SIMULATION OF AN INDUSTRIAL LINAC (5 MeV, 1 mA, 3 GHz) WITH MAGIC® ELECTROMAGNETIC PIC CODE

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Abstract:

The original linac consists of an electron gun (45 kV, 6 A peak, 4 µs pulses @ 210 Hz) and 8 accelerating cells coupled with coupling cells in π/2 mode @ 3 GHz to provide for a 1 mA and 5 MeV beam. A loss of control of electron emission was experimentally observed due to anomalous heating of the cathode. We simulate the linac operation with the 2D1/2 MAGIC® electromagnetic PIC code to understand and suppress these phenomena. We show that electrons are accelerated back from the accelerating structure to the cathode. Their power is responsible for the unwanted cathode heating and emission control loss. To overcome these phenomena, a new design is proposed. A buncher cavity and a solenoid are inserted to improve the coupling between the electron beam and the accelerating cells.

INTRODUCTION

Electron linacs are widely used in industrial applications, eg. radio-sterilization. Most of these linacs operate in S-band microwave around 3 GHz [1, 2]. The original linac design did not meet performance specifications (5 MeV, 1 mA mean, 4 µs @ 210 Hz) due to both cathode and anode overheating. Numerical simulations have been performed to understand and eventually overcome the phenomenon.

LINAC SIMULATION

The Particle-In-Cell electromagnetic 2D-1/2 MAGIC® [3] code is used for simulate this accelerator.

The original design of the linac was based on an e-gun followed by a neutral cavity and eight accelerating cells, as shown in figure 1.

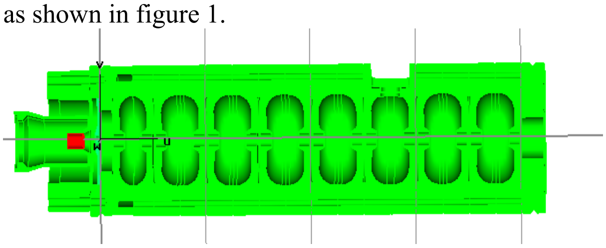

Figure 1: First linac version (cathode in red).

In the numerical simulations performed, only the first accelerating cavity is taken in account.

The simulations start with, on one hand a TEM wave going into the diode (inlet1), and on the other hand another TEM wave @ 3 GHz entering the first accelerating cavity.

The first TEM wave ensures that a potential difference of 45 kV DC is created between the cathode and the anode. The second one accelerates the electrons with a maximal energy of 600 keV.

When the TEM waves have filled the diode and the accelerating cavity, the electrons are emitted by the cathode with a constant current of 6 A. After being accelerated in the diode, they propagate into the drift guide.

The accelerating electric field "sweeps" the electrons as they enter the cavity gap. Electrons are either accelerated backward to the diode or forward to the second accelerating cavity depending on their arrival phase relative to the RF standing wave.

Figures 2, 3 display respectively the cross section of the electron beam and electrons phase space. Both show clearly that electrons are pushed back toward the diode.

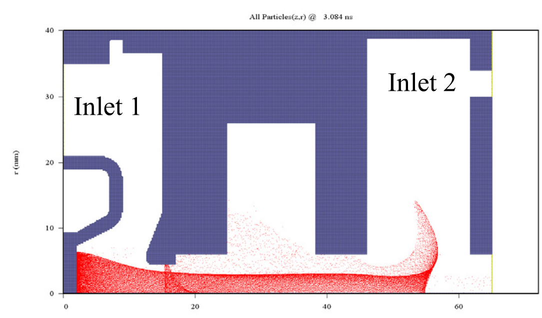

Figure 2: Cross section of electron beam.

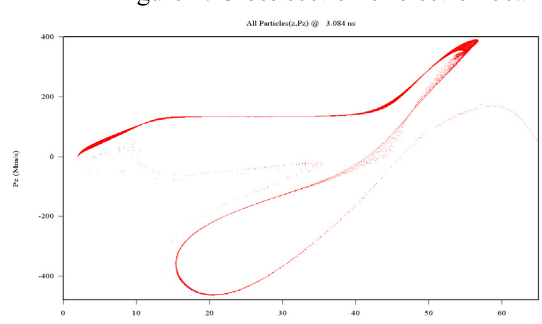

Figure 3: Electron phase space.

Electrons colliding with the cathode are responsible for additional uncontrolled heating which induces sufficient electron emission to increase the beam current beyond the threshold that the RF power supply can deliver to accelerate the beam to 5 MeV. As a result the beam energy drops and the nominal linac performance specifications cannot be reached.

In order to decrease the amount of electrons going backward and therefore to increase the current at the exit of the first accelerating cell, a buncher cavity is inserted between the diode and the neutral cavity. A cross section of this second linac version is shown in figure 4.

