Simulation of an Industrial Magnetron Using Cathode Modulation

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Abstract: Results of a simulation study of the L3Harris CWM75KW industrial strapped magnetron is presented. This study is part of a larger project which studies the feasibility of achieving phase control and faster startup in the magnetron via controlled electron injection by using gated field emission arrays (GFEAs). The device was simulated by using the 3-D PIC code VSim at its typical operating conditions (18kV, 5A, 1900G, 896-929MHz). The startup behavior was examined with 1) no priming of any kind, 2) RF Priming, and 3) cathode modulation. With no priming, no oscillations were seen up to 300 ns; with RF priming for the first 50 ns, oscillations were then observed at 150 ns; and with cathode modulation to create electron spokes, RF oscillation was observed at 130 ns.

Keywords: magnetron; PIC simulation

Introduction

Magnetrons can be phase-locked using external systems. Previous 2-D PIC simulations of a rising sun magnetron[1] have shown that phase-locking is possible using modulated electron injection to control the spoke formation. An experimental setup using Gated Field Emission Arrays (GFEAs) for the modulated electron injection offers a potential solution to this problem by permitting the injection of electrons into the interaction space. Current work focusses on extending previous simulation results into 3-D. A commercially available industrial cooker magnetron (the L3Harris CWM-75kW) has been successfully simulated by using the 3-D PIC code VSim under the magnetron's typical operating conditions. The following document summarizes the setup and results of simulation studies intended to support planned experiments.

Background and Theory

The L3Harris CWM-75kW is a CW industrial strapped magnetron capable of 75kW of sustained power output. The typical operating parameters are listed in Table 1. Collaborators at L3Harris have experimentally shown the magnetron is also capable of operating at a set of low-power parameters (also listed in Table 1). These lower operating conditions are planned for future experimental work. For any given external axial magnetic field, the DC-voltage regime that allows oscillation is bounded above by the Hull cutoff, the cutoff voltage for magnetic insulation, and bounded below by the Hartree condition, the breakdown voltage of the magnetron in the presence of a rotating perturbation field. The Hull cutoff and Hartree Condition for the CWM-75kW were calculated by using methods presented by Lovelace and Young[2]; the results are summarized in Figure 1. Maximum efficiency occurs when the operating point is slightly above the Hartree condition line. Both sets of operating conditions shown in Table 1 are consistent with the theoretical values for the optimum operation of the magnetron.

Simulation Setup

Simulation studies of the magnetron were conducted by using the 3D PIC code VSim. The detailed geometry of the magnetron was constructed with CAD designs based on measurements provided by L3Harris (as seen in Figure 2). The scale of the simulated geometry and the physical geometry of the CWM-75kW is 1:1, resulting in a size of 110x110x127 mm for the simulation domain, which was then uniformly subdivided into rectangular cells that are 0.5x0.5x1 mm. In the original assembly, the output antenna is inserted in an output waveguide, which was not included in the simulation to reduce the size of the simulation domain for shorter computational times.

Table 1: Operating Parameters for the CWM-75kW

	Cathode Voltage (kV)	Emission Current (A)	Magnetic Field (G)	Frequency (MHz)
Typical	-18	4.75	1800	896-929
Low-Power	-8.3	0.15	900	909

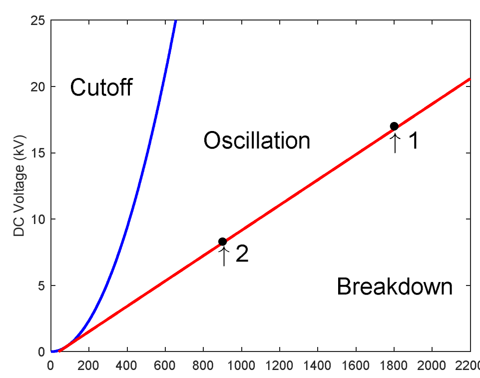

Figure 1: Hull cutoff (blue) and Hartree condition (red) of the CWM-75kW. 1: Typical operating point (1700G, 18kV), 2: Low-voltage operating point (900G, 8.3kV)

