Operation Improvement of CW 300 GHz Gyrotron FU CW I

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***Abstract*- A 300 GHz fully continuous wave gyrotron FU CW I has been developed for application to material processing in the millimeter to submillimeter wave range. In the operation test before commissioning, the maximum output power was 1.7 kW, which was less than the designed output power of 3.5 kW. Then, efforts have been done to understand the oscillation characteristics of this gyrotron. On the basis of the obtained information, the anode current was controlled and the output power has exceeded 2.3 kW. However, power saturation against the beam voltage still remains. Adjustment of the electron beam radius was tried next and power transition phenomenon was observed.**

I. Introduction And Background

GYROTRONS have been mainly used for electron heating in nuclear fusion experiment. Recently, many other applications to scientific, technological and industrial fields have been intensified. Material processing is one of important applications in the second direction. A 300 GHz cw Gyrotron FU CW I has been developed for this purpose [1, 2]. Its frequency is order of magnitude higher than those of gyrotrons currently used for material processing and a much stronger non thermal effect is expected.

A whispering gallery mode $TE_{22,8}$ is used as the main oscillation mode in FU CW I [3, 4]. This choice keeps the Ohmic loss on the cavity surface to be about 0.3 kW/cm^2 much less than the tolerable level. The design value of the beam voltage is 15 kV and that of the beam current is 1 A for the output power of 3.5 kW. A complex of a Vlasov radiator and beam shaping mirrors is installed in the gyrotron and a Gaussian beam is delivered horizontally from the vacuum window.

The oscillation characteristics of this gyrotron have been examined in advance of commissioning in the material processing system [5-7]. The output power was less than the design value and limited to 1.7 - 1.8 kW. One peculiar feature of FU CW I is radiation of the output beam into two directions stemming from simultaneous oscillation of parasitic modes [8].

Then, efforts have been done to understand the oscillation characteristics of this gyrotron and to realize the design power of 3.5 kW.

II. Results

At first, the optimum operation parameter was searched on a map of the beam voltage V_K and the cavity magnetic field strength B_C. The optimum value of B_C was determined for each value of V_K. For B_C thus determined, single mode oscillation of the $TE_{22,8}$ mode was realized. However, the output power P has not exceeded 1.8 kW at the maximum rating beam current 1 A. Therefore, multiple mode oscillation is not the main reason of the power saturation.

Originally, the electron gun of this gyrotron is designed to be operated as a quasi diode and hence the anode was connected to the ground through a small resister about 10 kΩ. This configuration resulted in a large increase in the anode current I_A with V_K. Moreover, a large fluctuation was observed on the beam current for V_K larger than 12 kV. This indicates some beam instability. Then, insertion of a large resister in between the anode and the ground was tried to limit I_A. As expected, I_A was reduced and the fluctuation on the beam current was fairly suppressed. Moreover, the value of P has substantially

