Acceleration and Bending of a Relativistic Electron Beam on the Sandia Recirculating Linac

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Abstract

Ion focused transport is used to generate and transport a relativistic electron beam in a recirculating linac. An ionized channel is formed in 0.06-0.2 mTorr of argon with a low energy e-beam that is contained and guided by a 200 G magnetic field. A 1.5-MeV, 20-kA beam has been generated in the injector and accelerated to 2.5 MeV by the accelerating cavity. Results of experiments on transporting and bending the beam through 270^o are presented.

Introduction

The Recirculating Electron Beam Linac is a linear induction accelerator designed in a racetrack geometry. To achieve high accelerating gradients, the relativistic electron beam, REB, is recirculated through the accelerating cavities in phase with a repeating accelerating voltage pulse[1]. The demonstration of ion focused transport of a REB around a 90^o bend led to the consideration of this transport method for the recirculating linac[2]. Ion focused transport in a recirculating linac allows the potential use of a single racetrack beamline rather than a spiral line that would be required for a B_z transport system. The other advantage is the elimination of the 10-kG magnetic guide fields. A schematic diagram of the accelerator is shown in Fig. 1. A low energy electron beam, ≈ 300 V, ≈ 1 A, guided by a 200-G solenoidal field, is used to form an ionized channel in low pressure argon. When the REB is injected onto that channel the resulting ion space charge electrostatically attracts and guides the REB around the racetrack. The channel diameter is typically equal to the diameter of the REB. For a recirculating linac a REB is generated in the injector and transported to the ionized channel with a wire or gas cell, laser generated ion channel, or by placing the injector in the racetrack. An ionized channel

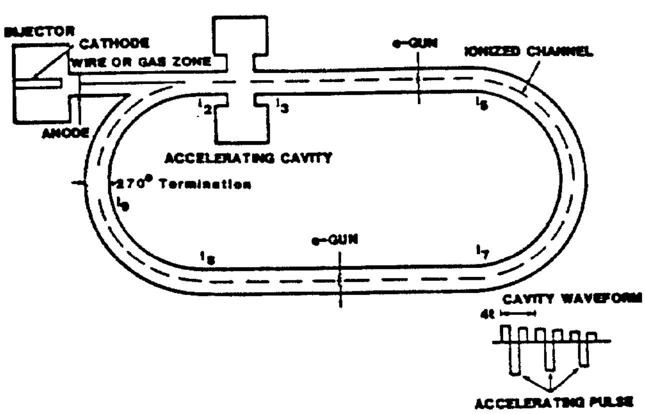

Fig. 1. Diagram of the recirculating linac illustrating Rogowski coil current monitor locations, e-guns, and 270^o experiment. The 200 G magnetic field coils (not shown) are wound around the drift pipe.

extended into the injector cannot be used since the 200-G magnetic field which guides the low energy beam around the racetrack is incompatible with a magnetically guided ion channel in the lambda section. The lambda section is the junction of the beamline from the injector with the racetrack beamline.

Straight Beam Transport

The initial experiments used an ionized channel from the injector since full recirculation was not going to be attempted. These experiments studied injector performance and investigated the effects of passing a beam through one accelerating cavity. Figure 2 shows the experimental setup. The present accelerator consists of a 1.5 to 2.0-MeV injector and

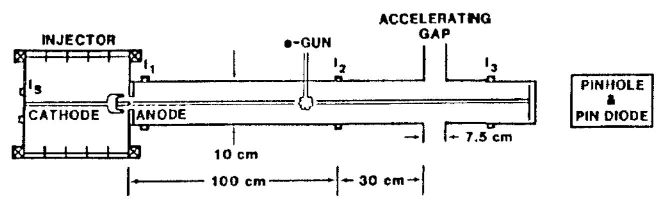

Fig. 2. Straight generation and transport experiment.

a 1-MeV accelerating cavity, ET-2. An ionized channel was formed with a 2-way e-gun using a 300-V, negatively biased hot tungsten filament located between the injector and the accelerating cavity. The 200-G guide field is DC and is applied prior to turning on the gun. The ionized channel was formed in 0.06 mTorr of argon and extended into the cathode region to extract the REB in a manner similar to the laser-based foilless diode[2]. A 20-kA, 1.5-MeV REB was generated and transported through the cavity where it was accelerated to 2.5 MeV. The current transport efficiency measured 1 m from the exit of the cavity was 100%. Pinhole photographs showed little or no expansion of the 3-cm diameter beam. A series of shots were fired with the accelerating cavity disconnected and shorted. PIN diode signals and range energy measurements in Lucite were compared to those with the cavity connected. The data confirmed the beam was being accelerated in the cavity.

