Operation Condition of GW Class Magnetron with Diffraction Output in Particle-In-Cell Simulation

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Abstract: Particle-In-Cell (PIC) simulations were performed to study the GW operation condition of an A6 Magnetron with Diffraction Output (MDO) with transparent cathodes. The input waveform is a -500 KV pulse of 100 ns pulse width. The results show the GW class output power appears after 30 ns at 0.36 T external magnetic field, which is within theoretical prediction of conventional Buneman–Hartree (B-H) condition, but is very sensitive to magnetic field strength. The actual energy efficiency maybe lower than expected.

Keywords: relativistic magnetron; diffraction output; resonance modes; Helmholtz Coils; PIC simulation.

Introduction

Recently, High Power Microwave (HPM) weapons seem to be closer to reality [1-5], and judging from these publicly available information, the output power of these demonstration systems seem to be limited by air breakdown in front of the output waveguide, which is typically around 500 MW in ordinary dry air, but also depends on frequency and pulse width [6-8]. However, in a humid air, air breakdown is harder to occur, therefore a higher output power may be useful for various tactical situations. Generally, a stable GW class source will be preferred by the system engineers of such weapon system.

Among all the HPM sources, magnetron is generally considered to be a compact and higher energy efficiency one, therefore is a possible choice for such system. Traditional cavity magnetron may produce steady 500 MW output power in S-band, while pulsed relativistic magnetron may produce higher power at a more unstable condition, also usually in S-band. The newly developed Magnetron with Diffraction Output (MDO) comes out of a legacy design [9], now fitted with transparent cathode offers advantages like quick start and high energy efficiency [10-13]. The output extraction of MDO is a forward circular waveguide, which makes it particular suitable for certain compact system design. However, there are still some technical challenges for this source, for example, long pulse operation.

In this article we present the scenario when a MDO produces GW class output power in PIC simulation. The structure is modeled after previous literature [13], but due to details in CAD model and simulation setups, the condition for GW class resonant output maybe different from reported experimental condition. Section II described the MDO in simulation, and section III describes the simulation results.

MDO CAD Model Used in PIC Simulation

The commercial PIC code CST Studio is used to simulate the source. Shown in Fig. 1(a-d) are the CAD models used in the PIC simulation, constructed with sizes referenced after [14], which is an A6 magnetron. Fig. 1a shows the exterior of the MDO with Port 1 (red) as the input for negative high voltage pulse, and Port 2 (red) as the output port. Fig. 1(b) shows the wireframe view of the inside of the MDO. Fig. 1(c) shows the 6 transparent cathode rod attached on the cathode shaft. Fig. 1(d) shows the cathode current monitor position. Fig. 2 shows the input negative high voltage waveform.

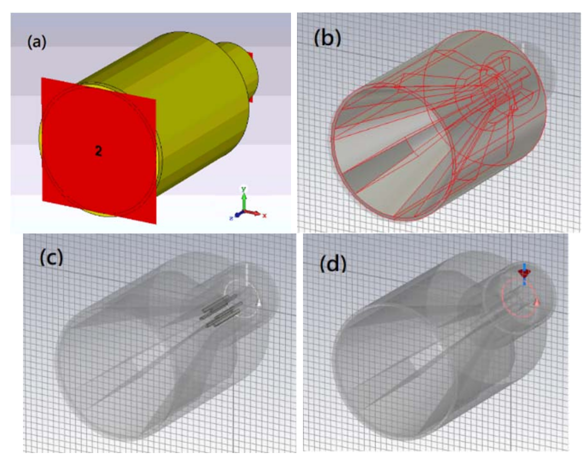

Fig. 1 (a) The exterior of the MDO with Port 1 (red) as the input for high voltage pulse, and Port 2 (red) as the output port. (b) The wireframe view of the inside of the MDO. (c) The 6 transparent cathode rod attached on the cathode shaft. (d) The cathode current monitor position.