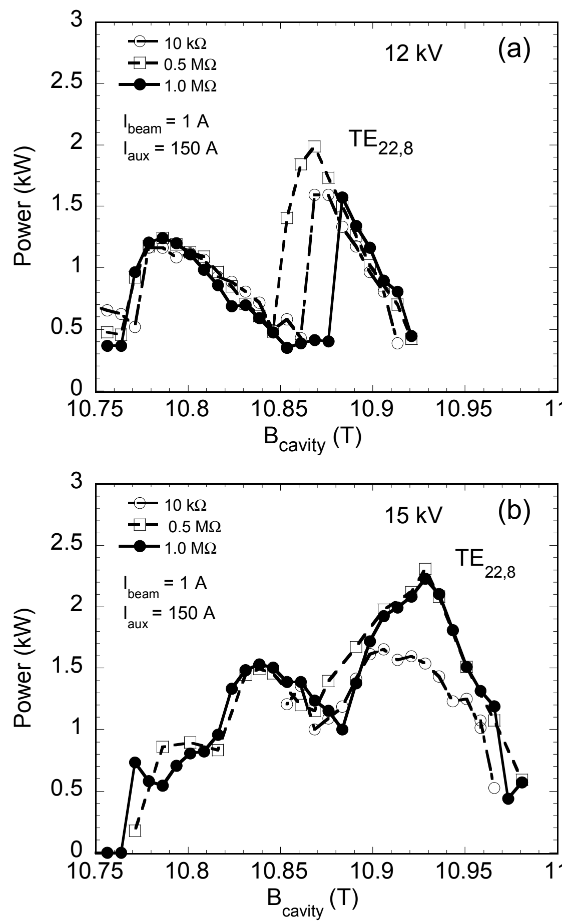

Fig. 1. Output power measured with a water load is plotted as functions of the cavity magnetic field strength with the anode resistance as a parameter for the beam voltage of 12 kV (a) and 15 kV (b). The beam current is 1 A. The auxiliary coil current is fixed at 150 A.

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increased with insertion of the anode resistance.

Figure 1 plots P as functions of B_C with the anode resister as a parameter. The output power was measured with a water load attached directly to the flange of the vacuum window. A separate experiment with an infrared camera confirmed that the gyrotron power was radiated in a shape of well collimated beam. Figure (a) and (b) represent P for V_K of 12 kV and 15 kV, respectively. The beam current was set at 1 A. Substantial increases in P were observed for both V_K and the maximum power of the $TE_{22,8}$ mode attained to 2.3 kW for V_K of 15 kV.

However, this value is lower than 3.5 kW. The V_K dependence of P was examined. Figure 2 (a) shows the output power of the $TE_{22,8}$ mode as functions of V_K. The value of P increases with V_K. The ratio of power increase with V_K has been improved while power saturation still remains for V_K higher than 12 kV. The anode resistance tends to decrease in the voltage V_{K-A} between the cathode and the anode. In fact, V_{K-A} decreased by one to two kV and the pitch factor of electrons likely decreased. Figure 2 (b) depicts P as functions of V_{K-A}. The output power sharply increases with V_{K-A}. The remarkable point is that a larger power was obtained with insertion of the anode resister in spite of the decrease in V_{K-A}. It is inferred that suppression of I_A improved the quality of the electron beam and the power increase was obtained.

Although a substantial increase in P was obtained, we could not resolve the problem of power saturation against V_k. The output power saturates also for V_{K-A}. For the anode resistance R of 0.5 MΩ and 1.0 MΩ, the value of P corresponding to the $TE_{22,8}$ mode reaches the maximum power at B_C higher than that for R of 10 kΩ. A further increase is necessary to attain to 3.5 kW in a lower B_C region. In fact, the value of P gradually decreases with the decreasing B_c. In addition, insertion of the anode resistance brought about narrowing of the oscillation region of the $TE_{22,8}$ mode in the V_K and B_C space. The oscillation region shrunk particularly in the low V_K region.

If the radius of the electron beam R_b in the cavity is different from the design value, we cannot expect to obtain the design value of the gyrotron power. Then, as the next try for higher power and for further understanding of this gyrotron, adjustment of R_b is now under way. The beam radius can be varied by changing the current of the auxiliary coils installed near the electron gun.

Preliminary experiments of R_b variation shows that a sharp transition of the output power P takes place within a very narrow region of R_b. This is likely due to turn between the co-rotation and counter-rotation modes, because the Vlasov radiator installed in CW I works for only one azimuthal rotation direction. Analysis of the power dependence on R_b for different oscillation modes as well as the $TE_{22,8}$ mode will provide information of real R_b. Then, it can be expected to achieve the design power.

Reliable identification of the oscillation modes other than the $TE_{22,8}$ mode is also expected. In particular, oscillation around 10.8 T in Fig. 1 (a) and around 10.85 T in Fig. 1 (b) should be identified as a mode with the same azimuthal rotation direction as that of the $TE_{22,8}$ mode. Moreover, multi mode oscillation problem will also be resolved.

