Development of a Sub Terahertz High Power Pulse Gyrotron for Collective Thomson Scattering

Teruo Saito[a], Takashi Notake[a], Yoshinori Tatematsu[a], Akihoto Fujii[a], La Agusu[a], Isamu Ogawa[a], Toshitaka Idehara[a], Vladimir N. Manuilov[b]

[a] Research Center for Development of Far-Infrared Region, University of Fukui, Fukui 910-8507, Japan

[b] Nizhny Novgorod State University, Radiophysical Faculty, Nizhny Novgorod 603600, Russia

***Abstract*- A high power sub terahertz pulse gyrotron is under development in FIR-FU for application to collective Thomson scattering from a high density plasma in the Large Helical Device. As the first step of this development, a pulse gyrotron using an existing electron gun was constructed and tested. Oscillations with frequencies around 400 GHz was observed at the second harmonic resonance. Several modes were confirmed to be single mode oscillation with the beam voltage up to 35 kV, near the maximum rating of the electron gun. A new gyrotron is now under construction as the second step of development. This gyrotron will be operated with a newly designed electron gun with the beam voltage up to 70 kV and the beam current up to 10 A.**

I. Introduction And Background

Recently, development of high frequency gyrotrons as power sources for many applications has been intensified. Among those, development of a sub terahertz high power pulse gyrotron as a power source of collective Thomson scattering (CTS) diagnostics is a challenging task.

For a power source of CTS, fusion grade gyrotrons with frequencies from tens of GHz to 140 GHz are considered and experiments with these gyrotrons has started [1, 2]. However, electromagnetic waves with these frequencies suffer from a strong plasma dispersion effect. Moreover, high level background electron cyclotron emission is a large noise source. Recently, a high density plasma has been produced in the Large Helical Device (LHD) and this plasma is considered to be a promising alternative to the medium density and high ion temperature plasma. Plasma dispersion effect is particularly strong in the high density plasma. Use of a sub-terahertz gyrotron will resolve these problems. Therefore, we have started development of a high-power, sub-terahertz pulse gyrotron with a frequency around 400 GHz and the output power of tens of kW in FIR-FU [3]. This frequency has been chosen for application as a power source of CTS diagnostics of a high density plasma in LHD [4]. This paper describes the results of the development of the sub-terahertz pulse gyrotron.

II. Results

The development of a high power, sub terahertz pulse gyrotron has two steps. As the first step, we have developed a gyrotron with an existing electron gun and an 8 T superconducting magnet. Design calculation was done and optimized for the electron gun that is designed to operate at the beam voltage of 40 kV and the beam current of 1 A. The radius of the cavity is 2.39 mm and its length is 10 mm. The oscillation frequency is 203.6 GHz when the gyrotron is operated at the fundamental TE_{03} mode at the cavity field strength B_c around 7.7 T.

First, oscillation of fundamental modes was examined. Figure 1 plots the oscillation signal as a function of the magnetic field at the cavity B_C. The beam voltage was 35 kV. The frequencies attached to each peak were measured with a Fabry-Perot interferometer (FPI). Starting currents for the TE_{03} mode and the TE_{23} mode calculated with cold cavity approximation are shown in the upper panel of Fig. 1. Oscillation of the TE_{03} mode as well as the TE_{23} mode was

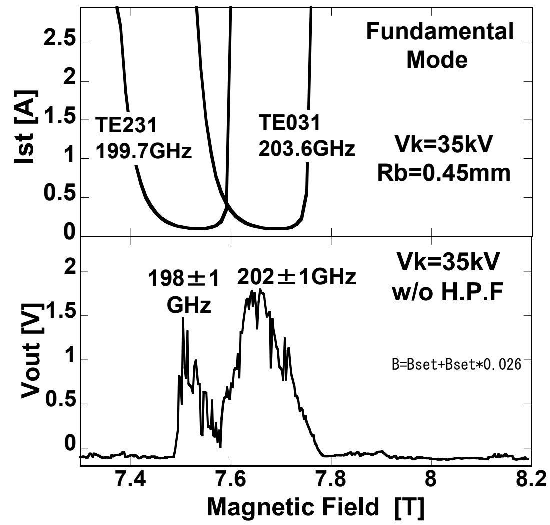

Fig. 1. Oscillation signal detected without a high pass filter is plotted as a function of the cavity field strength. The starting currents of the relevant modes are shown in the upper panel.

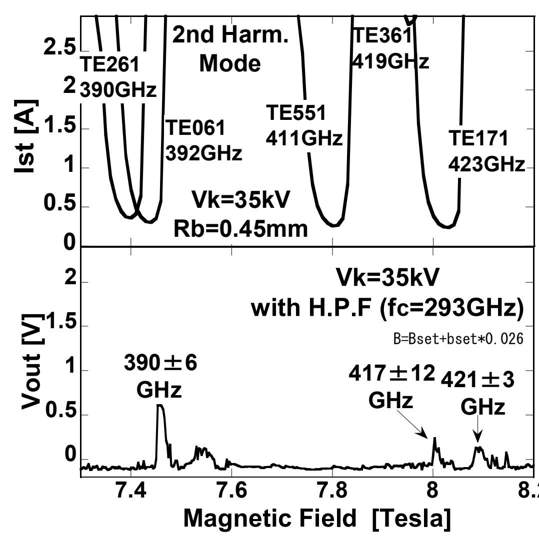

Fig. 2. Oscillation signal detected with a high pass filter is plotted as a function of the cavity field strength. The starting currents of the relevant modes are shown in the upper panel.

