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Long Pulse Test of 28 GHz - 1 MW Gyrotron for GAMMA 10 ECRH
GAMMA 10 ECRH 用 28 GHz – 1 MW ジャイロトロンの長パルス試験

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Gyrotrons which oscillate high power microwave are important tools for Electron Cyclotron Resonance Heating (ECRH). In the GAMMA10 tandem mirror, gyrotron has been used to achieve high plasma performance. A 1 MW gyrotron has been developed. The output power was achieved 1 MW in short pulse test, and 0.45 MW / 2 s in long pulse test. Moreover, the temperature rise of sapphire single disk window installed in 28 GHz 1 MW gyrotron was measured. The temperature rise was 9℃ at 0.45 MW / 2 s. This result shows that 1 MW 1 s operation is possible.

1. Introduction

In the GAMMA 10 tandem mirror, ECRH generates the axial ion confining potential and heats electrons. Becouse the plasma performance improves with increasing ECRH power, the developement of 1 MW gyrotron which has higher output power than the gyrotrons installed in GAMMA has started in 2009. Table 1 shows a set of design parameters of present and new gyrotron. New gyrotron is designed high power (1 MW) and long pulse length (1 s), and installs the sapphire window to ensure thermal stress of the output window. In 2009, initial demonstration of 1 MW / short pulse (~ 1 ms) was achieved [1].

The results of detailed performance test of the high power and the long pulse operation are presented.

2. Long Pulse Test of 28 GHz 1 MW Gyrotron

28 GHz 1 MW gyrotron has been designed and manufactured in 2009.

Short pulse test was carried out prior to long pulse test. The SCM (Superconducting Magnet) required for the gyrotron operation was borrowed from National Institute for Fusion Science (NIFS). We used, respectively, SCM#3 in 2009, SCM#1 in 2010, and SCM having the same magnetic field distribution of SCM#3 in 2011. The magnetic field of SCM#1 is slightly different from SCM#3 at gun region. Figure.1 shows the beam current dependence of the output power in short pulse test.

Table.1 A set of design parameters of Present and New 28GHz gyrotron

gyrotron	Present	New
Frequency	28GHz	
Output power	0.5MW	1MW
Pulse length	0.1s	1s
Beam current	20A	40A
Output mode	Gaussian like	
MIG	Diode	Triode
Output window	Alumina	Sapphire

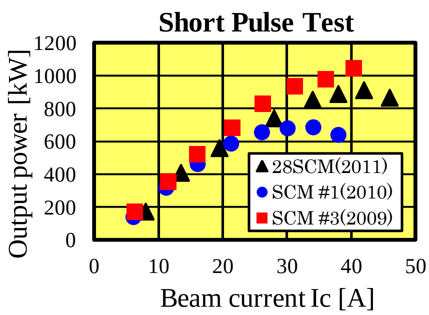

Fig.1 Beam current dependence of output power of 28 GHz 1 MW gyrotron

As shown in Fig.1, the initial demonstration of 1 MW was achieved in 2009. However, the output power in 2010 experiment was smaller than that in 2009 with Ic > 20A. The maximum output power was 0.69 MW. In 2011, the short pulse test was carried out with the SCM having the same magnetic field of SCM#3. It is shown that the reduction of the output power by using SCM#1 was improved.

Using the experimental operation parameters, the pitch factor α and the α spread were calculated by gyrotron's MIG simulation code. As a result, we found that the reason of the output power reduction was the deterioration of laminar flow of the electron beam and the increase of α spread caused by the difference of the magnetic field distributions at MIG region of SCM#1 and SCM#3.

Next, the long pulse test was carried out. Figure.2 shows the pulse duration dependence of output power. The output power and the pulse duration were achieved 0.4 MW 1 s in 2010 and 0.45 MW 2 s in 2011. The thermal damage and the deterioration of the withstand voltage weren't observed in this operating region.

The output power was restricted by the voltage and current capacity of the power supply in the long pulse test. And the pulse length was restricted by the heat capacity of dummy load.

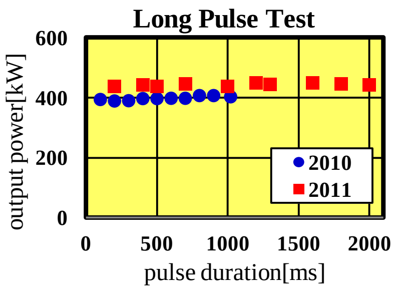

Fig.2 Pulse duration dependence of the output power

3. Temperature rise of the sapphire window

A little part of the output power is absorbed by the output window due to the dielectric loss. One of the factors of window break is the thermal stress by dielectric heating. The sapphire single disk window is installed in 28 GHz 1 MW gyrotron. The temperature rise of the sapphire window was measured to estimate maximum output power.

As shown in Fig.3, temperature rise of sapphire window were measured by infrared camera through a BaF_2 viewing port installed on the Matching Optics Unit (MOU). As shown in Fig.4, the center temperature increased proportionally with the pulse duration, and the maximum temperature rise was 9.0 ℃ at 2.0 s with the output power of 0.45 MW. As a result, the sapphire window temperature rise is calculated about 10 ℃ at 1 MW 1 s output. We found that temperature rise of the sapphire window will be no problem with the operation of 1 MW several seconds.

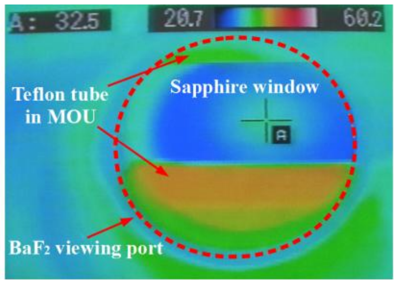

Fig.3 Temperature rise of sapphire window

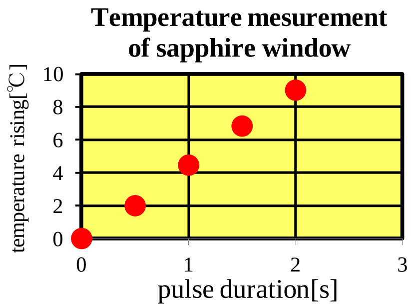

Fig.4 Pulse duration dependence of temperature rising of the gyrotron window

4. Summary

28 GHz 1 MW gyrotron was developed to achieve high plasma performance. The output power was achieved 1 MW in the short pulse test. The pulse duration was extended to 2.0 s with 0.45 MW in long pulse test. The maximum temperature rise of the sapphire window was 9.0 ℃ with 0.45 MW / 2 s. From this experimental result, we can estimate that sapphire window temperature increase is about 10 ℃ with 1 MW 1 s oscillation.

In future, after the improvement the power supply, the long pulse test will be performed to aim at 1 MW / 1 s operation. In consideration of the result of performance test, design improvement of 28 GHz gyrotron having higher power and longer pulse length is being performed [2].

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