J. Plasma Fusion Res. SERIES, Vol. 3 (2000) 368–371

Development of Long Pulse Gyrotron for Fusion Device

SHOYAMA Hiroaki*, KASUGAI Atsushi, SAKAMOTO Keishi, TAKAHASHI Koji,
TSUNEOKA Masaki, IKEDA Yukiharu, KAJIWARA Ken, IKEDA Yoshitaka,
FUJII Tsuneyuki, KARIYA Tsuyoshi[1], MITSUNAKA Yoshika[1] and IMAI Tsuyoshi
Japan Atomic Energy Research Institute (JAERI), Naka-gun, Ibaraki 311-0193, JAPAN
[1]Toshiba Corporation, Ohtawara-shi, Tochigi 324-8550, JAPAN

(Received: 19 January 2000 / Accepted: 24 February 2000)

Abstract

The breakthrough technologies such as high-order volume mode oscillation, depressed collector for energy recovery and diamond output window developed for the ITER gyrotron are applied to a high power 110 GHz gyrotron for JT-60U. The stable oscillation of 1 MW, 2 s was successfully achieved at 110 GHz. A stray RF is outputted from the DC break between the body and the collector. The stray RF measured by calorimetry found to be 5.4% of output RF power at 1 MW output. This is reasonable value compared with a predicted loss (~7% of output RF power) during RF mode conversion from TE22,6 to Gaussian beam mode by in-waveguide mode converter and phase corrected mirror in the gyrotron.

Keywords:

gyrotron, fusion device, long pulse operation, 110 GHz, ITER, JT-60U, stray RF, mode conversion

1. Introduction

The electron cyclotron range of frequencies (ECRF) is one of the most promising tools for the steady state operation of fusion reactors. High performance gyrotron is required as a ECRF source for steady state operation of the fusion reactor such as the International Thermonuclear Experimental Reactor (ITER). The required specifications of the gyrotron are 100 GHz band, 1 MW output power and CW operative, which will be used for electron cyclotron heating (ECH) and current drive (ECCD), and stabilization of MHD instabilities [1,2].

On the development of a gyrotron for fusion device, low efficiency, large heat load to the the cavity due to ohmic loss and CW operative output window at 1 MW had been crucial issues. At first, low oscillation efficiency was overcome by the energy recovery of spent electron beam by depressed collector [3]. At the next, high-order volume mode oscillation (TE31,8) was demonstrated [4]. As a solution of the last problem, diamond output window synthesized by the chemical vapor deposition was developed [5] and then a gyrotron operation of 170 GHz, 0.45 MW, 8 s was achieved [6]. These technologies are applied to a high power 110 GHz gyrotron for JT-60U.

In this paper, the design and the performance of a gyrotron for high power and long pulse operation are described and the estimation of the stray RF power in the gyrotron on the operation of high power and long pulse are carried out.

2. Design of the 110 GHz Gyrotron

Schematic drawing and design parameters of 110 GHz gyrotron for JT-60U are shown in Fig. 1 and Table 1, respectively. The length of gyrotron in the direction of electron beam trajectory is 3.0 m and the weight is 800 kg. A hollow electron beam is drawn from magnetron injection gun (MIG) of triode type. The emitter of the cathode is metal-coated Barium oxide,