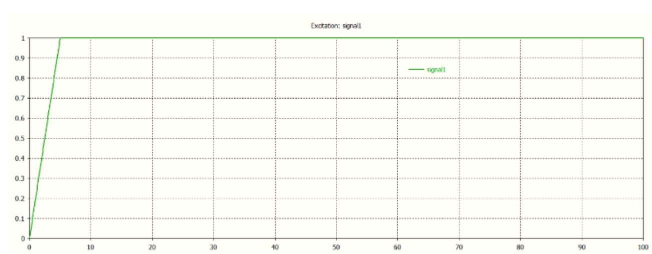

Fig. 2 The input negative high voltage waveform, peak voltage is -500 kV.

Simulation Results

A. *Particle Distributions*

Shown in Fig. 3(a) is the isometric and 2D cut plane (Z=35 mm) particle position view at 2.5 ns (cathode strips length is 75 mm). Fig. 3(b) is the 2D particle view at 5 ns. Fig. 3(c) is the 3D particle view at 10 ns. Fig. 3(d) is the 3D particle view at 20 ns.

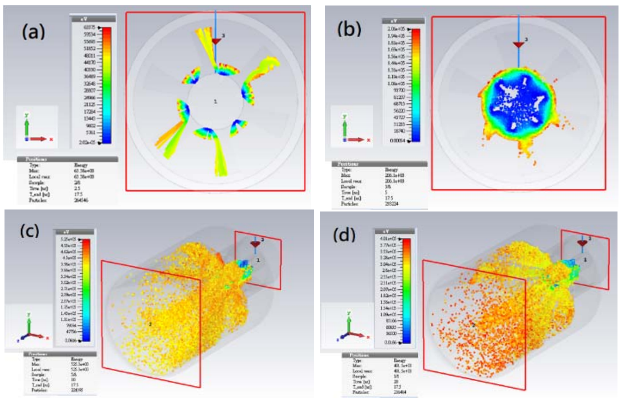

Fig. 3 (a) The isometric and cut plane (Z=35 mm) particle position view at 2.5 ns (cathode strips length is 75 mm). (b) The particle view at 5 ns. (c) The 3D particle view at 10 ns. (d) The 3D particle view at 20 ns.

B. The Output Power and Mode

Fig. 4(a) is the output power at Port 2 mode 10. The output power exceeds 5 GW, but it takes around 30 ns to reach this level. Fig. 4(b) is the FFT of the mode 10 at Port 2, which is the main mode and the resonant frequency is 2.0255 GHz. The code records 16 modes at the Port 2, and other modes exist.

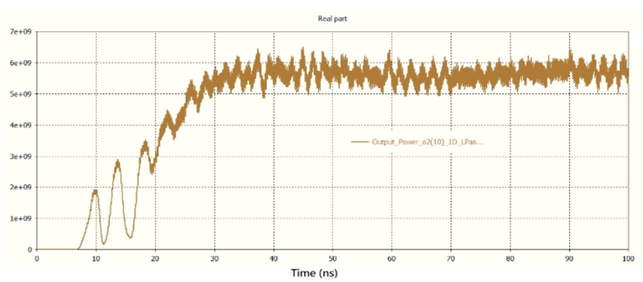

Fig. 4(a) The output power at Port 2 mode 10.

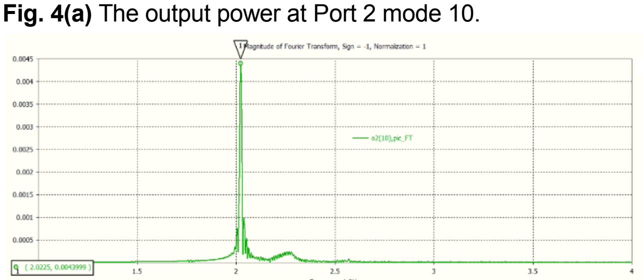

Fig. 4(b) The FFT of the mode 10 at Port 2, the main resonant frequency is 2.0255 GHz.

Conclusion

At first, we try to search the resonant condition for the GW output power according to traditional B-H theory by scanning the magnetic field strength, but we couldn't find one because we "skip" the resonant B field. Which indicates an unpleasant truth, although the magnetron is believed to be a HPM source of high energy efficiency, but because it has to rely on a pair of pulsed Helmholtz coils to generate the external magnetic field, the "moment" of high energy efficiency is actually quite short.

Acknowledgment

We thank CST Simulation for the academic license of CST Studio Particle Suite and financial support from MOST 109-2914-I-346-002-A1 and MOST109-2637-M-346-001.

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