NUMERICAL MODELS OF INJECTORS FOR HIGH-CURRENT ELECTRON LINACS*

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Abstract

We have used four types of codes to aid in the design of injectors for our high-current linacs. The typical procedure begins with the electrostatic field code JASON to find a geometry with acceptable field stresses. Next, the 2-D electromagnetic PIC code MAGIC[1] is used to study the addition of voltage waves from the input feeds, and the resulting beam generation and dynamics in a space-charge-limited diode. Then, the 2-D trajectory code TRAJ[2] is used for parameter and optimization studies. Finally, in some cases 3-D effects may be examined with the PIC code QUICKSILVER.[3]

Introduction

The codes used in modeling injectors for our electron linacs are summarized in Table I. Here we include only codes used in designing an injector itself, not the circuit codes used to design the pulse power system feeding the injector.

TABLE I
Injector-Design Codes at Sandia

Code	Space Dimensions	Type	Running Time
JASON	2	e.s. fields	secs
MAGIC	2	e.m. PIC	hour
TRAJ	2	trajectory	min
QUICK-SILVER	3	e.m. PIC	many hours

In the Table, "e.m. PIC" refers to an electromagnetic field solver coupled with particle-in-cell algorithms.[4] "Trajectory" refers to a "ray-trace" method coupled to electrostatic and magnetostatic solvers. The run times are given only to indicate orders of magnitude on a Cray machine.

The codes in Table I have been used to study many facets of a variety of electron accelerators. In this paper we shall briefly describe some recent results for three particular injectors for the accelerators listed in Table II. Here the voltages and currents are nominal values, applying to the injectors only.

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TABLE II
High-Current Linac Injectors at Sandia

Accelerator	Voltage	Current	B-Field, Cathode
RADLAC	12-14 MV	50-90 kA	immersed
RLA	4 MV	10 kA	non-immersed
CASSANDRA	1 MV	1 kA	non-immersed

RADLAC

Until recently, RADLAC[5] indeed qualified as an induction linac, using an injector as the source of a beam to be post-accelerated by 4-6 gaps. Recently, however, the machine has been re-configured in the Hermes III style.[6] This is illustrated by the MAGIC calculation in Fig. 1; note that the z-scale is very compressed relative to the r-scale (we work in cylindrical coordinates r, θ, z).

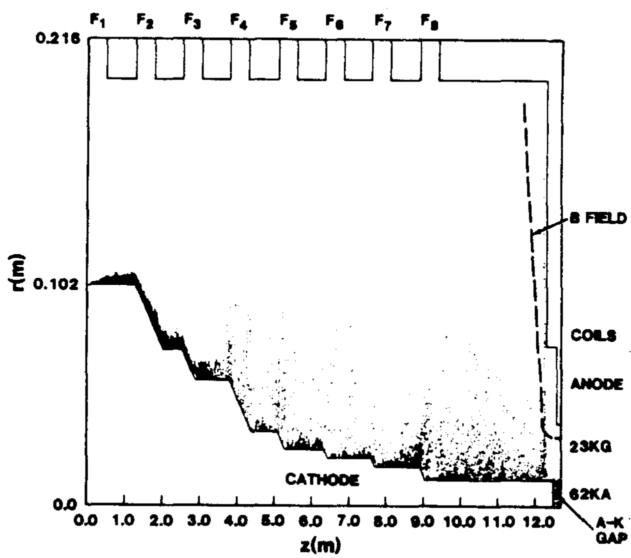

Fig. 1. The latest RADLAC injector ("SMILE") as simulated by MAGIC, shown at a time (60 ns) near peak total voltage on the A-K gap. The dots are electrons, and one B-field line is shown (cathode tip in 23 kG). In this example, a 62 kA beam is produced for about 12 MV on the A-K gap. The radial current loss occurs mostly along the fringing B lines. The F_i are the voltage feeds.

In Fig. 1, about 2 MV is fed into each radial line F_i, but the pulse shapes are somewhat triangular so there is some $L\dot{I}$ loss, and the sum voltage on the diode is about 12 MV, instead of 16 MV. The essence of the design is to use self-magnetic-insulation over most of the cathode shank. For strong applied fields (23 kG) on the diode, however, a substantial radial loss current develops along the fringing B-lines. Experiments with this new RADLAC configuration are now underway, and will be reported elsewhere at this conference.[7] Details of the diode design and the conditioning-cell behavior have also been simulated and will be discussed in future papers.

RLA

The Recirculating Linear Accelerator[8] has had a number of injectors designed for it, including laser diodes, immersed and non-immersed foilless diodes, and apertured diodes with or without anode foils. A JASON calculation of a diode at low voltage of 1.3 MV, with maximum stress 200 kV/cm, is shown in Fig. 2. Here, both anode and cathode surface shapes are optimized for minimum E-field stress; the bipolarity of the applied voltage pulse necessitates preventing emission from all surfaces except the inner r $\lesssim$ 5 cm on the cathode.

