EXPERIMENTAL INVESTIGATION OF BEAM GENERATION, ACCELERATION, TRANSPORT, AND EXTRACTION IN THE RADLAC-II PULSED TRANSMISSION LINE LINEAR ACCELERATOR*

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ABSTRACT

We have investigated the generation, acceleration, transport, and extraction of intense, high-voltage, relativistic electron beams with the RADLAC-II accelerator. A 40-kA, electron beam was produced by a foilless diode injector, which was immersed in, and accurately aligned with, the magnetic axis of a 17-kG solenoidal guide field. The solenoidal field guides the beam through the accelerator, which includes a number of post-accelerating gaps designed to provide radial force balance to suppress radial oscillations. Furthermore, the accelerating cavities have a very low Q and small transverse shunt impedance to suppress beam breakup instabilities. A 70% to 90% transport efficiency was observed, depending on the precision of the beam line alignment. Finally, the beam was extracted, without significant losses, and propagated into a magnetic field-free, air-filled region.

Introduction

In the last few years, considerable work has been devoted to the production, acceleration, extraction, and air propagation of intense relativistic electron beams. RADLAC I,[1] and most recently, RADLAC II are the Sandia National Laboratories' contribution to this effort. In this paper, we describe the RADLAC II accelerator and report the results of preliminary transport and extraction experiments into full pressure air.

RADLAC II Accelerator

The RADLAC II accelerator consists of two modules connected in series; each module contains four energized cavities powered by a Marx generator/intermediate store capacitor (IS) combination (Fig. 1). The design and operation of a single module (RIIM) have been described in detail in Ref. 2. A 1-joule KrF laser is used to trigger the four SF_6-filled gas switches (2 per module). The 1-σ time jitter of the gas switches is less than 5 ns.

The first two cavities of the first module are connected in series and power the injector, thus providing twice the post-accelerating gap voltage to a foilless diode electron source. The beam produced is guided through the entire accelerator by a strong axial magnetic field of 17 kG. The accelerating cavity and gap design, similar to that studied in Ref. 3, eliminates radial oscillations and suppresses beam break-up instabilities. There are 6 post-accelerating gaps each providing an energy increase of a few MeV to the beam. The beam current is of the order of 40-45 kA. Figure 2 provides the effective accelerating voltage and beam current waveforms. Effective accelerating voltage is the sum of all the accelerating cavity voltages as measured by the resistive monitors corrected for time coincidence with the passage of the beam pulse from each gap.

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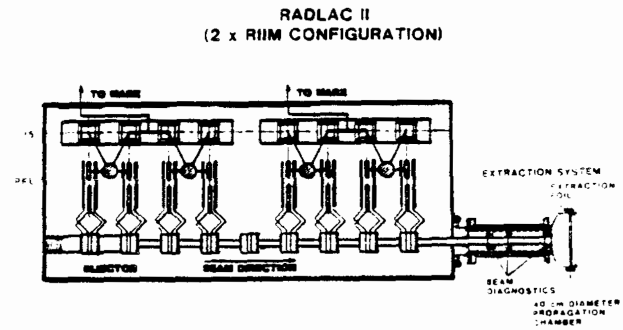

Figure 1: Top view of RADLAC II. In this configuration, RADLAC II can be considered as consisting of 2 RIIM accelerators connected in series. (2 x RIIM configuration). The beam line extension outside the water tank is also shown.

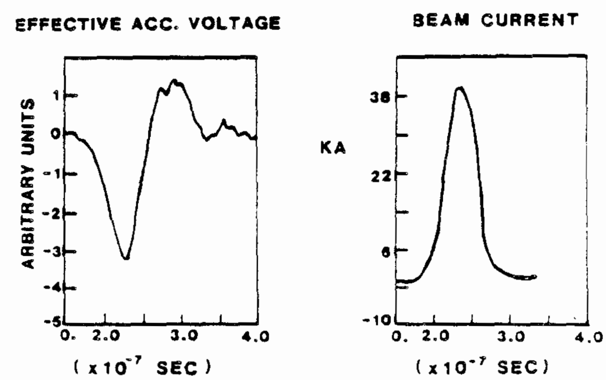

Figure 2: Effective accelerating voltage and beam current waveforms.

The beam envelope at the accelerator exit was observed using radiochromic foils, and most recently, a framing x-ray camera.[4] A 0.127-mm-thick tantalum x-ray convertor is placed over the extraction titanium foil on the air side for the x-ray measurements. Figure 3 shows the beam envelope on a radiochromic foil positioned inside the vacuum line just before the extraction foil. We will be able to measure the beam profile and current density with the x-ray framing camera, using photographs similar to that of Fig. 4. Beside the beam profile, this camera can provide excellent information about the x, y of the beam centroid in a time-resolved fashion. Each frame of Fig. 4 is 10 ns wide with a variable interframe time difference; here it was 0 ns. The first frame, coinciding with the arrival of the front of the beam pulse, is at the bottom left. The last frame, coinciding with the beam tail, is at the top right while the top left and bottom right frames correspond approximately to the main body of the pulse.

