Performance Improvement study of a Relativistic Magnetron using MAGIC-3D

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Abstract - *A three dimensional particle-in-cell (PIC) code, MAGIC3D, is used to examine the performance improvement in a relativistic magnetron by perturbing technique. Asymmetrical metal rods of different length have been used to perturb the magnetic field in the annular sector of the resonant system. Enhancement up to 45% in the radiated output power has been obtained in the perturbed magnetic field case over the unperturbed one. It has also been found in the simulation that oscillation start up time is reduced by 16 %, and the amplitude of the nearest competing mode goes down 9dB compared to unperturbed case. Perturbed magnetic field also reduces the end caps current improving the efficiency.*

Key words: Electromagnetic simulation, Relativistic Magnetron, MAGIC-3D

I. INTRODUCTION

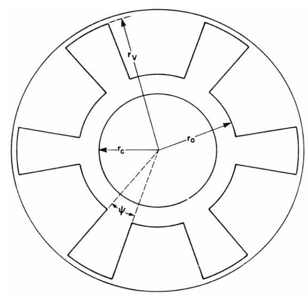
The relativistic magnetron, which operates at power levels ranging from 100's of MW to GW, is one of the major HPM source due to its compactness and efficiency [1, 2]. Because high power microwave with long pulse length are important to the Department of Defense and the plasma physics research community, there is continued interest in improving the performance of relativistic magnetrons. The aspect of magnetron performance in which improvement is required includes mode control, peak power, start oscillation time and pulse length. The improvements in the case of oven and relativistic magnetron by magnetic priming have been published [3-5]. In this paper we present the results of a 3-D simulation using PIC MAGIC-3D, conducted to investigate performance improvement in the case of a six vane relativistic magnetron.

II. SIMULATION MODEL

The magnetron model for the present study is a relativistic magnetron. The anode of this magnetron consists of six numbers of vanes. The cathode for relativistic magnetrons is mostly field emitters. For present study we have used explosive emission cathode [6]. For collection of the output power side resonator is connected to the output waveguide through smooth tapering. The coordinate system used in the simulation is polar coordinate system (r, θ, z). For this investigation we have used 2π-mode of operation. For the perturbation of magnetic field we use metal (OFHC copper) rod of 3mm radius in the side resonator along z-direction.

Figure 1 shows the cross sectional view of the resonator of the relativistic magnetron and table 1 summarizes the dimensional and other parameters used in the simulation model.

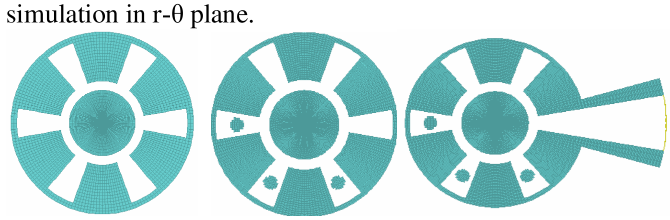
Table.1: Major parameters of the simulated relativistic magnetron



Parameters	Values
Frequency (2π-mode) GHz	4.27-4.60
Power (MW)	450
N	6
Ψ (degrees)	20^0
r_c (mm)	15.8
r_a (mm)	21.1
r_v (mm)	41.1

FIG: 1. Cross sectional view of resonant structure

We have carried out electromagnetic simulation of the model for the 2π-mode of operation without metal rod and with three rod positioned asymmetrically at 60 degrees. Figure 2 (a) and (b) show the cross sectional view of the simulation models and figure 2(c) show cross sectional view of complete geometry with three asymmetric metal tuners for the particle-in-cell simulation in r-θ plane.

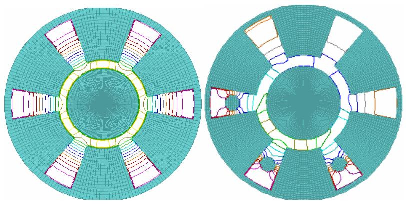


(a) (b) (c)

FIG: 2. Cross sectional view of relativistic magnetron in r-θ plane (a) without perturbation (b) asymmetric perturbation (c) Cutaway view of simulation model for PIC simulation in r-θ plane.

III. SIMULATION RESULTS

Before simulating the structure for non-linear beam-wave interaction we have first simulated both the model for electromagnetic simulation. The magnetic contour (B_z) plots for the unperturbed and asymmetrically perturbed case have been shown in figure 3(a-b). It is clear from figure that in the case of unperturbed magnetic field the magnetic field lines are uniform. The resonant frequency in our simulation is found to be 4.58GHz. In the case of perturbed magnetic field the magnetic field contours are non-uniform and there a shift in frequency as compared to unperturbed case. The resonant frequency in perturbed case is found to be 4.523GHz. The length of insertion of perturbing rod is up to axial center of the magnetron tube.



(a) (b)

FIG: 3. Magnetic contour plots (a) unperturbed magnetic field and (b) asymmetrically perturbed magnetic field.

