Design and Simulation of a Relativistic S-Band Inverted Magnetron

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Abstract: *A Giga-Watt class Inverted relativistic Magnetron Oscillator (IMO) was designed and simulated using the massively parallel electromagnetic particle-in-cell code ICEPIC and scaling/redesign of an existing L-Band IMO. The IMO presented here is designed to operate in S-Band at low magnetic fields (B ~ 0.13 T). An axial RF power extraction method is employed. This technique eliminates the need for waveguide combiners, mode conversion apparatus, and complex radiating structures. ICEPIC simulations confirm that the above features combined with the IMO's stable, robust and reliable performance in the desired mode yield a Giga-Watt class HPM source notable for its size and absence of downstream current loss.*

Keywords: magnetron; microwave power; particle-in-cell; numerical simulation;

Introduction

Standard non-relativistic and relativistic magnetron designs employ a coaxial structure. The cylinder at the inner radius is a cathode that is the source of charged particles in the magnetron. The outer radius is the anode. Resting along the inner surface of the anode is a Slow Wave Structure (SWS). The Inverted Magnetron Oscillator (IMO) inverts this geometry, placing the cathode at the outer radius and the anode/SWS along the inner radius (see Figure 1). This much larger cathode surface area enables a greater magnitude of current to flow for a given input power than for a standard magnetron design. Consequently the IMO may operate at lower voltages relative to the standard configuration. Furthermore, the cathode geometry deviates from a circular form. Eight areas of the cathode are flattened to provide a priming effect for the development of the π mode. Given that 16 vanes are present in the SWS a mode priming feature is desirable. A number of other performance advantages over standard relativistic magnetrons are gained from the IMO design. With operation allowed to occur at lower voltages the risk of radiation emission and thus hazardous exposure is significantly reduced due to charged particles, on average, impacting the SWS with much lower energy. Additionally, the IMO is able to oscillate in S-Band with confining magnetic fields that are much lower than standard relativistic magnetrons at S-Band. The IMO examined in this work employ an axial RF extraction approach. Traditional radial RF extraction methods have resulted in significant size increases due to the radial extent of the magnetron and the necessity of waveguide combiners and mode converters. The IMO is able to eliminate the need for such apparatus by simply exciting a cylindrical TM_{01} mode in the downstream waveguide portion of the magnetron. Finally, the IMO design is capable of eliminating all downstream loss current. This is due primarily to a tapered downstream geometry

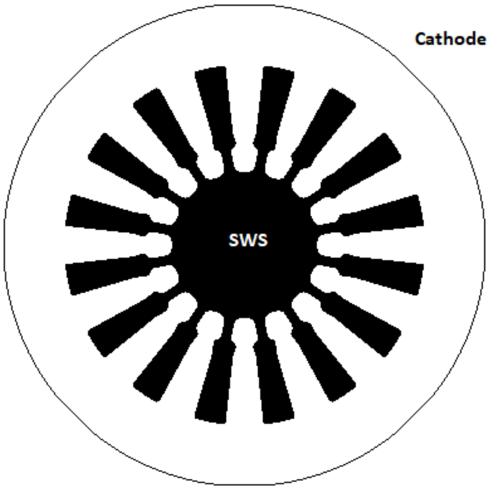

Figure 1. The IMO design in the r-θ plane of the interaction region. The interior is the Slow Wave Structure (SWS). The interior of the large radius is the cathode surface. The cathode surface is flattened at eight periodicly space areas to prime the π mode.

Method

A common numerical approach used for the evaluation of high power microwave tube designs, such as a magnetron, is the particle-in-cell (PIC) algorithm. The simulation data presented for the S-Band IMO is created using ICEPIC, short for Improved Concurrent Electromagnetic Particle-In-Cell code. The PIC algorithm is used to solve Maxwell's equations and the relativistic Lorentz force law in the time domain on a fixed staggered grid. ICEPIC is designed to run on parallel architecture and thus meet the challenge of full 3D simulations of the inverted magnetron. ICEPIC is a proven code that has been used in a number of high power relativistic magnetron studies [1] and for prototyping designs [2] and identifying loss mechanisms [3]. It has also been used to study non-relativistic magnetron designs [4].

