

Development of a 1-THz 4th-Harmonic Gyrotron

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Abstract—A design of a 1-THz 4th Harmonic Gyrotron is proposed in this paper. Fourth harmonic interaction is adopted to lower the strength of the external magnet. The magnet can be as low as 10T. Such a low-intensity magnetic field can be easily proposed by a superconduct magnet, which make the generation of continuous waves at 1 THz possible. Seeing that the mode competition is extremely fierce, a large orbit gun is employed as the driven source. An 80-kV, 0.7-A electron beam is injected into the interaction circuit to excite the fourth-harmonic electromagnetic waves. According to the cold dispersive diagram, the TE_{4,8} mode of the cylindrical waveguide is selected as the operating mode to further suppress the mode competition induced by the fundamental modes, the 2nd harmonic modes and the 3rd harmonic modes. It could be inferred based on the multi-mode time-domain theory that an output power of 1.15 kW can be achieved. The scheme diagram for the hot test is proposed. The LOG is chosen as the electron gun. Particular structure is employed for improving the output efficiency in the interaction circuit.

I. INTRODUCTION

Terahertz (THz) waves play a critical role in a wide range of potential applications, e.g., plasma fusion diagnostics [1] and dynamic nuclear polarization enhanced nuclear magnetic resonance[2]. However, the development of the THz technologies is limited by the generation of THz waves. Gyrotrons, based on the electron cyclotron maser, have the capability of outputting high power and high frequency electromagnetic energy. Existing research have proved the feasibility of generating electromagnetic waves beyond 1 THz. A second-harmonic, 1.005-THz gyrotron was confirmed experimentally with a TE_{6,11} mode using a 19.0-T pulse magnet at the University of Fukui, Japan [3]. The experiment designed, manufactured and tested at the Institute of Applied Physics, Russia Academy of Sciences, generated 1.5kW of coherent radiation at 1.022 THz using a 38.5-T pulse magnet [4]. The experiments mentioned above both necessitate high strength magnetic field. To achieve the desired peak value of the external magnetic field, such magnets normally produce pulse magnetic field, which means that the generated electromagnetic waves are likely to be short-pulse waves rather than continuous waves. To break the limitation induced by the external magnets, we propose a 4th-harmonic gyrotron scheme. The desired intensity of the magnetic field can be further lower, which make it possible that gyrotrons produce 1-THz electromagnetic waves continuously. The paper is organized as follows. In section II, the simulation results are presented. In

section III, the progresses of the experiment are demonstrated. The conclusions are drawn in Section IV.

II. SIMULATION RESULTS

The operating mode is TE_{4,8} modes. An 80-kV, 0.7-A electron beam is applied to excite the 4th-harmonic gyrotron. The velocity spread is 10%. The pitch factor of the electron gun is 1.5. The results calculated according to the frequency-domain single-mode theory [5] are shown in Fig. 1. The electron is 7%. 3.49% of the energy dissipates on the waveguide wall. Thus, the output efficiency is 3.51%.

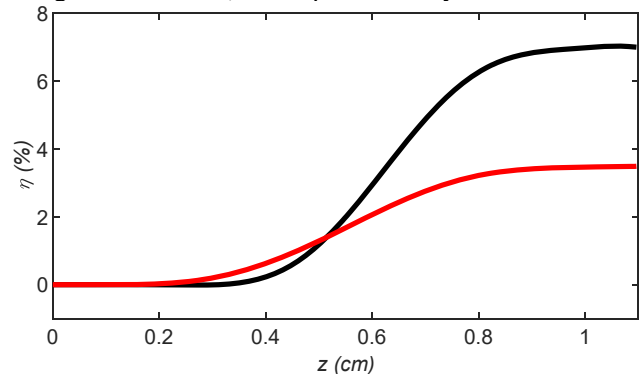


Figure 1. The black line indicates the electron efficiency, while the red line indicates the ohmic loss.

III. EXPERIMENT PROGRESS

The experiment design scheme is shown in Fig. 2. The gyrotron designed for experiment is composed of five parts, i.e. the electron gun, the anode, the interaction circuit with liquid cooling, the water-cooled collector and the output window. The LOG is quite different from the MIG. An auxiliary coil is used to produce a zero magnetic field point. The anode of the gyrotron is designed corresponding to the distribution of the external magnetic field. The inner radius of the anode is far more less than the length. Therefore, the anode was split into two parts to improve the co-axiality in fabrication. In hot test, the two anode parts are supported by several frames to keep the co-axiality. In the downstream part of the anode, there remains a ceramic probe. The probe is adopted to observe the current which move through the liquid cooling, the water-cooled collector and the output window. The LOG is quite different from the MIG. An auxiliary coil is used to produce a zero magnetic field point. The anode of the gyrotron is designed corresponding to the distribution of the external magnetic field. The inner radius of the anode is far

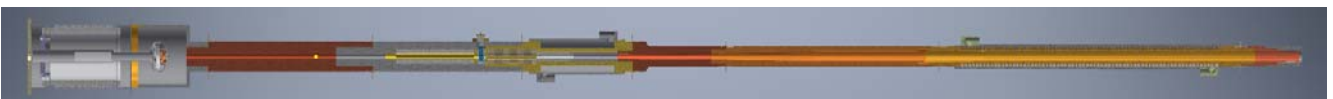


Figure 2. Schematic diagram of the 4th-harmonic gyrotron for experimental test.

external magnetic field. The inner radius of the anode is far more less than the length. Therefore, the anode was split into two parts to improve the co-axiality in fabrication. In hot test, the two anode parts are supported by several frames to keep the co-axiality. In the downstream part of the anode, there remains a ceramic probe. The probe is adopted to observe the current which move through the interaction circuit. In hot test, it's convenient to improve the co-axiality between the cylindrical waveguides and the external magnetic field. The interaction circuit is a two-layer structure. The innermost space is the cylindrical waveguide for beam-wave interaction. The space between two layers is designed as the coolant path. According to our previous study, liquid nitrogen was considered as the coolant. Due to the low efficiency of the 4th-harmonic interaction at 1 THz, the energy dissipated on the waveguide wall is quantitatively low as well. Thus, the liquid nitrogen can be considered to be at boiling temperature all the time. This assumption allows us to avoid many complicated problems in terms of fluid mechanics. The water-cooled collector is design corresponding to the distribution of the external magnetic field. The co-axiality of this part is not likely to be significant. Therefore, each part of the collector is quantitatively longer than that of the anode. All spent electrons finally hit the wall of the collector. The energy dissipated is quantitatively large than that in the interaction circuit. Thus, fins are employed for better cooling performance.

IV. CONCLUSION

The experimental scheme diagram of the 1-THz 4th-harmonic gyrotron is demonstrated. The gyrotron has five part, i.e., the electron gun, the anode, the interaction circuit with liquid cooling, the water-cooled collector and the output window. The LOG is employed as the electron gun to excite the electromagnetic waves. For improving the co- axiality in fabrication and hot test, the anode was split into two parts. A two-layer structure is used in the interaction circuit. The liquid nitrogen will be set into the space between two layers to improve the output efficiency. To lower the temperature induced by electrons hit on the wall in collectors, fins is adopted to improve the cooling performance.

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