By varying the insertion length in the side resonator we can tune the frequency of the resonant structure. For comparison of performance improvement in case of perturbed magnetic filed with that of without perturbed case we have simulated for radiated power and oscillation spectrum of the model.

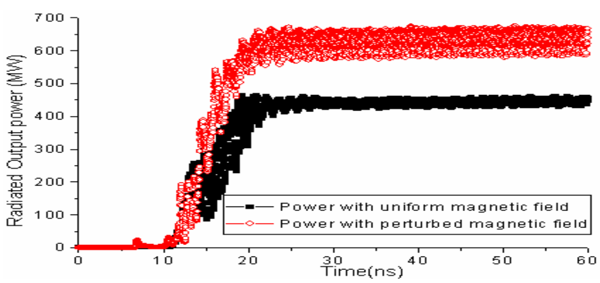


Figure: 4. Radiated output power in case of uniform and perturbed magnetic field.

It is clear from the figure 4 that in the case of perturbed magnetic field the output power is 669MW, which is 45 % higher than the unperturbed case, which is 459MW. It is also evident that oscillation start up time is also reduced by 3ns.

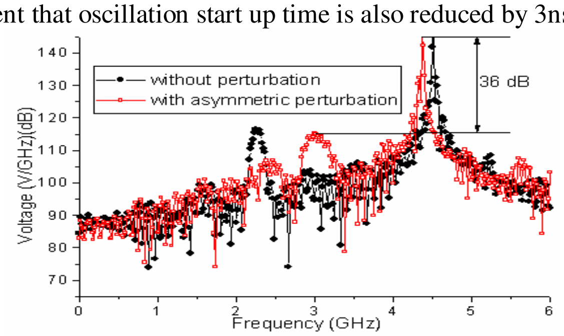


Figure: 5. Frequency spectrum of the rf power at the waveguide output of the uniform and perturbed magnetic field.

The spectral amplitude for both the cases is shown in figure 5. The amplitude of the nearest competitive mode in the case of perturbed magnetic field is 36 dB down, whereas in case of uniform magnetic field it is only 27dB. The oscillation frequency in perturbed magnetic field is 4.336GHz, so there is a frequency shift of 157MHz in comparison to cold condition. A large beam loading at relativistic voltage is major cause of frequency shift. Figure 7 show the variation of power and frequency with the pitch circle diameter of rod and axial position of the tuner. Zero points correspond to axial center of the simulated model.

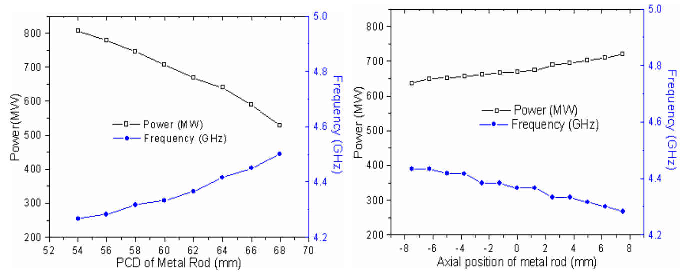


FIG: 6. Variation of power and frequency vs. (a) PCD of metal rod (b) vs. axial position of metal rod.

VI. CONCLUSION

A three dimensional particle-in-cell code, MAGIC3D, is used for eigenmode analysis and to examine the effect of perturbed magnetic field on the performance of relativistic magnetron. It is found that the radiated output power is increased by 45%. The oscillation start up time has been reduced and we have a better mode control. In summary, asymmetrical magnetic perturbation at an angle of 60 degrees is demonstrated for power improvement, reduced start up time and better mode control with well known particle-in-cell code MAGIC-3D.

ACKNOWLEDGEMENT

Authors are thankful to the Director, CEERI for granting permission to present this paper. Thanks are due to Dr. L. Ludeking at Mission Research Corporation for valuable discussions on MAGIC3D simulation techniques. They are also thankful to their colleagues for their supports.

REFERENCES

[1] James Benford, High-Power Microwave Sources, Edited by V.L. Granatstein and I. Alexeff. pp. 351-395.
[2] Hae Jin Kim and Jin Joo Choi, “Three-dimensional particle-in-cell simulation study of a frequency tunable relativistic magnetron.” IEEE Transaction on Dielectric and Electrical Insulation, Vol. 14 No.4; August 2007
[3] J.I Kim, J.H Won, and G.S. Park, “Electron Pre - bunching in Microwave Magnetron by Electric Priming using Anode Shape Modification”, Applied Physics Letters 86, 171501,2005
[4] V.B Baiburin and K.V. Kaminskii, “Effect of an Azimuthally Varying Magnetic Field on the Noise Level in a Multicavity Magnetron”, Technical Physics Letters, Vol.35 No.6,pp. 582-584, 2009
[5] Brad W. Hoff, et.al, “ Three-dimensional Simulation of Magnetic Priming of a Relativistic Magnetron”, IEEE Transaction on Plasma Science, Vol.38, No.6, June 2010.
[6] L.Ludeking, Mission Research Corporation, “National Workshop and Users Meeting on MAGIC Code”, At CEERI, Pilani, January 19-23, 2009.