Results

The reference simulation presented here was carried out at a magnetic field B = 0.135 T and a net input voltage of 338 kV. Voltage ramp-up was linear over 50 ns and remained constant for the remainder of the simulation. The mode dynamics realized in the simulation are displayed in Figure 2. After an initial period of transience, the π mode, operating in S-Band is well established by 75 ns. It is worth noting that the reference simulation concludes at 100 ns, however simulations of earlier design iterations were stable up to 150 ns. RF generation via a dual ring structure attached to the downstream face of the slow wave structure excited the TM_{01} mode. This energy is removed from the simulation via a Perfectly Matched Layer (PML) absorbing boundary condition.

Figure 3 displays the RF output power generated for the simulation. The IMO RF output power is 1.15 GW at ~ 20% efficiency thus demonstrating high power low voltage, low magnetic field performance. This is significant RF generation however given the scale of the source it is necessary to examine whether surface emission may prevent ideal operation of this device.

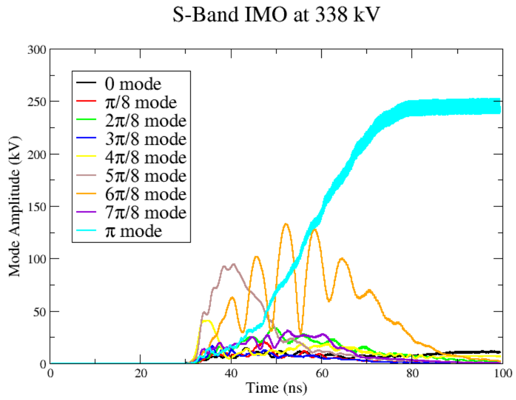

Figure 2. The IMO mode dynamics at 338 kV input voltage. The S-Band IMO operates in the π mode with mode dominance achieved by 75 ns

One area of concern for surface emission is the downstream taper that leads to the downstream chamber containing the PML boundary condition. This tapered surface is in close proximity to the primary RF generating ring mounted on the SWS. Along this surface, field amplitudes as high as 500 kV/cm have been observed. This greatly exceeds the peak field amplitude threshold of 300 kV/cm. This surface emission is driving research for a novel RF excitation mechanism due to the fact that coupling between the primary oscillating ring and the downstream chamber drives excitation of the TM_{01} mode. However further design iterations of the ring oscillating structure have also shown promise for field amplitude reduction. Further research on this matter will be forthcoming.

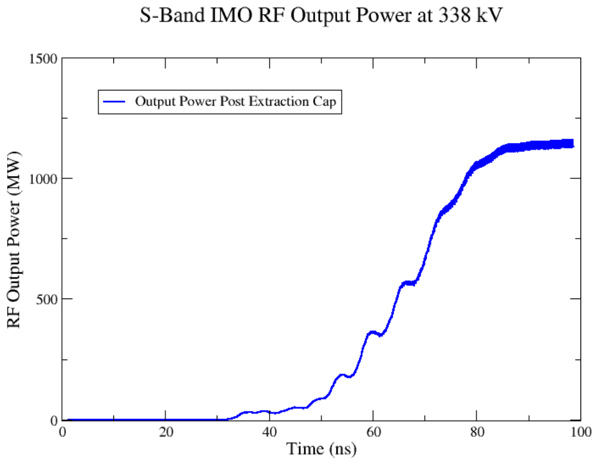

Figure 3. RF Output Power for the S-Band IMO exceeds a Gigawatt at 20% efficiency

Conclusion

An S-Band IMO has been simulated. This IMO is capable of stable and reliable operation in the π mode at the desired frequency with emission in the TM_{01} mode. This accomplishment is especially noteworthy due to the large number of modes that exist and may be excited when employing a 16 vane SWS. Indeed, mode competition remains absent for the duration of the model presented here.

References

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