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# Development of multi-frequency and multipurpose gyrotron FU CW GV
# 多周波数発振汎用ジャイロトロン FU CW GVの開発


Yoshinori Tatematsu, Yuusuke Yamaguchi, Ryoichi Ichioka, Masaki Miwa, Masafumi, Tanabe, Masaki Kotera, Toshihide Matsui, Kouki Terashima, Isamu Ogawa and Teruo Saito

立松芳典, 山口裕資, 市岡亮一, 三輪昌希, 田邉優文, 小寺政輝, 松井俊英, 寺島弘貴, 小川勇, 斉藤輝雄

*Research Center for Development of Far-Infrared Region, University of Fukui*
*3-9-1 Bunkyo, Fukui 910-8507, Japan*
福井大学遠赤外領域開発研究センター 〒910-8507 福井市文京3-9-1



Gyrotron FU CW GV has been developed as a multi-frequency gyrotron. The main mode is $TE_{10,6}$ and corresponding frequency is 265 GHz. Other modes were selected, of which the excited electromagnetic wave to be converted to a Gaussian beam by one mode converter. Actually, more than ten modes oscillated with different frequencies, and Gaussian beams were radiated. A double-disk window system was adopted to maintain the transmittance through the window in high level for a wide range of frequency.


## 1. Introduction

At FIR center in University of Fukui, Gyrotron FU CW G-series, equipped with internal mode converters, have being developed [1-4]. As the fifth gyrotron in this series, Gyrotron FU CW GV was developed. It was designed as a multi-frequency gyrotron. The main mode is $TE_{10,6}$ at the fundamental cyclotron resonance and the wave frequency is 265 GHz. The mode converter was designed for this mode. Nevertheless, we expected that several modes could oscillate in the cavity and that the electromagnetic wave would be converted to a Gaussian beam by the same mode converter. The expected modes are listed in Table I, where the frequencies were calculated with the cold cavity model and $\theta$ is defined as $\cos^{-1}(m/\chi'_{mn})$. The quantity $m/\chi'_{mn}$ is the important factor determining the direction and extension of the beam emitted from the Vlasov launcher [3]. Because $\theta$ values of the other modes in Table I are close to that of the main mode ($TE_{10,6}$), we expected that these modes could oscillate in the cavity with Gaussian beam radiation. A magnetron injection gun was designed to generate a high-quality electron beam with a small velocity spread for all the modes in Table I [5].

## 2. Experimental results

Gyrotron FU CW GV was installed on a 10-T superconducting magnet. Signal intensity of the radiated wave was measured for changing cavity magnetic field strength with a pyro-electric detector placed in front of the gyrotron window. The result is shown in Fig. 1, in which a lot of signal peaks are observed. The frequencies for each peak were measured with a heterodyne receiver system and the cavity modes were identified from the measured frequencies. Each peak is labeled by the identified mode and the measured frequency in units of GHz.

Table I: Cavity modes expected to oscillate and to be converted to a Gaussian beam on Gyrotron FU CW GV.

| mode | frequency (GHz) | $\theta$ (degree) |
|---|---|---|
| TE10,6 | 265.0 | 70.9 |
| TE9,6 | 253.6 | 72.1 |
| TE8,6 | 242.1 | 73.3 |
| TE7,6 | 230.4 | 74.7 |
| TE9,5 | 224.7 | 69.7 |
| TE8,5 | 213.4 | 71.0 |
| TE7,5 | 202.0 | 72.5 |
| TE6,5 | 190.5 | 74.1 |
| TE7,4 | 173.2 | 69.5 |
| TE6,4 | 161.9 | 71.2 |

Then, radiation patterns were observed for the signal peaks with an infrared camera. Two of them are showed in Fig. 2. Their cavity modes are $TE_{10,6}$ and $TE_{8,6}$, respectively. In addition to these modes, Gaussian-like patterns were obtained for others. In Fig. 1, the cavity modes with which a Gaussian beam was radiated are indicated by the letters surrounded by a square. Almost all of the observed modes were converted to the Gaussian beam with the same converter.

