PRODUCTION, TRANSPORT AND INJECTION OF A COLD NON-MAGNETIZED ELECTRON BEAM FOR THE RECIRCULATING LINAC

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ABSTRACT

A new foilless diode with a non-magnetically immersed cathode was recently designed and built for the Sandia Recirculating Linear Accelerator (RLA). Because there is also no radial component of electric field at the cathode, the electron beam starts almost parallel and is matched to a solenoidal transport system with minimum increase in divergence and radius.[1] The electrode emission surface is specified by an area covered with felt which undergoes explosive electron emission at low electrical field stresses (60 kV/cm). The 1.7-MV, 4.8-kA produced beam is transported 1.5 meters to the injection region of the racetrack via a system of solenoids and focusing coils. The maximum transverse velocity component at injection point (1.5 m downstream from the cathode surface) is $\beta_\perp = 0.03$ and the radius r = 2.8 cm which give a quite small beam emittance ε = 0.08 rad-cm. Three-dimensional numerical simulations suggest that tangential injection into the ion focusing regime (IFR) channel of the accelerator provides better beam-channel coupling. A 1.3-MV and 4-MV design are also described.

INTRODUCTION

The present RLA configuration (Fig. 1) consists of a 1.7-MV isolated Blumlein injector[2] and one post-accelerating (ET-2) cavity[3] with the accelerating gap located inside the IFR channel. A low-energy, 300-V, electron beam (LEEB) is utilized to ionize a 0.1 to 0.4-mTorr argon gas. The low-energy electron beam is focused and guided all along the racetrack by a 200-G solenoid wrapped around the outside walls. This way, a closed racetrack-shaped ionized channel is formed. When the main high-energy electron beam enters the channel, the low-energy electrons are expelled, leaving behind an ion channel (IFR) which electrostatically focuses and guides the beam. The electron diode of the injector is outside the racetrack and ~1.5 m away. The beam cannot be transported from the injector to the racetrack with a straight IFR channel formed by the same low electron beam (LEEB) ionizing technique, since the solenoids of the two IFR channels would not be compatible at the intersection point. A laser ionized channel is always possible, but it would add considerable complexity into the system, particularly if it required special organic gases.

Wire, gas cell, and classical IFR channels have been used to transport the beam from a foil-diode injector to the racetrack. The foil-diode produces a hot beam because of the strong pinching effect at the anode foil. This is due to low injector voltage and high ν/γ. The beam emittance further increases during transport with any of the above mentioned techniques. In this paper, we present a new foilless diode design that produces a very cold beam and a magnetic transport system which carries the beam from the diode to the injection point with minimum beam quality deterioration.

Non-Immersed Foilless Diode

This diode design incorporates the advantages of both a planar and an immersed foilless diode. It produces a fairly parallel laminar beam with small divergence as in the case of the planar diode (Fig. 2). The pinching effect of the anode foil is eliminated along with the canonical angular momentum term of an immersed foilless diode.

Close to the anode electrode, the beam encounters the magnetic field region of the transport system. The cathode is at zero magnetic field. The electric field at the cathode is kept as low as possible and at a right angle to the cathode surface ($E_r = 0$). The electron emission region is specified by an area covered with felt which starts undergoing explosive electron emission at as low an electric field as 60 kV/cm. The current density for these configurations scales as

$$j = \frac{3.52\times10^3}{d^2}\left(\gamma^{2/3} - 1\right)^{3/2} \quad (1)$$

where $\gamma = eV/mc^2 + 1$.

The A-K gap (d) is selected depending on the beam radius and total current required for each diode voltage. There is an additional design constraint in that the maximum electric stress on the cathode electrode should not exceed the value of 200 kV/cm or the entire cathode surface may start an uncontrollable explosive emission.

In designing these diodes, we select first the approximate A-K gap and define the emitting area according to the scaling formula (1). Then we define the shape of the electrodes using the JASON code.[4] Finally, we use the code TRAJ[5] to study the beam produced and to design the magnetic transport system. Much care is taken in designing the cathode surfaces to avoid electric fields in excess of 200 kV/cm. However, since the voltage of the injector is bi-polar (Fig. 3), attention is given to reducing the field on the anode electrode. Figure 4 is a design of the 1.7-MV diode with both cathode and anode electrode shapes optimized.

Magnetic Transport System

With the above geometries one can produce very cold beams at the foilless diode exit. These beams, however, must be transported with the minimum possible losses and emittance growth ~1.5 m downstream to the injection region. For beams of the order of 5 kA, the lower the energy the more complicated the magnetic transport system becomes. Figure 5 presents in a pictorial way the beam production transport and injection technique. We use only coil focusing lenses and long solenoids. Figure 6 shows the electron trajectories for the 1.7 MV case. Unfortunately, this cold beam will increase its temperature as it crosses the foil due to the large ν/γ. The foil is necessary in order to separate the vacuum transport section from the low pressure argon atmosphere of the racetrack. A differentially pumped injection pipe may make the foil unnecessary and eliminate that problem. In the 1.3-MV design where ν/γ is even higher, the foil effect is included in the simulations (Fig. 7). At the IFR injection point, the beam is hotter. But by this time it is already inside the IFR channel where the electrons should not diverge any further. Figure 8 shows the location of the focusing elements and the magnetic flux lines for the 1.7-MV case. The 1.3-MV transport system requires more solenoids and focusing coils to achieve the same results. The magnetic field on axis (Fig. 9) is quite modest, and it must be close to zero not only at the emitting surface of the cathode, but also at the injection point. An absence of magnetic field at the cathode eliminates the canonical angular momentum term of the emittance, while at the injection point, it prevents any distractive interference with the IFR channel. The 1.3-MV and 1.7-MV designs utilize the same diode and vacuum pipe hardware.

