RADLAC-II UPGRADE EXPERIMENTS

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Abstract

The linear induction accelerator, RADLAC II, is being upgraded to produce a 20-MeV, 40-kA, annular electron beam. Prior to the upgrade, RADLAC II produced a 15-MeV, 15-kA electron beam. Modifications to the pulsed power, injector, and magnetic transport have resulted in a faster rising flat-topped voltage pulse. A high quality, 40-kA, 2.0-cm diameter beam with a low perpendicular thermal velocity, $\beta_\perp c$, has been produced from the injector, $\beta_\perp<0.2$. The high quality beam has been accelerated through two accelerating gaps. The final four accelerating stages are being added to RADLAC II and transport experiments through the full accelerator are beginning. Simulations show the beam quality will be maintained through the entire accelerator.

Introduction

RADLAC II is a pulsed, high gradient linear induction accelerator. The electron beam is produced in a 5-MeV injector and transported in a 20-kG magnetic guide field through six, 2.5 MeV accelerating gaps that were designed to minimize beam instabilities.[1] The performance of the accelerator has been improved by straight-forward changes to the pulsed power and modifications to the injector.[2,3] The upgrade was performed in three steps. The first step was installation of the modified pulsed power feeding the injector, the second was adding two accelerating stages, and finally, we are going to the full accelerator.

Pulse Power Modifications

In the final upgraded accelerator, four Marx generators rather than two, will be used to drive four Hermes-III intermediate storage capacitors (ISC).[4] The oil-water interfaces were relocated to provide symmetrical, low inductance feeds (Fig. 1). Each ISC charges two pairs of pulse-forming lines (PFL) through low inductance, low jitter, laser-triggered gas switches developed for PBFA II.[5] The PFLs were lengthened to increase the pulse width from 40 to 50 ns. The improved geometry and electrical properties of the new pulsed power configuration provide for faster charging times and enables two self-breaking water switches per line to close, rather than one, resulting in a flat-topped voltage pulse at the diodes. Figure 2 is a comparison of the old and new diode voltage waveforms.

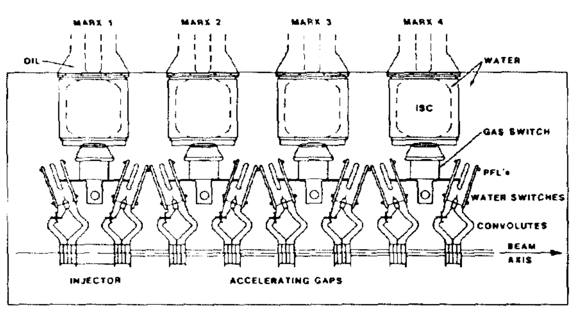

Figure 1. Diagram of the upgraded accelerator showing component layout.

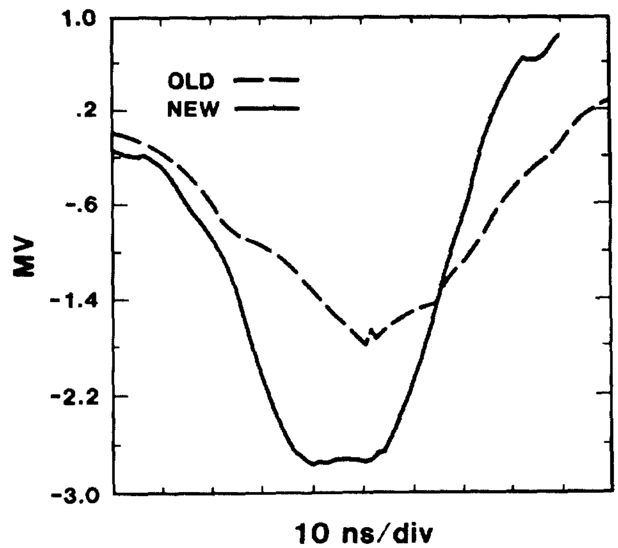

Figure 2. Comparison of the old and new diode waveforms. The Marx charge in both cases was 85 kV.

