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Improved design of 28 GHz Mega-Watt Gyrotron
28GHz-MWジャイロトロンの改良設計

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At Plasma Research Center (PRC) in University of Tsukuba, a 28 GHz 1 MW gyrotron has been developed to upgrade the electron cyclotron heating (ECH) systems of GAMMA10 tandem mirror. In consideration of the first tube test results, the design improvement for the second tube is being performed for the higher efficiency, the higher power and the longer operation. This 28 GHz improved gyrotron design aims to satisfy the design specification of the gyrotrons for the ECH system of QUEST in Kyushu University or NSTX in Princeton Plasma Physics Laboratory (PPPL), too.

1. Introduction

A 28 GHz 1 MW 1 sec. gyrotron with $TE_{8,3}$ cavity has been developed to upgrade the ECH systems of GAMMA10. The picture and the structural cross-section of the first tube are shown in Fig.1. 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 [1]. In the long pulse test, the pulse length extended to 2 sec. with 0.45 MW which was limited by the power supply and the water dummy load [2].

In these days, 28 GHz gyrotrons are required in some plasma experimental devices. For the ECH system of QUEST in Kyushu University, a 0.4 MW CW gyrotron is needed. A few sec. with 1～2 MW gyrotron is useful for Electron Bernstein wave (EBW) heating system of NSTX in PPPL.

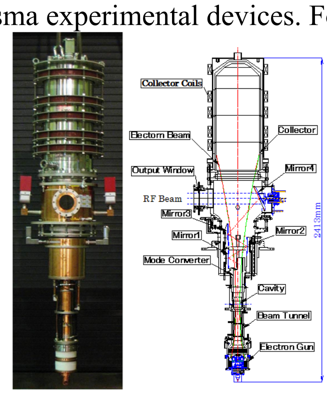


Fig.1. Picture and structural cross-section of 28 GHz 1 MW gyrotron.

In considerations of the first tube test results and the requirements for 28 GHz gyrotrons, the design improvement for the second tube is being performed for the higher efficiency, the higher power and the longer operation. The first results of the improved design of 28 GHz gyrotron are presented.

2. Improved Design of 28 GHz Gyrotron

Each component design of first tube is examined, as the design targets are 1.5 MW 2 sec. and 0.4MW CW operations.

2.1 *Magnetron Injection Gun (MIG)*

The experiment of the first tube were performed by using three SCM for NIFS 77 GHz #3 gyrotron, #1 gyrotron and PRC 28 GHz gyrotron in 2009, 2010 and 2011 respectively. The different saturation tendencies of the output power at higher beam current were observed in each SCM experiments [2]. It is thought that these differences are caused by the small difference of the magnetic field profile at the gun region of the each SCM and adjustment between gyrotron and SCM. The first tube MIG has same cathode structure with the NIFS 77 GHz 1.5

MW #3 gyrotron to get compatibility. Therefore the laminar flows of the electron beam in front of the cathode ware not necessarily good.

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. An electron beam trajectories calculated by MIG code are shown in Fig.2. The upper figure is first tube design and the lower figure is improved one, respectively. As shown in Fig2, the laminar flow of the electron beam in front of the cathode is improved. A good anode voltage dependences of the electron beam parameter is obtained by MIG simulation, that is the pitch factor α are 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.

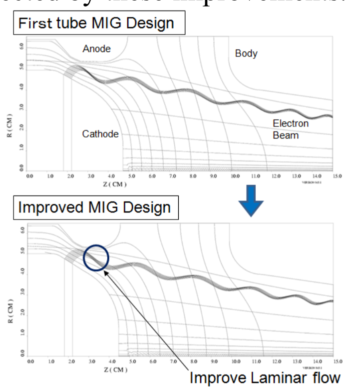


Fig.2. Electron beam trajectories of first tube MIG (upper) and improved MIG design (lower).

2.2 *Cavity*

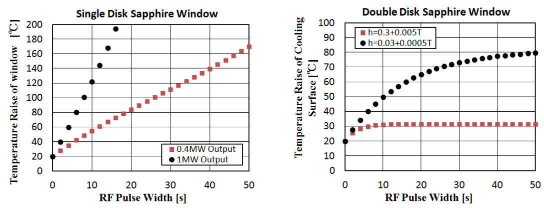
In the cavity calculation results of the first tube, an oscillation power of 1.44 MW with the oscillation efficiency of 45.1% was obtained at beam voltage V_k=80 kV, beam current I_k=40 A and α=1.2. In the improved design tube, the cavity design is the same as the first tube cavity, because oscillation power is not saturating at I_k=40 A and higher power will be obtained at the higher I_k by MIG improvement.

2.3 *Radiator and Mirrors*

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 Matching Optics Unit(MOU), and couples to a corrugated waveguide as HE_{11} mode. The total transmission efficiency from the mode converter to the output window is 94.7% and to the corrugated waveguide is 90.2% in the first tube. The improved designs that reduce the side loves of RF beam launched from the radiator and increase the transmission efficiency of the mirrors is being performed now with the target of total transmission efficiency over 95%.

2.4 *Output Window*

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 sec.[2]. 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 [3] are shown in Fig.3. As shown in Fig.3(a), the operation of 1.5 MW 2 sec. is possible by single disk sapphire window, but the operation of 0.4 MW CW isn't possible. As shown in Fig3.(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^{2}K..



(a) (b)

Fig.3. RF pulse width dependences of the window temperature. (a) Single disk, (b) Duble disk.

2.5 *Other Components*

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 stray RF and the ion pump enlargement for exhaust of outgassing.

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