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Proof of High Power Oscillation of a Sub Terahertz Gyrotron for Application to Collective Thomson Scattering Experiment on LHD

LHDにおける協同トムソン散乱への適用を目指したサブテラヘルツ帯ジャイロトロンによる高出力発振の実証

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High power sub terahertz pulse gyrotrons are under development in FIR FU for application to CTS measurement on a fusion plasma device, especially on high density plasmas produced in LHD. Very recently, a new record of pulse sub terahertz radiation exceeding 80 kW at about 390 GHz has been obtained from a gyrotron with second harmonic oscillation. This paper reports detailed study of oscillation characteristics of the gyrotron along with design consideration to realize high power single mode oscillation at second harmonic. Discussion will also be given about the mode competition.

1. Introduction

Application of high frequency gyrotrons has been intensified in various fields. Sub terahertz gyrotrons are very attractive for plasma diagnostics of high density plasmas such as those in LHD. Although over one terahertz oscillation has been realized with both second harmonic (SH) and fundamental harmonic (FH) oscillations [1,2]. SH oscillation is attractive to relax the requirement to superconducting magnets. On the other hand, SH oscillation has a serious problem of mode competition with FH modes, especially when we aim for high power oscillation. It is a very challenging task to realize a 100 kW-level sub terahertz gyrotron as a power source of a CTS apparatus [3,4]. On the other hand, this study will bring a lot of problems to be studied.

We have demonstrated more than 50 kW SH oscillations at 350 GHz and about 40 kW at 390 GHz with a demountable gyrotron in the first stage [5]. This paper reports the study for higher power in the second stage.

2. Design Consideration

For realization of single mode SH oscillation, suppression of mode competition is very important. Figure 1 shows the distribution of Bessel prime zeros near candidate modes. Upper and lower numbers correspond to the SH and the FH resonances, respectively.

Single mode oscillation of the SH $TE_{3,7}$, $TE_{1,8}$ and $TE_{17,2}$ modes can be expected because they are far from the neighboring FH $TE_{4,3}$ mode.

The cavity radius R_c of 2.99 mm was determined from a comprehensive consideration for radiation frequency and the coupling between the RF-electric field. For this radius, the resonance frequencies are around 390 GHz.

3. Proof of High Power SH Mode Oscillation

We fabricated a new gyrotron of sealed-off type to examine oscillation characteristics of the $TE_{3,7}$, $TE_{1,8}$ and $TE_{17,2}$ modes [6]. It operates in pulse mode. The pulse width is several microseconds and the repetition rate is less than 10 Hz. We began with the $TE_{1,8}$ mode and obtained a maximum power of 62 kW at the cathode voltage V_k of 65 kV and the

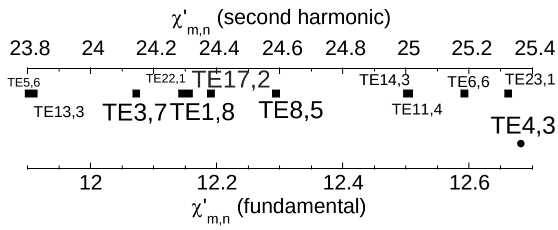

Fig. 1. Distributions of SH and FH modes

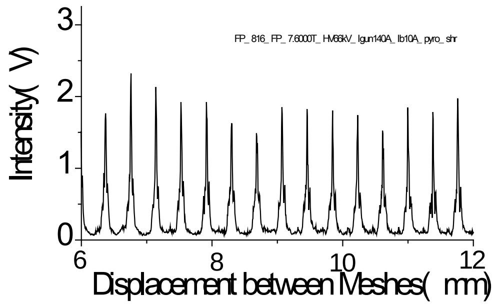

Fig. 2. An Example of FPI signal of single mode oscillation

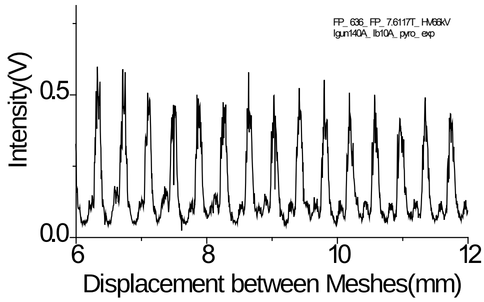

Fig. 4. An Example of FPI signal with mode competition

beam current I_b of 11 A with no simultaneous oscillation with the FH $TE_{4,3}$ mode. However, the electron beam radius R_b corresponding to the emission belt radius R_k of the electron gun lies in the range of low coupling coefficients.

Then, R_k of the electron gun was changed to realize the maximum coupling with the $TE_{17,2}$ mode. The new power record has attained to 83 kW at V_k of 60 kV and the beam current I_b of 10 A. Figure 2 shows a signal transmitted through a Fabry-Perot interferometer (FPI). The pulse train corresponds to the $TE_{17,2}$ mode with the frequency of 388,8 GHz. Single mode oscillation is clearly shown.

Figure 3 plots new power records of SH gyrotron in the sub terahertz region. Power records obtained with the previous gyrotron of demountable type are also plotted.

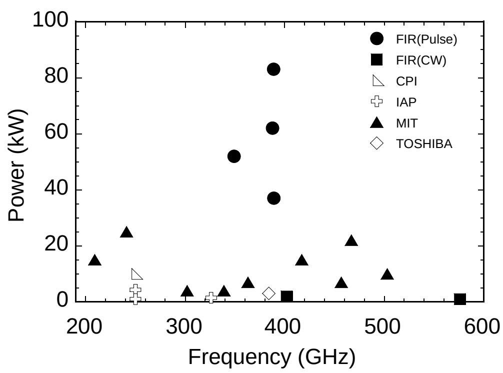

Fig. 3. Record powers against frequency

4. Observation of Mode Competition

We have proven high power single mode oscillation of SH modes. However, a little changes of the magnetic field strength B_c at the cavity or the current of the auxiliary coils installed near the electron gun result in mode competition. Figure 4 represents an example of such a case. A small pulse train in between each peak of the main $TE_{17,2}$ mode indicates simultaneous oscillation of the neighboring SH $TE_{8,5}$ mode. The combination of simultaneously oscillating modes changes with variation of the operation conditions.

5. Design of a Fundamental Harmonic Gyrotron

We have succeeded to demonstrate single mode oscillation of SH modes at power levels reaching 100 kW. However, it is rather sensitive to the operation condition.

Then, a 300 GHz FH gyrotron has been designed. Mode selection is also important for FH mode. Compatibility with the mode converter is another factor because the new gyrotron will be equipped with a built-in mode converter. We have selected the $TE_{14,2}$ mode. An electron gun has been designed for this gyrotron [7]. A mode competition calculation predicts more than 200 kW oscillation.

6. Summary

SH oscillation of the $TE_{3,7}$, $TE_{1,8}$ and $TE_{17,2}$ modes has been confirmed with a newly manufactured sealed-off gyrotron. The maximum power obtained with the $TE_{1,8}$ mode was 62 kW at 388 GHz. A further higher power of 83 kW has been attained at 389 GHz with the $TE_{17,2}$ mode. We have succeeded in high power single mode oscillation of SH modes.

A FH gyrotron with a 12 T magnet has been designed. It is now under fabrication.

Acknowledgments

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