**Corresponding author's e-mail: shoyamah@fusion.naka.jaeri.go.jp*

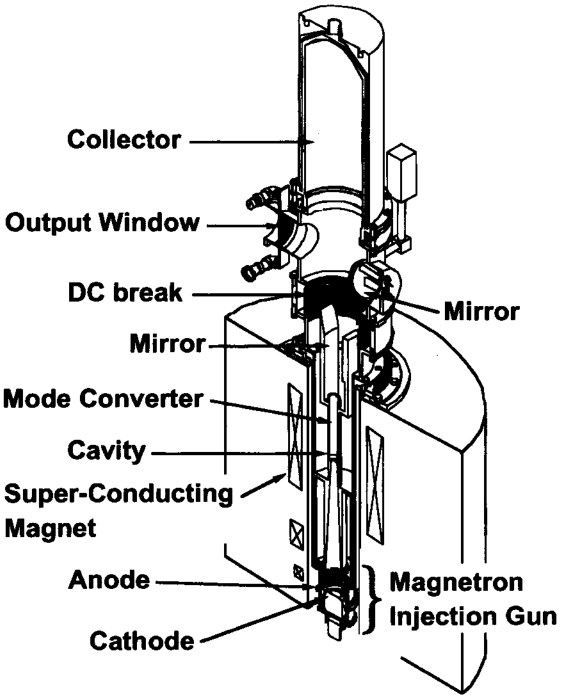

Fig. 1 Schematic drawing of the 110 GHz gyrotron for JT-60U.

Table 1 Desighn parameters of the 110 GHz gyrotron for JT-60U

Frequency	110GHz
Power	1.2MW at 95kV, 50A
Pulse Duration	5s
Oscillation Mode	TE 22,6
Q-value	~1300
Pitch Factor	~1.2
Output Mode	Gaussian Beam
Output Window	CVD Diamond
Collector	Single Stage Depressed Collector up to 50kV
Hight	~3m
Weight	~800kg

where radius and the width are 45.6 mm and 4 mm, respectively. A cavity is conventional cylindrical open type and made of copper strengthened with dispersion of alumina. The operation mode is TE22,6. The electron beam is injected at rb (beam radius) = 10.1 mm in the cavity, where the coupling coefficient with TE22,6 mode is maximum. The heat load at the cavity is less

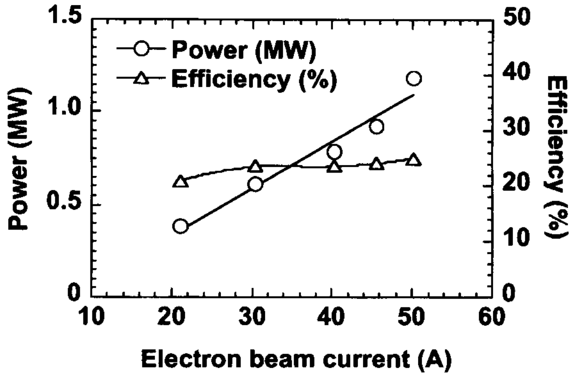

Fig. 2 Dependence of the RF output power and the output efficiency on the electron beam current at short pulse operation (~1 ms) without energy recovery.

than 1.3 kW/cm^2 at 1.1 MW oscillation. The TE22,6 mode is converted into Gaussian beam using in-waveguide radiator and phase corrected mirrors in the gyrotron and is output through a diamond window. The mode conversion efficiency from TE22,6 to Gaussian beam mode at the output window is ~93% without ohmic loss.

The gyrotron have a single stage depressed collector for efficiency enhancement which is inevitable for long pulse operation to reduce the heat load to the collector. Thus the gyrotron have a body section that is insulated from the collector by alumina cylinder. The body section is insulated also from metal wall of a super-conducting magnet by an insulator jacket.

3. Performance of The 110 GHz Gyrotron

3.1 Oscillation characteristics

The dependence of the RF output power and the output efficiency on the electron beam current at short pulse operation (~1 ms) without energy recovery is shown in Fig. 2. The static magnetic field intensity was optimized for each electron beam current. The accelerating voltage was 85–95 kV. The output efficiency is ~25% from 30 A to 50 A and the output RF power is in proportional to the electron beam current.