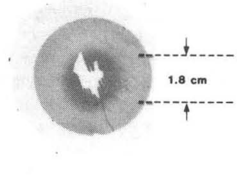

Figure 3: Beam envelope on radiochromic foil inside the accelerator. The part of the foil enclosed by the beam annulus is carbonized.

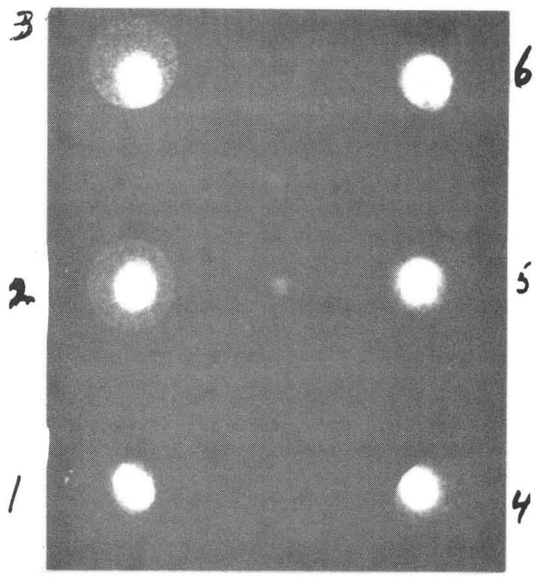

Figure 4: Preliminary measurements of the beam profile on the extraction foil using the x-ray framing camera. The beam appears filled in; however, the spacial resolution of the camera is not yet adjusted to optimum. For each frame, the shutter stays open for 10 ns. The interframe distance was 0 ns. The beam centroid is only 1 mm off axis. The apparent larger displacement is due to the paralax of the camera's 6 apertures. Notice that the beam does not show any B.B.U. or other type of oscillations.

Experimental Setup and Results

In the first series of extraction experiments, the accelerator vacuum beam line and the axial magnetic field were extended outside the water tank (Fig. 1). The extraction foil was located at the end of the uniform axial magnetic field. The field decays to zero within 16 cm from the extraction foil. Figure 5 is a schematic diagram of the RADLAC II extraction experimental setup including the vacuum transport extension and the 1.50 m-long, 40-cm diameter propagation chamber.

All of our RADLAC II extraction work was done in 630 torr air. The radius and profile of the extracted beam was observed by using radiochromic foils positioned at various distances inside the propagation chamber. The foil survives better in the air than inside the vacuum pipe.

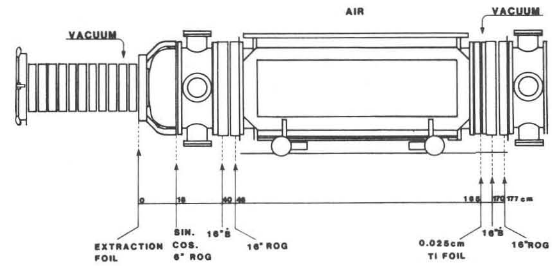

Figure 5: Schematic diagram of the extraction experimental setup.

In these experiments, we extracted under "overmatched" conditions. That is, the beam parameters were such that the equilibrium average beam radius in full pressure (630 torr) was somewhat smaller (0.75 cm), than the 0.9 cm beam radius in the vacuum line of the accelerator. The measured beam radii are in good agreement with the simple envelope theory and with numerical calculations done with the codes DYNADISC[5] (Fig. 7) and EXTRACT. The extracted beam net current measured by the 6" and 16" Rogowski (Fig. 5), which also agrees quite well with the code predictions was 18-20 kA (Fig. 6).

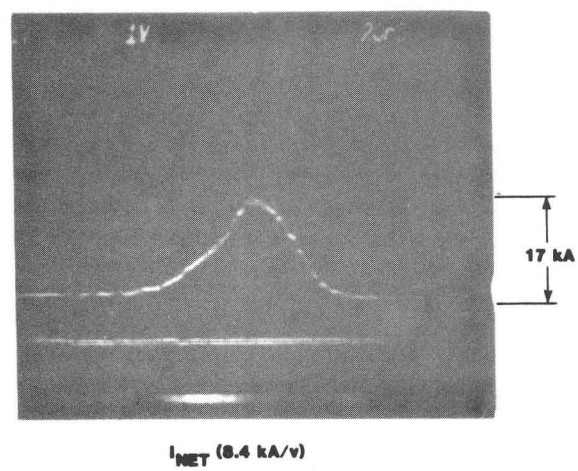

Figure 6: Net current waveform for a 40-kA beam current extracted beam.