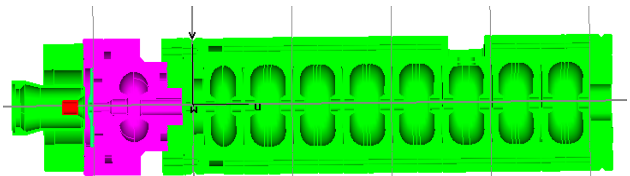

Figure 4: Second linac version including a buncher cavity (purple).

The buncher cavity prebunches the electron beam at 3 GHz. This cavity is powered with a TEM wave @ 3 GHz which enters via the inlet 3, see figure 5. The potential at the cavity gap is about 30 kV.

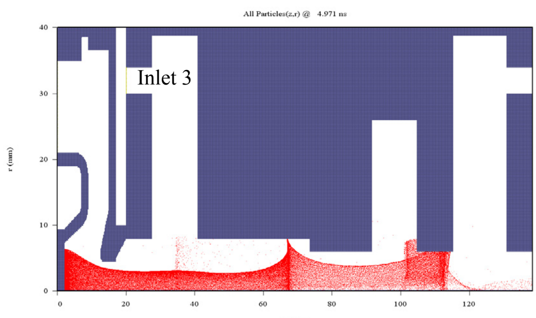

Figure 5: Cross section of the electron beam.

The buncher cavity and the first accelerating cell are synchronized in such a way that the electrons with maximum energy at the buncher exit undergo a maximal acceleration as they go through the accelerating cell.

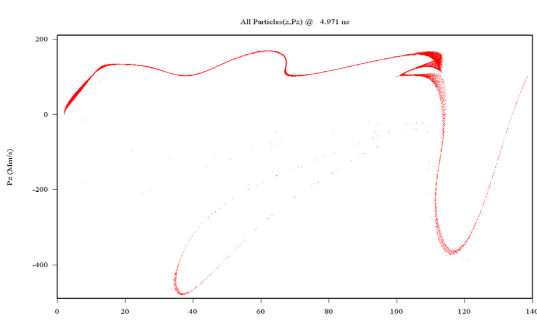

Figure 6: Electron phase space.

The cross section of the electron beam is displayed in figure 5, as well as the electron phase space (figure 6) point out that most of the electrons collide now with the RF cavity irises before reaching the accelerating cell. The length of the drift tube appears too long, and as a result the electron beam spreads out under the space charge effect.

To prevent this effect and confine the electron trajectories, a magnetic field is added around the buncher cavity, see figure 7. This field can be generated by either coils or PPM ("Periodic Permanent Magnet") [4,5].

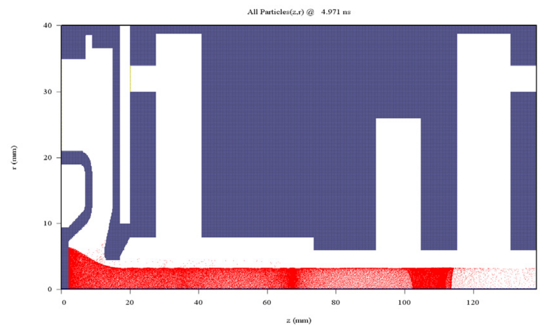

Figure 7: Cross section of the new linac version.

When applying an external magnetic field with an amplitude of 0.1 Tesla, the electron trajectories remain confined along the guide, see figure 7. Collisions with the irises are no longer observed. The phase space representation clearly shows in figure 8 a drastic decrease of the amount of electrons going backwards.

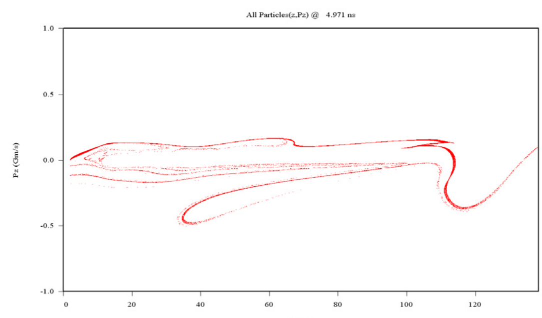

Figure 8: Electron phase space.

Finally, table 1 summarizes the performances associated with the different designs considered, in terms of percentage of electrons going back into the cathode and the irises, as well as those exiting the accelerating cell. In comparison to the former versions, the new one drastically decreases the amount of electrons hitting the anode, maximizes the output current and unfortunately slightly heats the cathode.

Table 1: Electron distribution in percentage in the linac

	Cathode	Irises	Exit
First version	0.6	49.7	49.7
Second version	0.8	74.7	24.5
New version	6.8	1.2	92.0

CONCLUSION

The simulations performed with the MAGIC® code when considering only one accelerating cell, have allowed us to reproduce the cathode heating phenomenon observed experimentally. A new design involving an external magnetic field has been proposed to overcome this problem. Magnetic coils have been placed between the buncher cavity and the first accelerating cell. This new version has been tested with success both numerically and experimentally. The cathode is still slightly heated. Numerical simulations of the entire linac with its 8 accelerating cavities need to be performed, along with full 3D simulations.

REFERENCES

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