Injector Experiments

Before the upgrade the RADLAC-II injector produced a 3-MeV, 15-kA, 40-ns electron beam. Time integrated x-ray pinhole photographs of the old injector showed the beam was large and had a halo that was approximately the same diameter as the drift tube, Figure 3(a). Particle simulations for this geometry indicated there was a large loss of shank current (60%) due to the loss of magnetic insulation on the cathode shank. There was also electron emission from the face of the cathode holder allowing electrons to fill the drift pipe. Nonuniformities of 40% in the magnetic guide field also contributed to the poor beam quality. These coils were replaced by new magnets that produced fields with variations of only 15%.

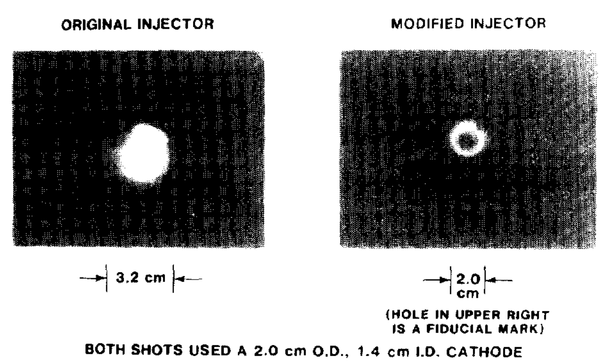

Figure 3. Comparison of x-ray pinhole photographs from the old injector (3a.) and the new injector (3b.)

The cathode shank was redesigned to reduce spurious electron emission and maintain magnetic insulation to minimize electron losses.[3] The modified injector and

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the improved magnetic field produced a 2-cm diameter, 5.3-MeV, 47-kA annular beam. Figure 3(b) is a pinhole photograph of a beam produced by the new injector. The $\beta_\perp$ for this beam was 0.16. The maximum perpendicular velocity can be calculated directly from measurements of a time-integrated, x-ray pinhole photograph. The measured annulus width is a function of the cathode dimensions, the applied magnetic field, the beam energy and camera geometry. There are known quantities and can be used to calculate $\beta_\perp$ from Larmor radius effects.[6] Typical measured values for $\beta_\perp$ ranged from 0.1 to 0.19 and agreed with the values obtained from particle simulations.

The measured injector currents are consistent with the space charge limited currents predicted by analytic theory. The space charge limited current is given by:[7]

$$I_{ANAL} = (1-0.3L^*)(\gamma^{2/3}-1)^{3/2}(17\ \text{kA})\ \frac{r_b}{\delta}\ [\text{Ln}\ \frac{8\delta}{a}\ ]^{-1}$$

$\gamma = \frac{V(MV)}{.511} + 1$, L^* = Dimensionless number equal to the anode-cathode gap in cm

$$r_b = \frac{r_1 + r_2}{2}\ ,\ \delta = R - r_2\ ,\ a = r_2 - r_1$$

For the RADLAC injector, $r_1 = 0.7$ cm, $r_2 = 1.0$ cm, $R = 1.6$ cm, and $L^* = 1.0$ cm. A comparison of the predicted current and measured current along with our geometry is shown in Figure 4.

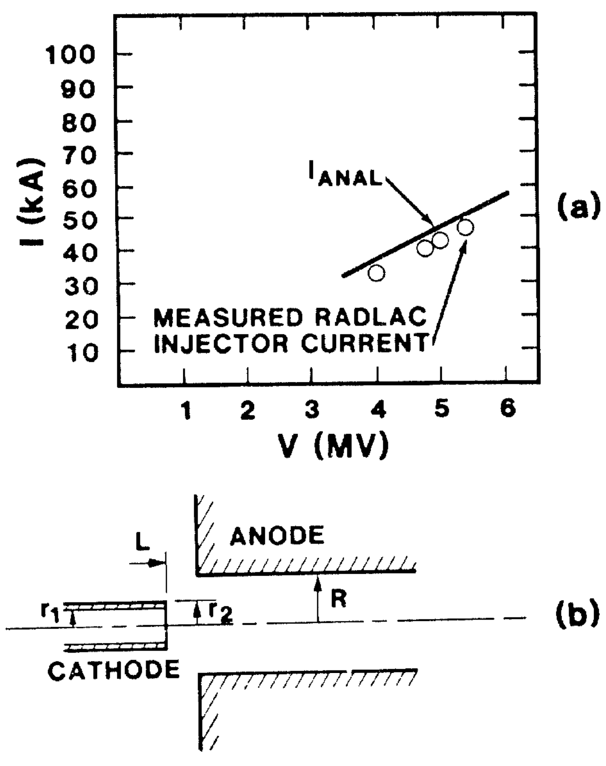

Figure 4. Comparison of analytical and experimental currents is shown in part a. The geometry is shown in part b.