The accelerating cavity voltage starts positive before reversing to the desired negative accelerating potential (see Fig. 1). There was a small current of ≈ 1.2 kA flowing 40 ns early due to the positive voltage. ET-2 cavity shots fired with the injector disconnected also produced a current of ≈ 2 kA, indicating channel electrons were being accelerated. These electrons could be producing additional channel ionization.

Bending Experiments

The next phase of the experiment was to measure transport efficiency around the 0.8 m radius of curvature bends. In these experiments the racetrack was terminated before the lambda section at the 270^o point. The 10-cm diameter drift tube was backfilled to 0.1 mTorr with argon in the straight sections and 0.2 mTorr in the curved sections. The higher pressure

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was necessary in the curved sections to provide stronger tracking forces to compensate for the centrifugal force. Two, 2-way e-guns were used to form the ionized channel.

A 1.2-MeV, 11-kA beam was generated and accelerated to 2 MeV by the accelerating cavity. The transport efficiency around the 17-m of the racetrack is shown in Fig. 3. Refer to Fig. 1 for the location of the net current monitors. Most of the current is lost in the first 3 m of transport. The two e-guns had to form a longer ionized channel than was used in the straight transport experiment, and there was some

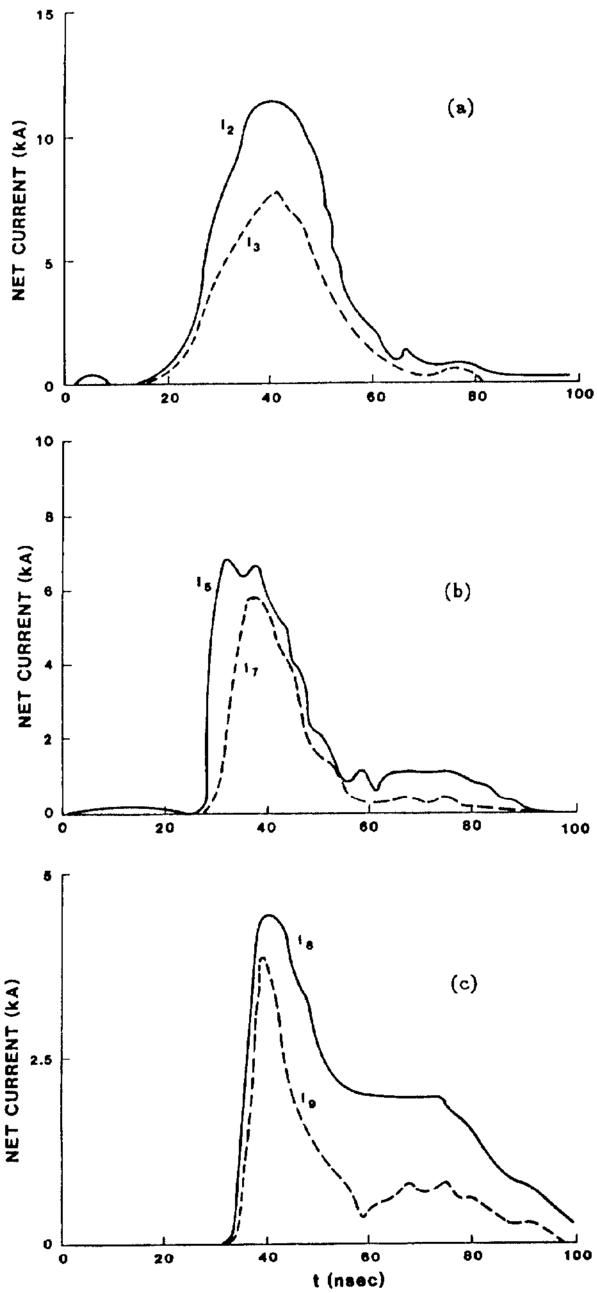


Fig. 3. Net current monitor waveforms for 270° bending experiment. Figure 3a is the current in and out of the accelerating cavity, Fig. 3b is the current in and out of the 180° bend, and Fig. 3c is the current in and out of the 270° bend.

spreading of the channel, requiring the use of a higher argon pressure to get the correct peak ion density. The resulting channel was not as uniform as it was in the straight transport experiments described above. The use of additional e-guns may solve this problem. The transport from the entrance of the 180° bend to the end of the 270° bend is 66%. This suggests there may be a large transverse velocity component of the beam that is being lost. This is reasonable since the particular diode used in this experiment has very large radial electric fields and produces a beam with a β_t of ≈ 0.45. No effort has been made to optimize the diode since this diode cannot be used in the full recirculation experiments.