The beam signal intensity of the design mode ($TE_{10,6}$) was strong, however, the others were significantly weaker as shown in Fig. 1. One of reasons for this is that the transmittance of the electromagnetic wave through the window depends on the wave frequency. To prevent the drop in the transmittance due to this frequency-dependence, a double-disk window system was adopted. Both window disks are made of sapphire and have the same width, which was determined from the optimization of the transmittance at 265 GHz.

The second disk was attached to a frame, which was engaged with the main window by a screw. The screw of 1 mm-pitch is cut on the frame. The distance between the two disks was varied by rotating the frame. With variation of the distance between the two disks, the transmittance of the electromagnetic wave periodically changed because of the interference of the wave. We observed the signal intensity while varying the distance between the window disks. When the disk distance was changed, the measured signal intensity changed periodically. The transmittance can be significantly improved by using the two disks with an appropriate disk distance.

Window power was measured with a water load for this gyrotron and the result is shown in Fig. 3. The red squares represent the power for the main $TE_{10,6}$ mode oscillation for the single-disk window case. The maximum power of 1.3 kW was obtained. The closed and open blue circles represent the power for one of the sub-modes ($TE_{8,6}$) in the cases of the double-disk window with an optimized disk distance and single-disk window, respectively. The beam current was 0.5 A. The power ratio for the single to double-disk window was 0.38 with $V_k$ = –20 kV, and the corresponding theoretical ratio of the transmittance is 0.39. Thus, there is good agreement between the theoretical and experimental results. Figure 3 shows that the output power of the $TE_{8,6}$ mode becomes comparable to that of the main mode with the double-disk window system.

## 3. Summary

A multi-frequency gyrotron, Gyrotron FU CW GV has been developed. Gaussian beams were observed for more than ten cavity modes. The drop of the window transmittance due to its frequency dependence can be improved by the introduction of a double-disk window system, with which the output power of a sub mode oscillation became comparable to that of the main mode.

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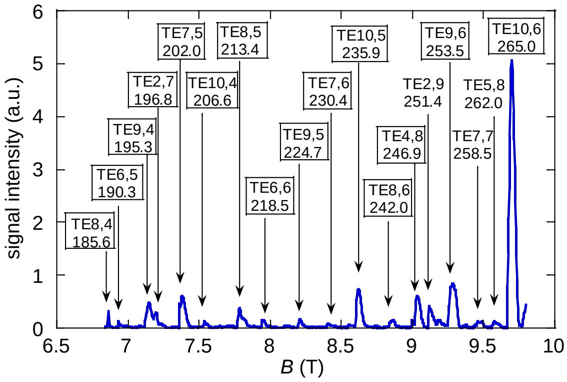


Fig. 1 Signal intensity and frequency measurements on Gyrotron FU CW GV for single-disk window.

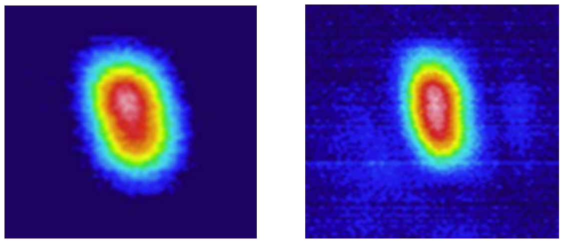

Fig. 2 Measured radiation patterns with an infrared camera. The cavity modes are $TE_{10,6}$ (left) and $TE_{8,6}$ (right).

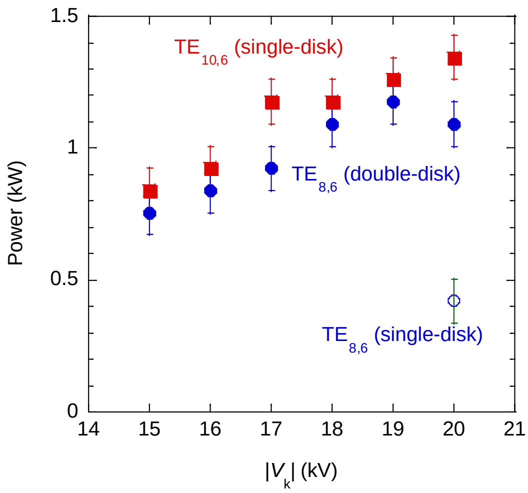


Fig. 3 Power measurement for the $TE_{10,6}$ mode with a single-disk and the $TE_{8,6}$ mode with double and single-disk.