UPGRADE OF THE PHERMEX ACCELERATOR*

T. P. Hughes
Mission Research Corporation
D. C. Moir and R. L. Carlson
Los Alamos National Laboratory

Abstract

The PHERMEX electron beam accelerator at Los Alamos National Laboratory, a 50 MHz, 30 MV standing-wave device, typically operates with a 500 A, 600 kV injector. A higher-current injector is under consideration, and we have modeled a flat-cathode diode geometry which can deliver 1–1.5 kA. A three-coil field configuration has been designed to maintain low beam emittance in the diode region. We show that the existing two transport magnets are marginally capable of transporting a 1 kA beam to the first RF cavity. We also examine at the possibility of accelerating a 4 kA, 4 MV beam, which could be provided by an existing pulsed power machine, through the first RF cavity.

I. INJECTOR UPGRADE

The nominal beam parameters produced by the spherical Pierce diode on PHERMEX [1] are 500 A at 600 kV. It is not practical to increase the diode current by raising the applied voltage because of the likelihood of surface breakdown of the focusing electrode. To avoid this problem, we have investigated using a non-Pierce diode, with a flat emission surface on a flat electrode. This allows the stress on the emission surface to be significantly increased without breakdown of the surrounding electrode. Since one is giving up the electrostatic focusing of the Pierce geometry, a magnet is required to capture the beam as it enters the anode structure.

We have considered two designs with nominal parameters of 1.5 kA at 600 kV, and 1 kA at 750 kV, respectively. Initial diode simulations were carried out with a coil configuration consisting of a focusing solenoid inside the reentrant anode and a bucking coil in the plane of the cathode surface. The bucking coil was adjusted to zero out the axial field at the edge of the cathode. A rather large normalized emittance of 0.15 cm-rad was obtained at 40 cm from the cathode due to the radial nonlinearity of the magnet focusing. To reduce this effect, we introduced a third coil with radius smaller than, and carrying current in the opposite direction to, the focusing solenoid. This coil reduces the focusing nonlinearity. It is most effective when placed at the location where the beam radius is largest. The improved beam emittance in the diode region can be seen in Fig. 1(c).

After extraction from the diode, the beam is transported to the first of the three PHERMEX RF cavities, the α-cavity. In the present machine, the distance from the cathode to the α-cavity entrance is about 1.57 m, and two iron-clad magnets are used to focus the beam (Ref. 1, p. 201). We assumed that this distance would remain unchanged for the upgraded diode. Using the code “POISSON” [2], we computed the axial magnetic field for the two iron magnets. This was used in an envelope model of the beam transport. It was quickly apparent that the fields from the iron magnets were too localized for good transport of the high-current beam. To widen the fields, iron shielding was removed from the inner radius of the magnets, and the field profile was recalculated. This allowed the beam to be transported about 1.2 m. To take the beam further, an additional magnet would be needed.

For a 1 kA beam at 750 kV, the beam can be transported further using just two magnets because of the lower perveance. The envelope results show that it is possible to reach $z \approx 150$ cm before the beam starts to expand. This is confirmed by the particle simulation in Fig. 1. We see that emittance, which is assumed constant in the envelope code, oscillates due to the variations in the radial magnetic field profile, $B_z(r)$. This does not have a significant effect on the *rms* radius, since space-charge is the dominant defocusing

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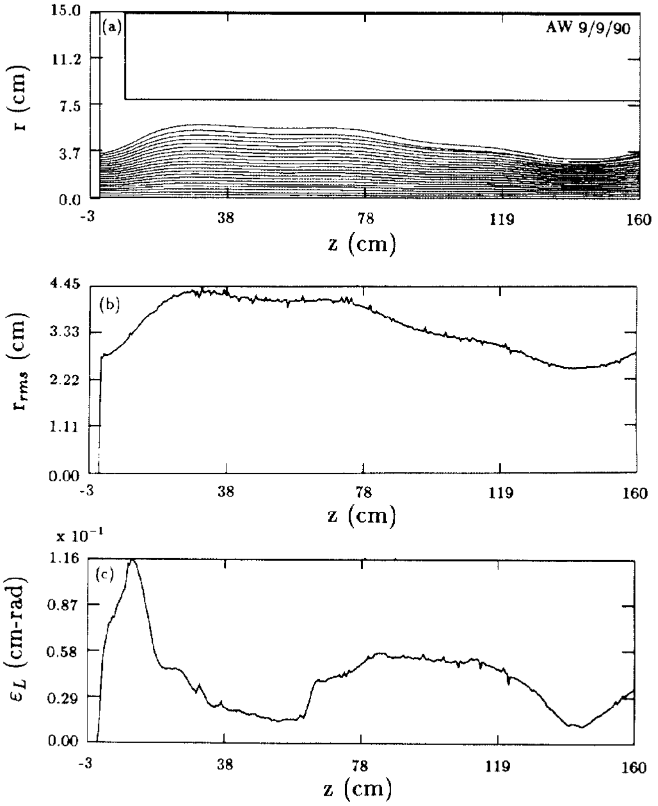