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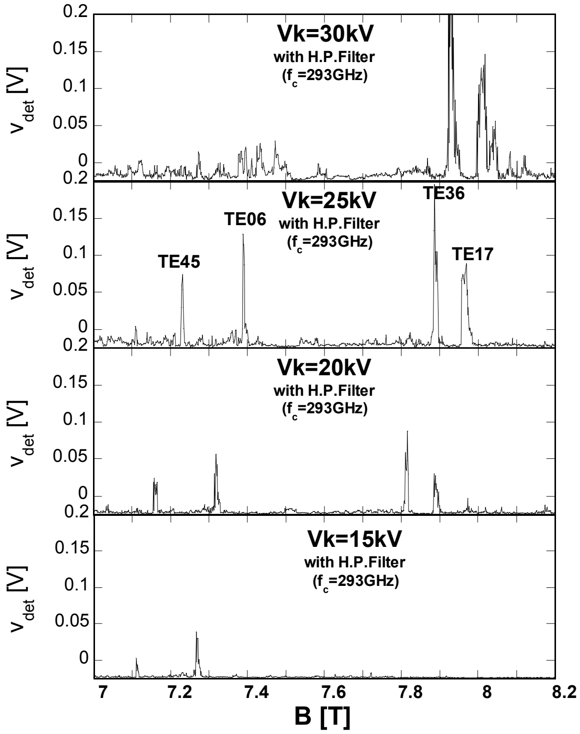

Fig. 3. Oscillation signal detected through a high pass filter is plotted as functions of the cavity field strength with the beam voltage as a parameter.

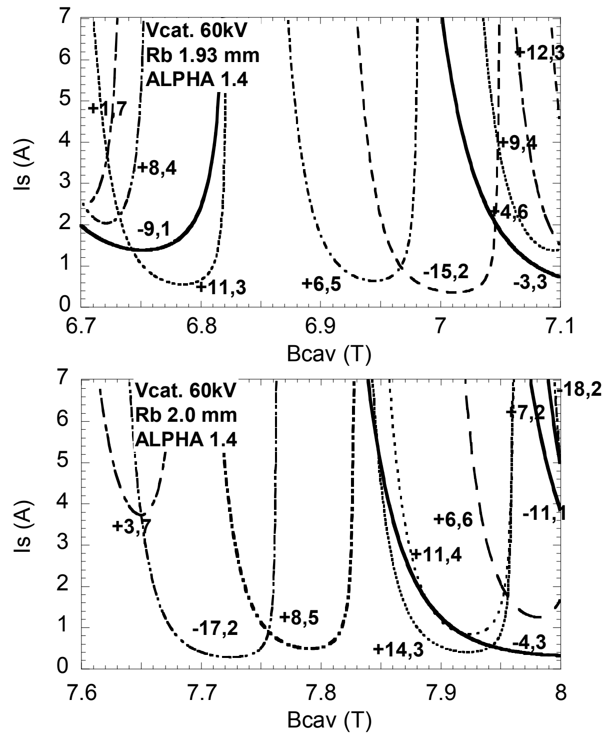

Fig. 4. Starting currents the TE65 mode and the TE85 mode are shown. Those of the competing nodes are also plotted. The thick solid lines stand for fundamental modes.

confirmed.

Next, second harmonic oscillation with frequency around 400 GHz was searched. The oscillation signal through a high pass filter, the cut off frequency of which was 293 GHz, is shown in Fig. 2. The frequencies were measured with the FPI for the three peaks. Comparing with resonance frequencies and the starting currents plotted in the upper panel, these peaks can be identified as the TE_{06}, TE_{36} and the TE_{17} modes, respectively, within a possible error of the evaluation of B_C. When we use a second harmonic mode, it should be single mode oscillation. By using a filter that allows partial transmission of the fundamental oscillation power, single mode oscillation of the TE_{36} and TE_{17} modes was confirmed.

Figure 3 plots the oscillation signal as functions of B_C with the beam voltage V_k as a parameter. Second harmonic modes start to oscillate for V_k as low as 15 kV. Second harmonic modes become difficult to oscillate in single mode as the beam voltage increases. Single mode oscillation of these modes has been confirmed for V_k up to 35 kV and possibly up to 40 kV. Single mode oscillation of the other two modes in the lower field region, TE_{06} and possibly TE_{45} has not been confirmed at the moment.

One important is that the second harmonic TE_{55} mode as shown in Fig. 2 did not oscillated. This is probably due to mode competition with the TE_{032} mode with the axial mode number 2. In fact, oscillation signal with a frequency corresponding to this mode was observed near the B_C region of the TE_{55} mode.

The second step gyrotron using a new electron gun with the beam voltage up to 70 kV and the beam current up to 10 A was designed and constructed. The electron gun was newly designed and manufactured for this gyrotron. To expand the beam current as high as 10 A, the cavity radius should be expanded. The target frequency ranges from 350 GHz to 400 GHz at second harmonic oscillation. In addition to the larger cavity radius, the working voltage higher than the first step gyrotron, mode competition will be much more severe. We have searched appropriate modes well isolated from other modes, particularly from a fundamental mode in the low field side.

Figure 4 shows the result. The cavity radius is 2.99 mm. The TE65 mode oscillates at about 350 GHz and the TE85 mode oscillates at about 393 GHz Both modes are well isolated from competing modes, especially from fundamental modes in the low field side. Both oscillations with frequencies about 350 GHz and 390 GHz have been observed in the initial experiment.

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