Fig. 3 shows the dependence of the leakage current to the anode and the body section on the voltage of the depressed collector. Long pulse operation was done at 38 kV of the depressed collector voltage where the leakage current to the anode is small, i.e., the number of the repelled electron is small. The maximum efficiency of 39% was obtained by applying the depressed

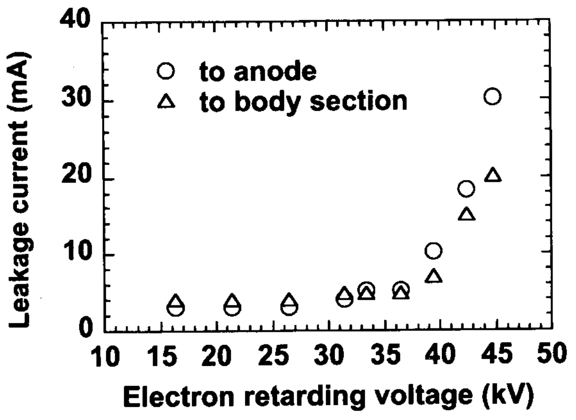

Fig. 3 Dependence of the leakage current to the anode and the body section on the voltage of the depressed collector.

collector voltage of 38 kV where the output power was 1.1 MW, and the beam current was 50 A, and the pulse width was 0.1 s.

3.2 High power long pulse oscillation

As for the high power long pulse operation, the output power of 1MW, the output efficiency of 24% and the pulse width of 2 s were obtained where the beam current was 49 A and the accelerating voltage was 85 kV and the anode voltage was 40 kV. The depressed collector voltage was 28 kV so that the total efficiency was 36%. The time evolution of voltage of the body section, the anode, the cathode, beam current, and diode signal monitoring the output power for 1 MW long pulse operation are shown in Fig. 4. All of the valuables are kept constant during the 2 s operation. Reduction of the oscillation efficiency did not occur. Stable oscillation of 1 MW, 24% and 2 s was confirmed experimentally.

The temperature increase of the cavity, the collector and the output window at the operation of 1 MW, 2 s are shown in Fig. 5. The temperature increase of the cavity was stabilized at 0.5 s and that of the output window was also almost stabilized at 2 s. Though a downshift of the oscillation frequency due to the expansion of the inner diameter of the cavity was observed, which did not make the oscillation unstable. The downshift was ~0.1 GHz. Though, as for the collector, the temperature was not saturated within 2 s, it is predicted that the temperature increase of the collector is stabilized at ~5 s and reaches ~100 K at 1 MW operation by rough estimation. Therefore, the further long pulse operation will be possible.

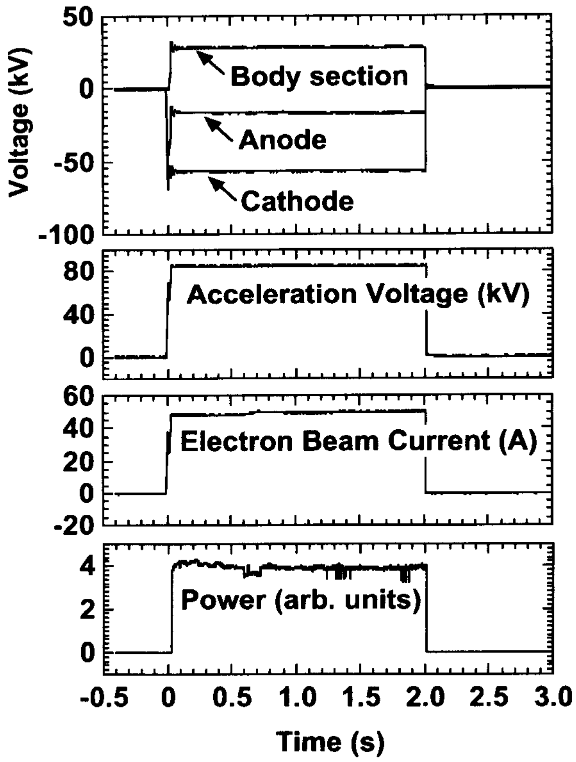

Fig. 4 Time evolution of voltages of body section, the anode and the cathode, acceleration voltage, electron beam current, and diode signal monitoring the output power for 1 MW long pulse operation.