In anticipation of a better 4-MV injector, we investigated the design shown in Fig. 10. It is obvious that with higher energy injectors we can produce larger currents and better quality beams. The magnetic transport system also becomes much simpler. Only one coil and one solenoid is utilized. Figure 11 shows the electron trajectories for a 3.5-MV beam launched into the 4-MV transport system. Much of the beam is lost. A 10% energy variation can cause large beam losses. This is why a higher energy injector with a flat top voltage waveform would be preferable. Such an injector is currently being designed. Also, future experiments are planned utilizing the 4-MV IBEX accelerator as an RLA injector.

Presently, we have built a foilless diode capable of operating at the range of 1.3 to 1.7 MV injection voltage, and a vacuum hardware system that could accommodate the necessary coils and solenoids for the transport of the produced beams. To provide better current tunability three independent capacitor banks will be utilized to power the coils.

Beam Injection

Figure 5 depicts an axial injection. Extensive numerical simulations with the 3-D code BUCKSHOT[6] have demonstrated that axial injection may not be the right approach. As is shown in Fig. 12, tangential injection actually provides a better coupling of the incoming beam to the IFR channel. To that effect, we have built an injection chamber (Fig. 13) that replaces the lambda section of Fig. 1. The chamber provides flexibility in adjusting the offset and the injection angle of the incoming beam relative to the axis of the racetrack straight section. These injection parameters are energy and IFR neutralization dependent.

CONCLUSIONS

The non-immersed foilless diode design investigated here produces very low temperature and emittance electron beams that can be controlled and guided by a system of magnetic lenses and solenoids. This technique eliminates the foil from the anode plane and the need for a gas or wire transport section, both of which cause excessive beam temperature increase. For the diode voltages of the present injector (~1.7 MV) the beams produced are of relatively low current; however, they can be transported with minimal emittance growth provided that the coil currents are accurately tuned for each injector voltage. A 10% variation in beam energy can cause beam losses. Thus, a higher voltage and a flat top waveform injector will greatly enhance the success of the technique. In addition, a tangential injection provides better beam matching with the IFR channel. The beam offset and injection angle are energy and channel neutralization dependent. The hardware already built provides flexibility of angle and offset adjustment.

ACKNOWLEDGEMENT

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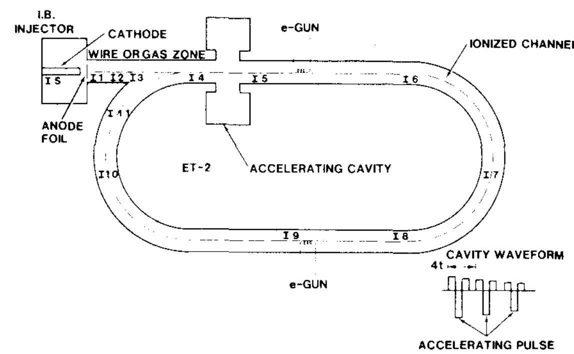

Fig. 1. Schematic diagram of the RLA.

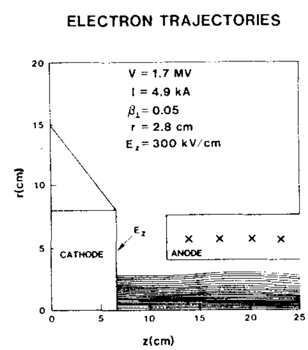

Fig. 2. Non-immersed foilless diodes can produce very cold beams.

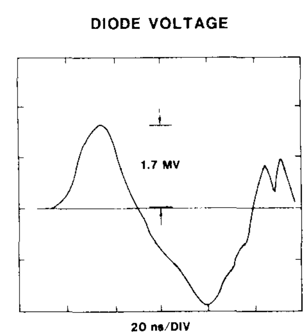

Fig. 3. Injector voltage as measured along the diode stack.

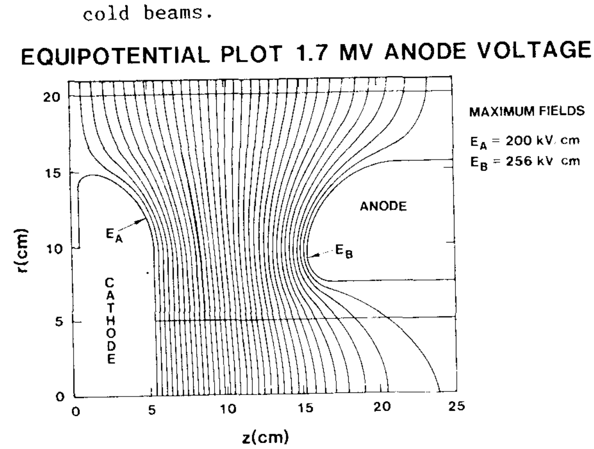

Fig. 4. Both the anode and cathode surface shapes are optimized for minimum electric field stresses.