Acceleration Experiments

The next phase of the experiment was to accelerate the beam through one accelerating gap. Hollow electron beams with energies of 3.5 to 4.2 MeV and beam currents of 25-35 kA were produced in the injector and accelerated to final energies of 5.6 to 6.3 MeV. The pinhole photographs indicated there was some expansion of the beam and some thickening of the annulus. The final $\beta_\perp$ for these beams was 0.08-0.12. Figure 5 shows a pinhole photograph of one of the accelerated beams.

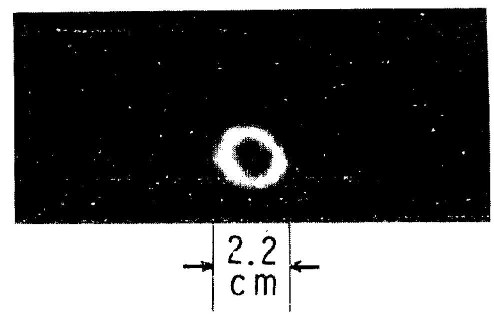

Figure 5. Pinhole photograph of beam after acceleration through one gap.

The beam was then accelerated through two accelerating gaps resulting in final energies of 7.3 to 8.3 MeV and currents of 27 to 36 kA. A pinhole photograph for one of these shots is shown in Figure 6. The final $\beta_\perp$ for these beams was 0.09 to 0.12. Again, these values are consistent with particle simulations.

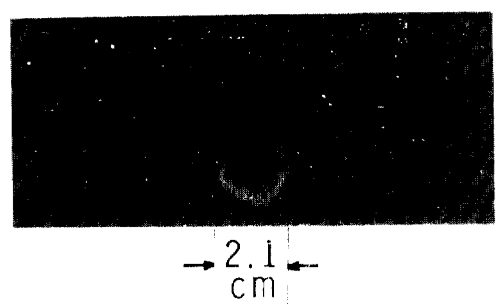

Figure 6. Pinhole photograph of beam after acceleration through two gaps.

The full accelerator has now been installed and experiments have begun. The final accelerator will produce a higher current, higher energy, better quality beam. Table 1 shows the comparison between the old beam parameters and the predicted parameters for the upgraded accelerator, based on the experimental results.

Table I
Comparison of RADLAC-II Beam Parameters

Parameter	Before Upgrade	After Upgrade
Energy ($(\gamma-1)mc^2$)	14 MeV (1.75 MV/stage)	20 MeV (2.5 MV/stage)
Current (I)	18 kA	42 kA
Beam Radius (r)	1.4 cm	0.9 cm
Perpendicular Thermal Velocity ($\beta_\perp c$)	0.16 c	0.05 c
Normalized Emittance Including Rotation (ϵ_n)	7.5 rad-cm	5.9 rad-cm
Brightness (B_n)	33 A/(rad-cm)^2	123 A/(rad-cm)^2

Parameters from before the upgrade are based on measured output from the accelerator. Parameters for the upgraded beam are based on particle code predictions of accelerator performance using measured input beam parameters from the first step injector experiments. The normalized emittance, ϵ_n, is defined as[8]

$$\epsilon_n = \sqrt{(\gamma r \beta_\perp{}^2) + (P_\theta/c)^2} ,$$

$$\text{where } (P_\theta/c) = \frac{1}{2}\frac{1}{mc^2} r_k^2 B_k$$

In the accelerator magnetic guide field, r_k and B_k are the cathode radius and magnetic guide field at the cathode, and $(P_\theta/c) = r\gamma\beta_\theta$ after extraction from the magnetic guide field. The brightness is defined as[9]

$$B_n = \frac{I}{(\pi\epsilon_n)^2} .$$

Conclusions

We have improved the performance of the RADLAC-II accelerator. An injector has been developed that produces a high voltage, high current, high quality annular beam. The beam has been accelerated stably through two accelerating gaps. Simulations and experiments indicate the full accelerator will produce a 20-MeV, 40-kA annular beam with a $\beta_\perp < 0.2$.

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