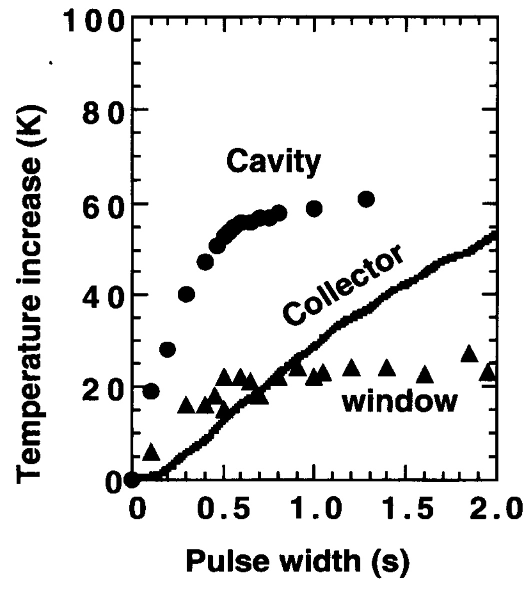

Fig. 5 Temperature increase of the cavity, the collector and the output window at the operation of 1 MW, 2 s.

4. RF Leak from the 110GHz Gyrotron

The heat generation by the stray RF at the components inside the gyrotron becomes critical for further pulse extension. Large heat generation causes intense release of outgas. Though the outgas per a operation is reduced shot by shot so that the pulse duration can be extended continuously, the stray RF should be reduced significantly for CW operation. One method we adopted was to use the DC break as an output window of the stray RF. In order to investigate the level of the stray RF, the leakage of RF power from the DC break was estimated from the temperature increase of fluorocarbon coolant which flow along the DC break ceramic as a coolant. The schematic drawing of the DC break and the surroundings are shown in Fig. 6. The insulator (absorber) absorbs almost leakage RF from the DC break, whose cylindrical wall is 10 cm in height and 30 cm in diameter, and the heat produced at the insulator is transferred to the coolant. The leakage of RF power measured was 5.4% of output RF power, which is a reasonable value since the RF loss during the mode conversion from TE22,6 to Gaussian beam is estimated ~7% by a calculation based on the diffraction theory.

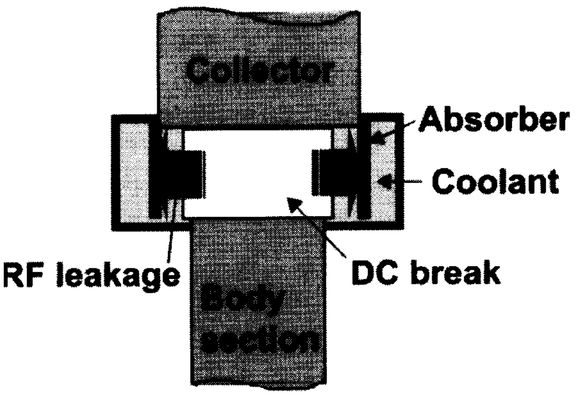

Fig. 6 Schematic drawing of the DC break and the Surroundings.

5. Summary

High power long pulse (1 MW, 2 s) operation of 110 GHz gyrotoron was successfully achieved. The oscillation of gyrotron was stable during the pulse duration of 2 s. It was clearly shown that the cavity, the output window and the collector withstand the operation of 1 MW, over several seconds. A leakage RF power from the DC break between the body section and the collector was estimated to be 5.4% of the output power of 1 MW, which is comparable with the predicted lost RF power during the mode conversion inside the gyrotron calculated based on the diffraction theory.

References

[1] M. Makowski, IEEE Trans. Plasma Sci. **24**, 1023 (1996).

[2] K. Sakamoto *et al.*, Int. J. Infrared Millim. Waves **18**, 1637 (1997).

[3] K. Sakamoto *et al.*, Phy. Rev. Lett. **73**, 3532 (1994).

[4] K. Sakamoto *et al.*, J. Phy. Soc. Jpn **65**, 1888 (1996).

[5] A. Kasugai *et al.*, Rev. Sci. Inst. **69**, 2168 (1998).

[6] K. Sakamoto *et al.*, Rev. Sci. Inst. **70**, 208 (1999).