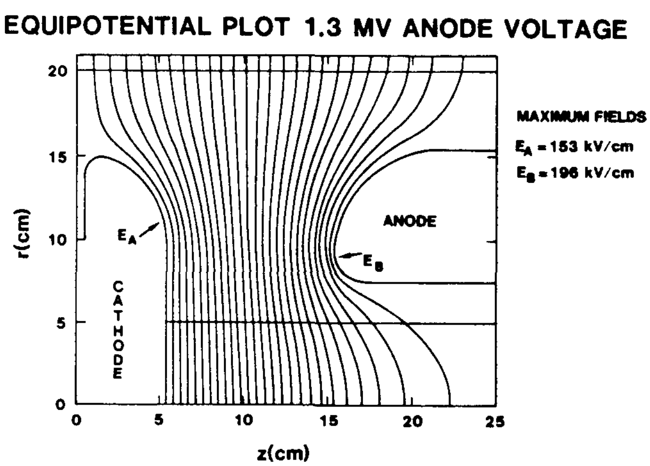

Fig. 2. A sample JASON run of an RLA diode, with surface shapes chosen to keep electric stress < 200 kV/cm.

A more recent design, at peak V = 4.6 MV on the diode (1.15 MV per feed), is shown in Fig. 3. Here the (equilibrium) trajectory code TRAJ was employed, although JASON was used in designing the feeds and electrode shapes. Also, MAGIC was run with realistic input time-dependent feed voltages, and at peak diode (total) voltage, the MAGIC result agreed very well with the TRAJ solution, justifying use of the much more economical TRAJ (see Table I) code to do parameter variations on this type of injector. The four-feed re-entrant injector in Fig. 3 is now being assembled.[9]

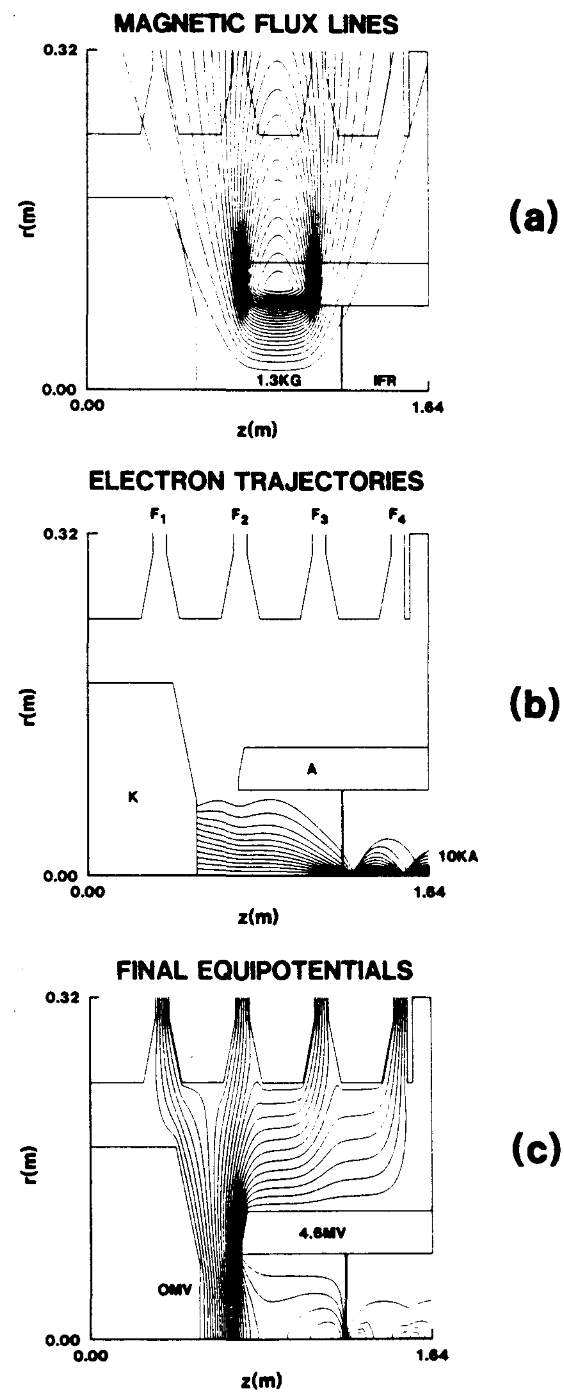

Fig. 3. The new RLA injector, as modeled with TRAJ. Top (a): applied B field. Middle (b): electron trajectories (every fifth is plotted). Bottom (c): equipotentials with beam space charge.

The physical result in Fig. 3 is straightforward. The 10 kA beam is focused by the applied B onto an IFR channel (f=0.5), which guides the beam to the "racetrack" for further acceleration. Based on further TRAJ runs, this design is not unduly sensitive to small variations in voltage amplitude, applied B, or IFR modeling details.

CASSANDRA

The 1 kA, 1 MV CASSANDRA[10] injector is shown in Fig. 4; again, TRAJ was used. The basic system design is similar to the RLA in Fig. 3, with two important differences. First, a Pierce geometry was employed for the cathode to help focus the lower-current beam. Second, no IFR channel is used, necessitating a more complicated applied B (Fig. 4a, b). The result, after some parameter variation, is a very well-focused beam (Fig. 4c) which will be further accelerated by gaps located downstream. Only the first two gaps have been simulated thus far; no problems are foreseen provided the applied B transport coils are designed carefully.

