INJECTOR DESIGN FOR A MODEL ELECTRON RING AT THE UNIVERSITY OF MARYLAND*

T.F. Godlove, FM Technologies, Inc., Fairfax, VA
S. Bernal, J.J. Deng[a], Y. Li, M. Reiser, J.G. Wang and Y. Zou, Institute for Plasma Research,
University of Maryland, College Park, MD

Abstract

A model electron recirculator is being developed at the University of Maryland. It employs a 10-keV, space-charge-dominated beam injected into a 1.8-m radius ring equipped with a strong-focused lattice based on printed-circuit quadrupoles and dipoles. The motivation and general features are described in separate papers. Here we describe the design for injecting a single-turn bunch into the ring. The system includes a low-emittance e-gun, matching section, pulsed dipole and Panofsky quadrupole. The dipole at the injection point must deflect the beam -10° during entry and +10° after entry, with about 25 ns transition time. The Panofsky quadrupole must be off during entry and on for subsequent laps, with a similar rise time.

I. INTRODUCTION

During the last decade increasing attention has been given to issues related to achieving higher intensity in particle accelerators. Applications include synchrotrons and storage rings for colliders, spallation neutron sources, free electron lasers and heavy-ion inertial fusion. Many of these applications either require or can make good use of intense beam pulses if they were available. A recirculating linac is an attractive new approach to achieve high intensity beam pulses. The idea is to use space-charge-dominated beam currents appropriate to a linac but limit the number of turns to achieve stable operation.

A project to develop and build a small electron ring to study the evolution of a space-charge-dominated beam in a circular lattice is in progress at the University of Maryland's Institute for Plasma Research (IPR). The general features of the ring have been described, including an accompanying paper at this conference [1,2]. Briefly, a 1.8-m radius ring is designed for a 100 mA, 10-keV e-beam using a FODO lattice with 72 quadrupoles and 36 dipoles, all based on a printed circuit design [3].

Major issues include resonance crossing, bunch profiles, longitudinal-transverse coupling, space-charge waves and instabilities.

In this paper we describe the planned injector system including the special components required and some of the calculations pertaining to the injector.

II. INJECTOR

Figure 1 shows the injector system. Q1 is a Panofsky-type pulsed quadrupole. It replaces one of the ring quadrupoles. Since it is centered on the main ring it must be turned on after the beam bunch enters and remain on for subsequent laps. D1 is a pulsed dipole, replacing one of the 36 ring dipoles. It must deflect the beam -10° during entry and +10° after entry.

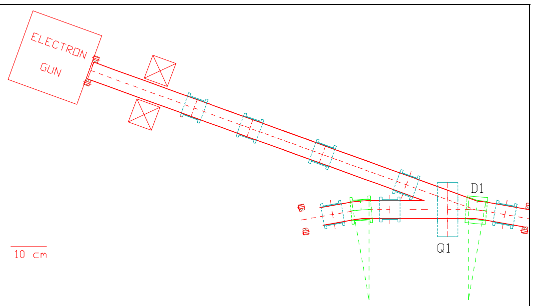

Fig. 1. Injector layout.

This arrangement allows the angle between the injector and the adjacent straight section to be 20°. Considering a lap time of 200 ns, a switching time of about 25 ns is acceptable for the pulsed elements.

The system includes a matching section which consists of a solenoid and four quadrupoles. This system has been assembled with one of the two e-guns available in the IPR laboratory in order to evaluate the beam performance with the new printed-circuit quadrupoles. The e-gun operates at 4 kV. An aperture of 3.18 mm radius was added, yielding a beam current of 18 mA. The generalized perveance, $2I/(I_o\beta^3\gamma^3)$, is 0.0011, i.e., a space-charge-dominated beam. Here I_o is 17 kA and β, γ, are the usual normalized velocity and total energy of the electrons.

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* Research supported by the US Department of Energy.

III. SIMULATION

Several codes have been used to design the injector beam line, to predict the performance, and most important, to compare with the experiments. We report here on calculations using an envelope code due to C.K. Allen [4] and the particle-in-cell code WARP3d developed at the Lawrence Livermore National Laboratory [5]. Figure 2 shows an envelope code result and Fig. 3a shows the corresponding WARP3d result.