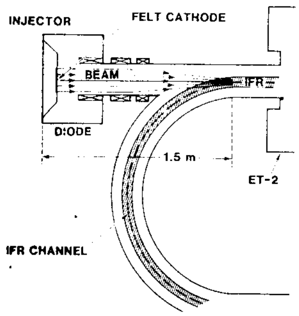

Fig. 5. Schematic diagram of a cold beam production, transport, and injection technique.

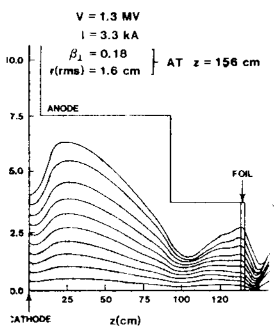

Fig. 7. 1.3-MV beam electron trajectories. The exit foil causes the relatively large transverse velocity.

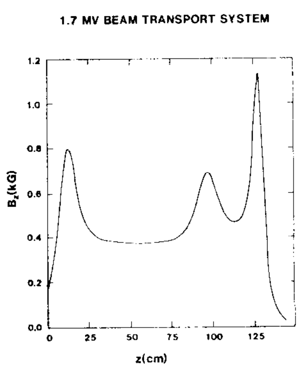

Fig. 9. The magnetic field B_z on axis (1.7-MV system).

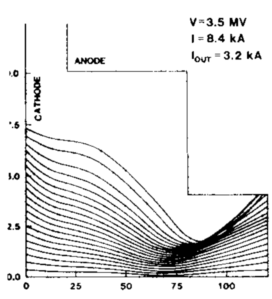

Fig. 11. Electron trajectories for a 3.5-MV beam obtained with the transport system tuned for 4-MV electrons.

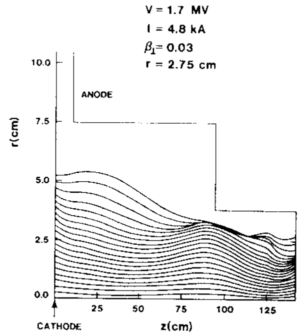

Fig. 6. Electron trajectories for a 1.7-MV beam. The quoted transverse velocity and radius are at the exit foil. The code TRAJ has been utilized.

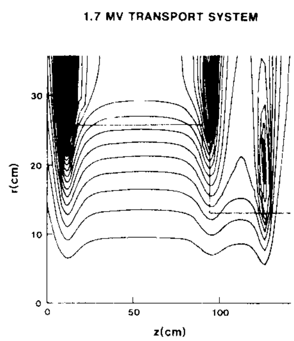

Fig. 8. Applied-B lines due to three coils (8, 5, 7 kA) and two solenoids (600 A, 1 turn/2 cm).

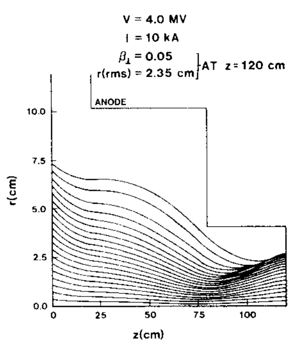

Fig. 10. Electron trajectories for a 4-MV beam. The A-K gap is 20 cm.

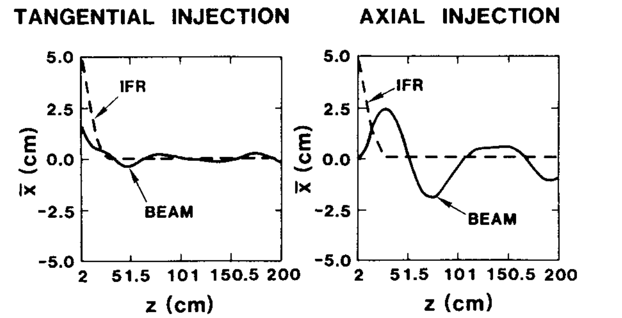

Fig. 12. Numerical simulation of beam injection obtained with the code BUCKSHOT. It appears that axial injection along the straight section of the racetrack IFR channel is not the right approach. The required injection angle and offset are functions of the beam energy and channel charge neutralization factor f.

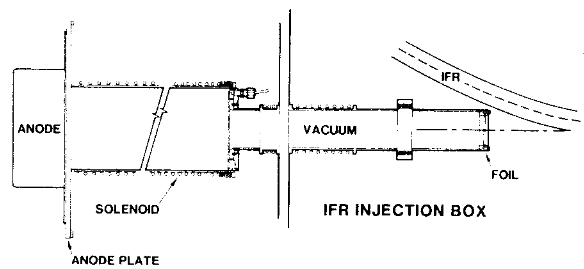

Fig. 13. Schematic diagram of the new beam transport and injection hardware.