QUICKSILVER

It is not usually practical to simulate large systems with 3-D PIC codes, so work thus far has concentrated on relatively simple off-center beam effects. For example, an RLA beam (10 kA) in a vacuum wire conditioning cell with initial 1 cm offset is seen to evolve into a "corkscrew" mode with a 20% loss; a return current of 5 kA is induced in a 2 mm wire carrying 15 kA. Injector asymmetries could also be studied with this code, in principle.

Conclusions

The utility of the design codes MAGIC, TRAJ, and JASON has been demonstrated in the problem of injector design for electron linacs in the multi-kA range. Where comparisons with experiment can be made, the codes are found to agree well with reality. Besides design aid, the major value of the codes is found to be in making sensitivity and optimization studies.

References

1. B. Goplen et al., Mission Research Corp., report MRC/WDC-R-068, 1983.
2. R. B. Miller et al., J. Appl. Phys. 62, 3535 (1987). Also, J. W. Poukey, Proc. 12th Conf. Num. Sim. Plasma, San Francisco, 1987, PM10.
3. M. L. Kiefer et al., Bull. Am. Phys. Soc. 34, 2079, (1989).
4. C. K. Birdsall and A. B. Langdon, Plasma Physics via Computer Simulation (McGraw-Hill, 1985).
5. R. B. Miller et al., J. Appl. Phys. 52, 1184 (1981).
6. T.W.L. Sanford et al., J. Appl. Phys. 67, 1700 (1990).
7. See paper "Smile": A New Version for the RADLAC II Linear Accelerator, by M. G. Mazarakis et al., this conference.
8. M. G. Mazarakis et al., Proc. Linac Conf. Newport News, VA, Oct. 3-7, 1988, CEBAF-Report 89-001, p. 345.
9. See paper "Electron Diodes and Cavity Design for the New 4-MeV Injector of the RLA," by M. G. Mazarakis et al., this conference.
10. J. M. Wilson et al, Proc. 19th Power Modulator Symposium, June, 1990, paper 11.5.

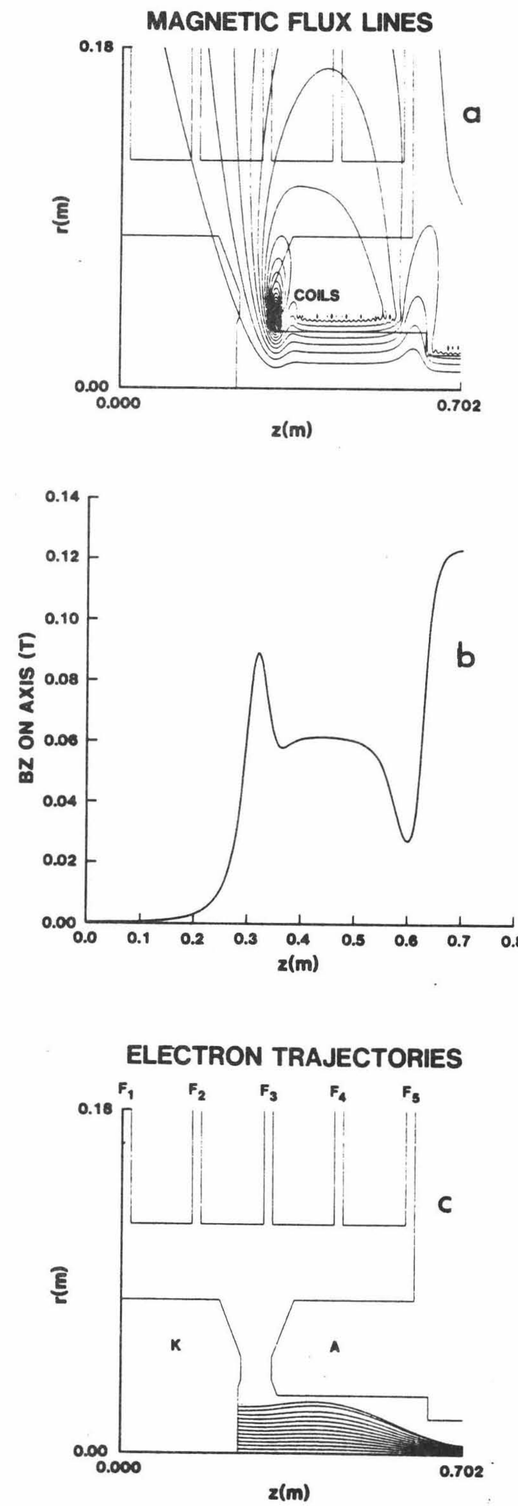

Fig. 4. TRAJ model of the CASSANDRA five-feed injector at 1 MV, 1 kA. Note the Pierce cathode design. Unlike Fig. 3, magnetic transport (not IFR) is used downstream.