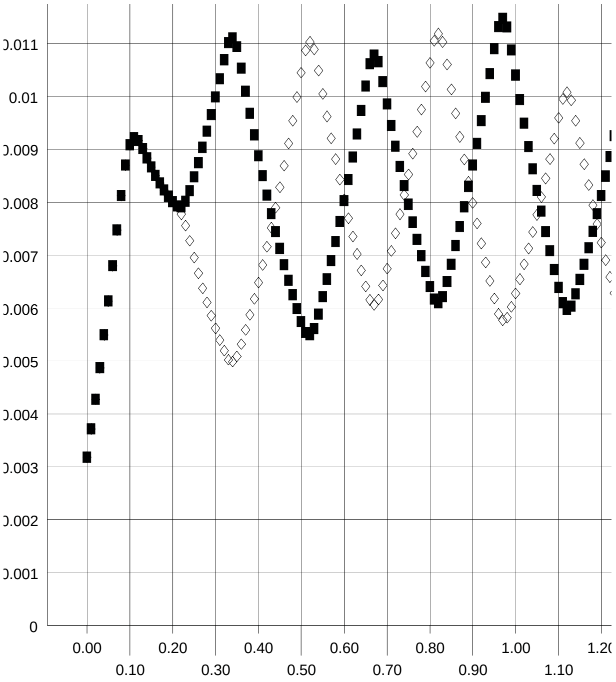

Fig. 2. Envelope code.

The beam radii in the two transverse dimensions are plotted vs. z (m). For WARP, twice the rms radii are plotted. Table I gives the parameters used.

Table I. Parameters for Fig's 2 and 3.

	Solenoid	Q1	Q2	Q3	Q4	Q5
Location (cm)	10	22.4	34	52	67	82
B_o (G) Envelope	73	5.6	-11.7	13.1	-13.1	13.1
B_o (G) WARP3d	72	5.3	-11.7	13.1	-13.1	13.1

The peak field for the quadrupoles refers to a radius of 2.20 cm; the gradient, for example, is 5.95 G/cm from Q3 on. z = 0 at the aperture.

Other parameters are emittance (unnormalized, effective) = 50 mm-mrad; and aperture x' = y' = 54 mrad, in rough agreement with previous experiments.

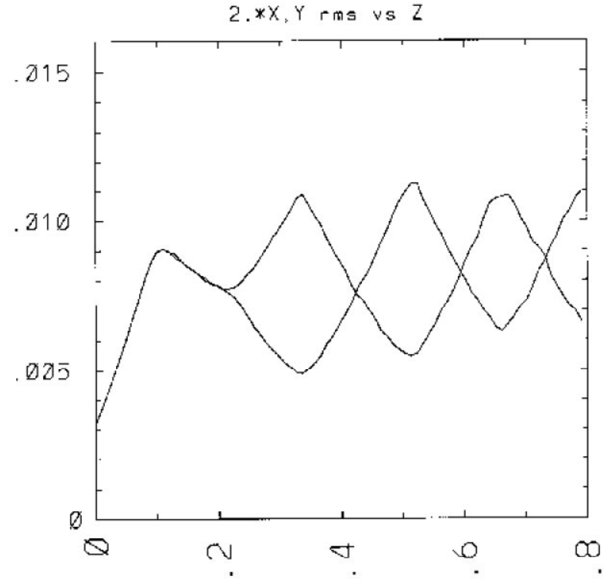

Fig. 3a. WARP3d simulation.

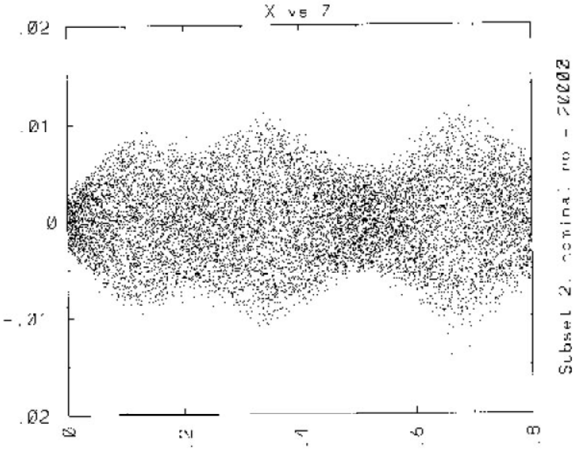

Fig. 3b. WARP3d, x vs. z.