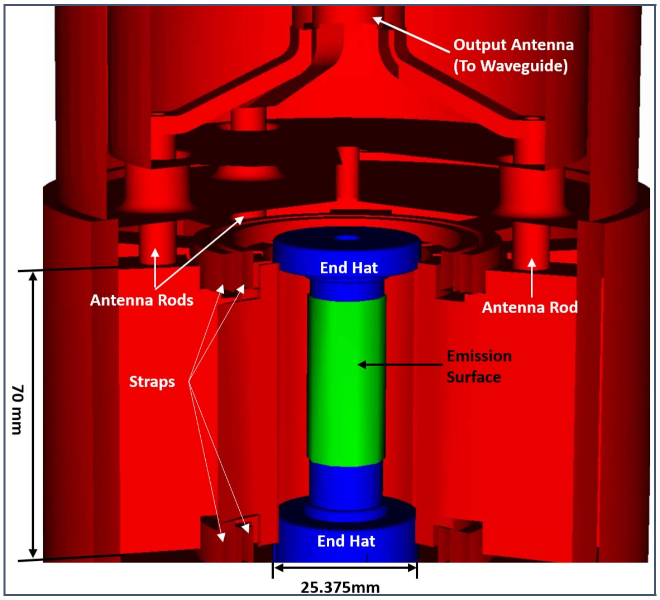

Figure 2: Geometric model of the CWM-75kW used in simulation

Simulation Results

With no priming or modulation of any kind, the simulated device failed to oscillate in a simulation time of 300 ns; this result was not unexpected since the actual device startup may take milliseconds. RF priming is a standard technique to speed up magnetron startup in simulations by defining an electric field in the magnetron resonators at the beginning of the simulation. For the RF priming study, a π-mode RF field at the magnetron's operating power (75kW) was defined in the magnetron's interaction space; this driving field was then shut off after 50 ns. Upon removal of the RF driving field, the RF field strength begins to decay; however, after another 100 ns (150 ns from the beginning of the simulation), the RF field strength begins to regrow, and the device starts to oscillate. This behavior can be seen in Figure 4, which plots the cavity voltage in one of the ten resonators. Hence, the RF-primed electron hub contains the necessary conditions to start oscillation even though the RF field has been stopped. With cathode modulation, electrons are injected in-phase to form electron spokes; the simulated device was able to reach full oscillation within 130ns of startup by continuous modulated electron injection. There is no RF priming in this case. Figure 3 shows the particle distributions at various simulation times showing the electron modulation creating spokes. Analysis of the cavity voltage, after full oscillation was reached, indicates an oscillation frequency of 898.07-914.49 MHz. The method of particle injection in the current simulation model can be further improved to gain tighter control of the output phase as it is believed that the spoke rotation timing is not in full synchronization with the particle injection timing in the current model.

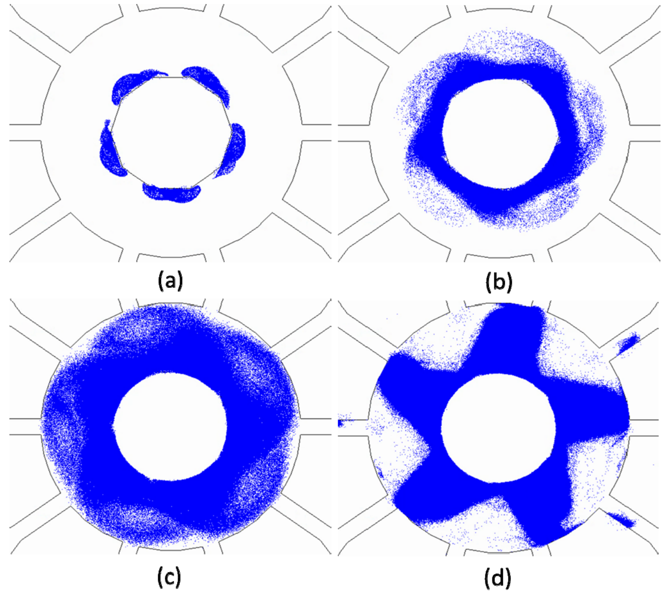

Figure 3: Cross-sectional view of the particle distribution in the horizontal center plane of the magnetron under cathode modulation. (a) beginning of electron injection (t=0.5ns), (b) initial spoke formation (t=10ns), (c) spoke buildup (t=75ns), (d) full oscillation (t=120ns)

Acknowledgements

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References

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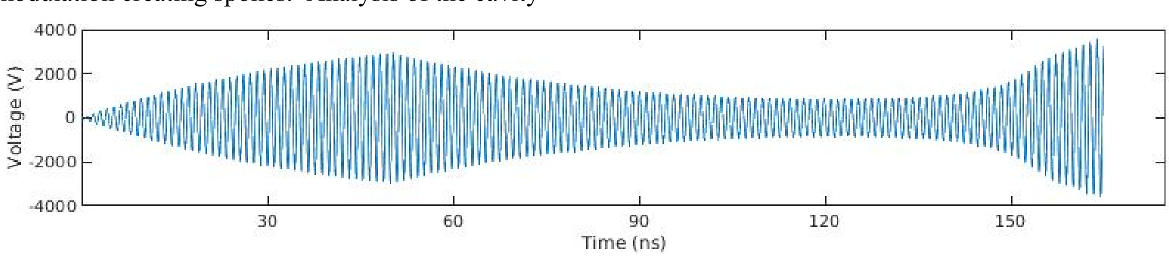

Figure 4: Cavity voltage plot of the magnetron under RF priming. The priming field shuts off at 50 ns, and self-oscillation begins at about 150 ns