QUEST gyrotron is CW operation, so the reduction of stray RF is important issue. By reducing the side lobes of RF beam launched from the radiator and increasing the transmission efficiency of the mirrors, the total transmission efficiency from the mode converter to the output window is improved from 94.7% to 98.5%, and to the corrugated waveguide is from 90.2% to 95.3%.

The output window of the first tube is a single disk sapphire window with the diameter of 136 mm. The temperature raise of the output window measured by IR camera was 9 K with 0.45 MW 2 s. From this result, the dielectric loss (tanδ) of sapphire is estimated to be 3.3×10^{-5} at 28 GHz. The RF pulse width dependences of the window temperature calculated with this tanδ considering the experiment and the temperature dependence of tanδ are shown in Fig.2. As shown in Fig.2(a), the operation of 1 MW 5 sec. is possible by single disk sapphire window, but the operation of 0.4 MW CW isn't possible. As shown in Fig2.(b), the operation of 0.4 MW CW is possible by double disk sapphire window with the heat transfer rate h>0.03 W/cm^2K. Other important points of the design improvement for second tube are the adoption of CPD type collector to reduce heat load of the spent electron beam and the power supply requirement, the cooling reinforcement against the heating by the stray RF and the ion pump enlargement for exhaust of outgassing. Good result of the preliminary plasma heating test by using this gyrotron in QUEST will lead to a development of QUEST 28 GHz 400 kW CW gyrotron, which will lead to the establishment of the higher power and the longer pulse gyrotron design at lower frequency region where stray RF power is large.



(a) Single disk (b) Double disk

Fig.2 RF pulse width dependences of window temperature.