Figure 1. Particle simulation of transport for 1 kA, 750 kV beam from cathode surface through anode magnet and two iron-shield magnets. Particle plot is shown in (a), rms radius vs. z is in (b), and emittance vs. z is in (c).

term. Our conclusion is that two magnets are only marginally sufficient to transport the beam to the α-cavity. A third magnet would give considerably more flexibility.

Our studies to date have not looked at the effect of diode voltage fluctuations on the downstream transport. This needs to be addressed before a final magnet design is chosen.

II. HIGH CURRENT BEAM ACCELERATION IN THE α-CAVITY

A possible future experiment on PHERMEX is to accelerate a beam of several kA, such as that produced by the 4 MV, 4 kA REX machine [3], through the three RF cavities. The present PHERMEX injector produces a 200 ns beam pulse, which gives a train of ten micropulses, since the period of the PHERMEX RF is 20 ns. For a pulsed power injector like the REX machine, the beam pulse length is on the order of 70 ns, so that one could generate up to 4 micropulses. Calculations using an envelope model of the PHERMEX accelerator [4] show that the total charge going through the final 1 cm aperture is 54 μC, or about 6 times more than for a stream of ten 500 A pulses. The envelope model does not take account of the energy depletion of the RF cavities as pulses are accelerated. The resulting energy dispersion may make it impossible to obtain a small spot size for each micropulse. Assuming the accelerating field is of the form $E_z(t) = -E_0 \sin(\omega_0 t)$, then the energy absorbed by a pulse of length τ and current I_b is

$$\Delta E = \frac{2cAI_b}{\omega_0^2} \sin \frac{\omega_0 \tau}{2} \cos(\phi + \omega_0 t_c) \qquad (1)$$

where

$$A = E_0 \left[\left(1 - \cos \frac{\omega_0 L}{c}\right)^2 + \sin^2 \frac{\omega_0 L}{c} \right]^{1/2} ,$$

$$\tan \phi = \sin \frac{\omega_0 L}{c} \Big/ \left(1 - \cos \frac{\omega_0 L}{c}\right) ,$$

L is the length of the cavity (2.6 m), and t_c is the time at which the center of the pulse exits the cavity. We have simulated beam transport through the PHERMEX α-cavity using the electromagnetic PIC code IVORY. To initialize the fields, the cavity was pumped up over about 8 RF cycles using artificial currents until the electric field amplitude was about 6 MV/m. The artificial currents were then turned off and the beam was injected. Results for continuous beam injection over two RF periods are shown in Fig. 2. The current, rms radius and energy plots show that the two micropulses are quite similar at the exit of the cavity. The width of the pulses at peak current is about 6 ns. Prior to beam injection, the energy in the cavity is about 1.8 kJ. The energy drops by 140 J after the first pulse, and by an additional 230 J after the second pulse. The large difference between the two pulses is due to the work done on beam particles which accumulate in the cavity during the deceleration cycle.