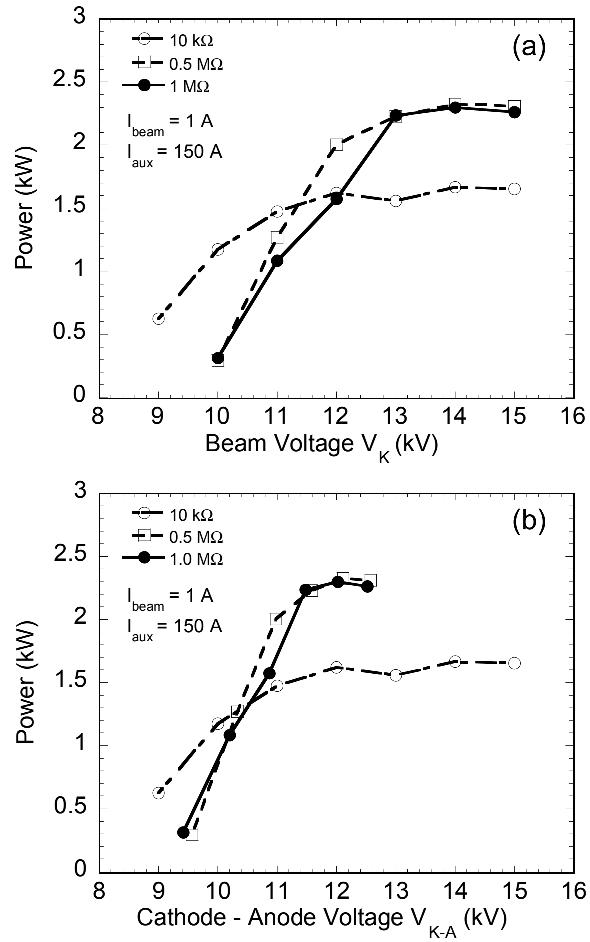

Fig. 2. Output power of the $TE_{22,8}$ mode measured with a water load is shown with the anode resister as a parameter in (a) as functions of the beam voltage and in (b) as functions of the voltage between the cathode and the anode. The cavity field is adjusted to maximize power for each beam voltage within the range of single mode oscillation of the $TE_{22,8}$ mode. The beam current is 1 A. The auxiliary coil current is fixed at 150 A.

REFERENCES

[1] H. Hoshizuki, K. Matsuura, S. Mitsudo, T. Idehara, O. V. Malygin et al., "Development of the material processing system by using a 300 GHz gyrotron", *Conf. Digest of IRMMW 2005*, pp.375-376, (2005).

[2] S. Mitsudo, K. Sakai, T. Idehara, et al., Conf. Digest of 31th IRMMW & 14th THz (2006) p.572.

[3] V. E. Zapevalov, V. K. Lygin, O. V. Malygin et al., Conf. Digest of 29th IRMMW & 12th THz (2004) p.149.

[4] V. E. Zapevalov, et al.,"High Power Oscillator of Continuous Electromagnetic Radiation with a Frequency Range 300 GHz", Radiophysics and Quantum Electronics **50** (2007) 420.

[5] T. Saito, T. Idehara, S. Mitsudo et al., Conf. Digest of 31th IRMMW & 14th THz (2006) p.24.

[6] T. Saito et al., "Performance Test of CW 300 GHz Gyrotron FU CW I", Int. J. Infrared Millimeter Waves **28**, (2007) 1063.

[7] S. Sabchevski et al., "Simulation of Mode Interaction in the Gyrotron FU CW I," Int. J. of Infrared and Millimeter Waves **28** (2007) 1079.

[8] T. Saito, T. Nakano, S. Mitsudo, I. Ogawa, T. Idehara, Plasma and Fusion Research, Vol.2 024 (2007).

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