The envelope code and WARP agree quite well, with the exception that the parameters in the envelope code had to be modified slightly for the peak field in the solenoid and Q1, as given in Table I. Without this small change the agreement was poor. We ascribe this to the fact that the envelope code treats the solenoid as a linear element, whereas WARP includes the nonlinear fields to fourth order.

A separate question involves the quadrupole fields. We currently use an empirically fit formula in WARP. In the near future we plan to use the exact field array derived from a 3-D magnetics program. Since the quad's are "thin" we do not expect a significant change in the result, but it remains to be tested. Also, we plan to compare these calculations with the experiments as soon as reliable data are available.

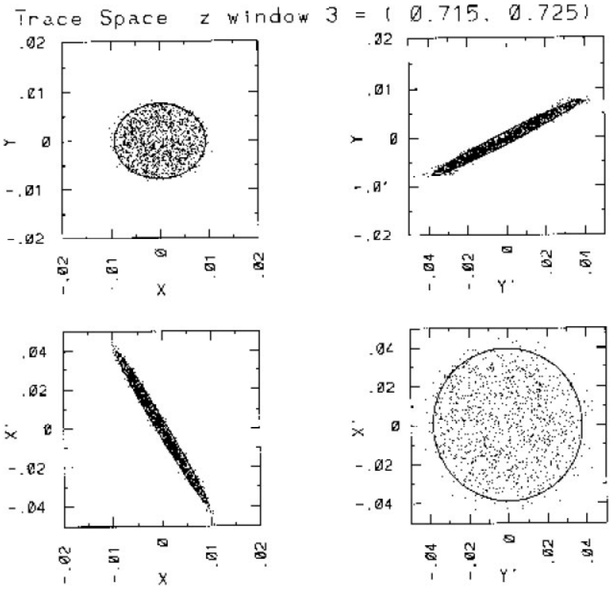

Fig. 3c. WARP3d phase-space plots, at 0.72 m, with Δz = 1 cm.

IV. PANOFSKY QUADRUPOLE

Figure 4 shows a sketch of a proposed geometry for the conductors of a pulsed Panofsky-type quadrupole. As with the cylindrical quad's, the conductor location is determined using a 3-D magnetics program to optimize the linearity. Conductors are paired to reduce the stray fields from the "twisted-pair" external connections. The peak current required in each conductor is ~40 A. An alternative geometry using loops analogous to the ring quad's would require less current, but would have higher inductance, hence longer switching time.

A detailed design is in progress. Currently, the linearity is of the order of 1% to 3%, depending on the number of conductors and the details of conductor placement. Linearity is based on the integral of Bdz, as it is for the ring quadrupoles.

A number of electronic switch circuits will be required, the number depending on the final number of required parallel circuits. Precision resistors will guarantee equal currents in parallel conductors.

The vacuum chamber at the injection point must be glass or ceramic to allow field penetration on a 25-ns time scale. We currently favor glass in view of the skills available at the IPR. It should have a thin inner conducting coating to avoid charge buildup.

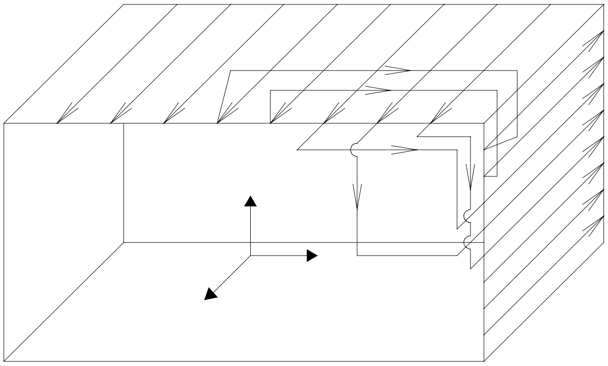

Fig. 4. A proposed conductor geometry for the Panofsky quadrupole.

V. ACKNOWLEDGMENTS

We are grateful to A. Friedman and D. Grote of LLNL for the use of the WARP3d code. In this connection, TFG acknowledges invaluable assistance from Irving Haber at the Naval Research Laboratory in the use of the code.

VI. REFERENCES

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a. Permanent address: PO Box 523-56, Cheng-Du, China.