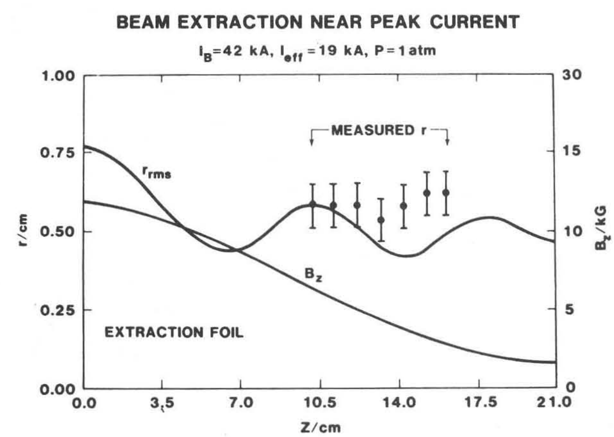

Figure 7: The rms radius calculated with DYNADISC. The solid circles with the error bars are the experimental envelope measurements with the radiochromic foils.

In the first series of experiments reported here, there was a misalignment in the beam line. As a result, the beam became unstable after approximately 1 m of air propagation. In a second series of extraction experiments performed recently, the accelerator beam line was accurately aligned, with a maximum offset between injector and exit pipe axis less than one millimeter. The extraction hardware of Fig. 5 was removed and the beam was allowed to propagate freely in the accelerator high bay. The beam propagated straight and without oscillations for at least 2 m in the air (Fig. 8). The beam radius was smaller than 1 cm. The framing camera (Fig. 4) showed a stable beam emerging from the accelerator (no oscillations) and well centered on the axis of the 5 cm vacuum pipe.

In another set of experiments, the RADLAC II beam was conditioned in a 16-m-long, ion-focused transport section[6] and then was allowed to propagate outside the accelerator building in the open air. Figure 9 shows that the beam propagated in a stable manner for quite a distance.

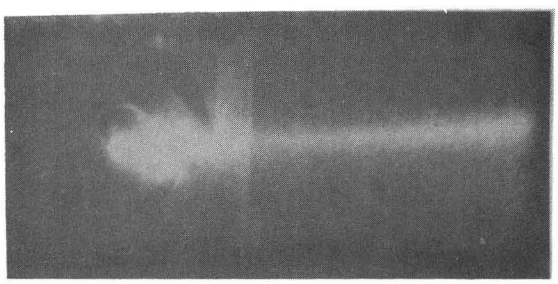

Figure 8: Open-shutter photograph of the extracted beam following precise alignment of the accelerator beam line. The beam exits at the left and propagates straight to the right. The beam path appears compressed, since this photograph was taken through a mirror making an angle with the beam direction. The trajectory scanned is equal to 2 m.

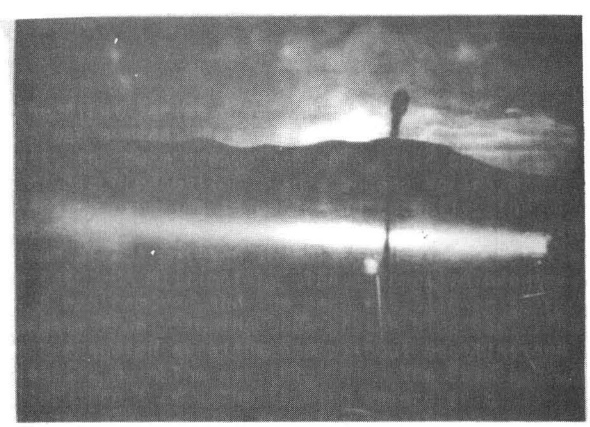

Figure 9: Open-shutter photographs of the RADLAC II beam propagating outdoors at night. The Manzano mountains are visible in the background.

Conclusions

We have successfully operated the RADLAC II accelerator and optimized its parameters to meet design specifications. A 40-kA electron beam was accelerated and extracted from the accelerator. It was established that when the accelerator beam line is well aligned, the tightly pinched exiting beam propagates for at least 2 m stably in the open air without oscillations. In addition, the RADLAC II beam propagated stably in the air outside the accelerator building after being transported in a 16-m ion focusing channel.

Further experiments studying beam extraction and air propagation are in progress.

References

1. R. B. Miller, et al., J. Appl. Phys. 52, 1184 (19)

2. M. G. Mazarakis, et al., Proceedings of 1985 Particle Accelerator Conference, Vancouver, B.C., May 13-16, 1985. Also IEEE Trans. Nucl. Sci. 32, No. 5, 3237, 1985

3. M. G. Mazarakis, et al., Proceedings of the 1984 Linear Accelerator Conference, Darmstadt, 1984, GSI-84-11, p. 466

4. W. A. Stygar, et al., Proceedings of IEEE International Conference on Plasma Sciences, St. Louis, MO, May 14-16, p 114, 1984

5. J. R. Freeman, et al., J. Appl. Phys. 59 (3), 725, 1986

6. C. A. Frost, et. al., "Ion-Focused Transport Experiments," Linac '86 Logistics Meeting, June 1986, Stanford, CA