In the case of a chopped beam, injection is timed to occur so that particles are near the peak of the accelerating voltage. Results for two consecutive 6 ns pulses are shown in Fig. 3. We see that the two pulses are quite similar, although a drop in the peak energy is visible. From Fig. 3(a), we find that the pulses are clipped to about 5 ns by the exiting aperture. We find that 165 J and 172 J are extracted by the first

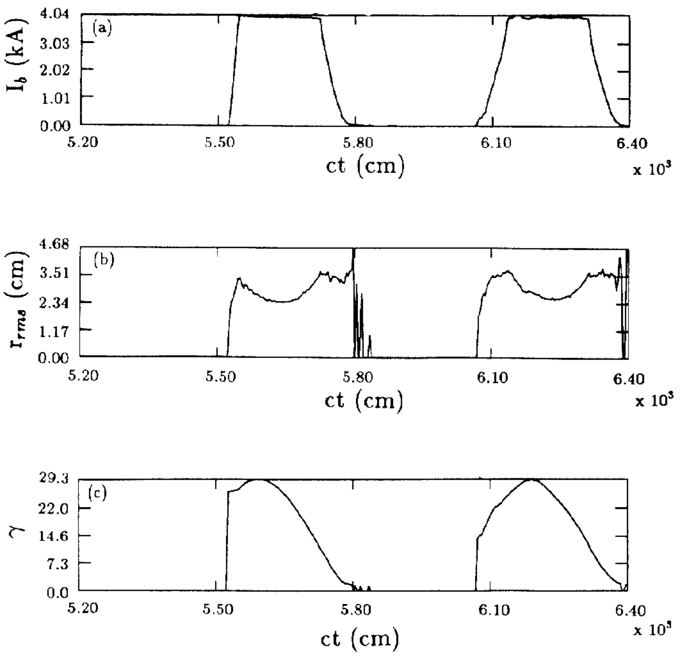

Figure 2. Time histories of (a) beam current, (b) rms radius and (c) energy (γ) at the exit of the α cavity for continuous beam injection (Run AE).

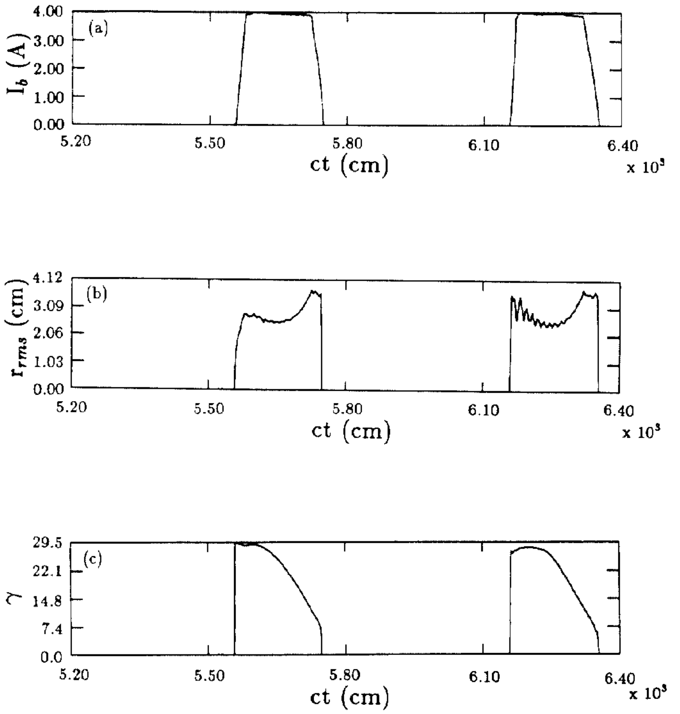

Figure 3. Time histories of (a) beam current, (b) rms radius and (c) energy (γ) at the exit of the α cavity for chopped beam injection (Run AE1).

and second pulse, respectively. Since the pulses have a well-defined length, we can compare these values with the estimates from Eq. (1). This expression predicts that the first and second pulses should absorb about 169 J and 171 J, respectively, in good agreement. The pulses in Fig. 3 are injected about 2.1 ns too late in the RF cycle to absorb the maximum possible energy, which is about 220 J.

The above results indicate that at least two similar 4 kA pulses can be accelerated in the α-cavity. If we assume that the pulses are timed to absorb maximum energy, then based on the Eq. (1), the second, third and fourth pulses would have energy gains approximately 94%, 87%, 80%, of the first pulse, respectively. It would be straightforward to extend the simulations to check these estimates. It is also possible to take the particles exiting the α-cavity and inject them into subsequent cavities. This would provide an accurate estimate of transport efficiency and energy dispersion at the end of the accelerator.

ACKNOWLEDGMENTS

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III. REFERENCES

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