The lambda section has been installed and the total length of the racetrack adjusted to half the pulse spacing. This will allow the REB to be in phase with the accelerating pulse every other pass around the racetrack. The use of wire transport of the beam from the injector to the racetrack is currently being investigated.[3] Preliminary experiments indicate a new diode configuration is needed to produce a REB with less transverse velocity to allow better matching onto the wire. Another diode being investigated is the inverse diode that is being used on the TROLL accelerator.[4] The anode and cathode are located in a uniform axial electric field, E_z. The REB is then injected into a magnetic lens and focussed onto the wire. Another possibility is to locate the injector in the racetrack and generate the REB directly onto the ionized channel, eliminating the lambda section.

Channel Densities

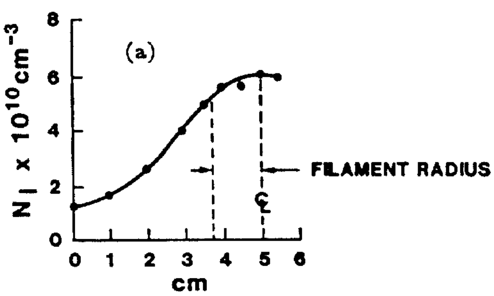
The channel plasma density was measured using a cylindrical Langmuir probe consisting of a 2.5-cm long, 0.025-cm diameter tungsten wire oriented parallel to the applied magnetic field of 200 G. The electron temperature derived from the logarithm of the probe current indicated that the channel plasma had an approximately Maxwellian velocity distribution with a value of 8 and 10 eV for argon pressures of 0.19 mTorr and 0.08 mTorr respectively. The corresponding peak ion densities derived from the ion saturation current for a probe bias of -200 V were $1.5\times10^{11}/\text{cm}^3$ and $5.5\times10^{10}/\text{cm}^3$. Typically the channel plasma is excited by a low energy e-gun that uses a tungsten filament biased to -250 V with respect to the wall of the drift tube with an emission current of approximately 1 A. Figure 4 shows two typical profiles. Note that the geometry of the tungsten filament determined the general shape of the density profile. The REB's used in the experiments typically had peak densities of 2-$6\times10^{11}/\text{cm}^3$ with diameters comparable to the filament diameters.

Simulations

Single particle simulations and full 3-D codes have been run for the recirculating accelerator. The results are being presented at this conference.[5,6] The emittance growth in the transition sections from curved to straight are acceptable for a multiple pass accelerator. Also, with the addition of bending magnets, the technology can be extended to energies on the order of several hundred MeV or higher.

Conclusions

We have demonstrated acceleration and bending of an intense relativistic electron beam using ion focused transport. Experiments are in progress to demonstrate multiple-pass acceleration. Simulations indicate this technique can be extended to higher voltage gradient accelerators.



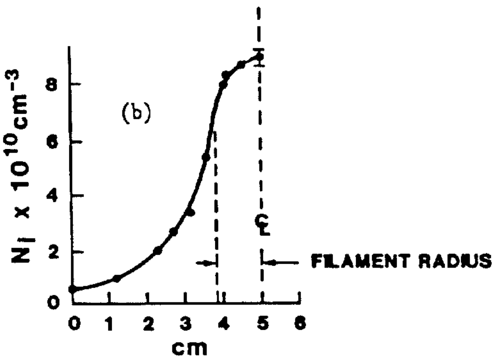


Fig. 4. Typical ion density profiles. Figure 4a was for an emission current of 100 mA, a pressure of 0.1 mTorr of argon, and a B_z = 50 G.

Figure 4b had an emission current of 75 mA, a pressure of 0.05 mTorr argon, and a B_z = 100 G.

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