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PHERMEX AS AN INJECTOR TO A MODIFIED BETATRON

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Abstract

The PHERMEX accelerator is a pulsed three-cavity, 50-MHz, standing-wave rf linear accelerator. It is used to produce a 30-MeV, 200-ns envelope of electrons for flash radiography and electron beam experiments. The 200-ns electron pulse contains 10 micropulses. The FWHM of a single micropulse is 3.3 ns. Peak micropulse current varies from 350 to 850 A with widths of 3 and 5 ns respectively. We propose to inject this beam into a solenoidal field with a neutralizing background gas and stack the PHERMEX micropulses in a 28-cm-diam ring to obtain a 3-ns multi-kiloampere beam. Coupled to the background magnetic field will be a ramped field driven by a magnetic flux compression generator. Beam kinetic energy approaching 100 MeV is theoretically possible. Simulations of ring stability with and without the accelerating field are presented.

Introduction

The PHERMEX accelerator is a standing-wave, 50-MHz rf linear accelerator.[1,2] The rf fields in the three cavities are pulsed for a period of 3 ms. Peak cavity field strengths are between 5-6 MV/m. At maximum field amplitude, a 40-, 100-, or 200-ns pulse of electrons is injected into the first cavity. The portion of the injected beam in phase with the rf accelerating cycle is transported to the second cavity; the remaining electrons are dumped to the accelerator wall. The resulting beam transported through the three cavities contains micropulse structure determined by the characteristic accelerating cycle of the 50 MHz. The overall pulse envelope is determined by the injector-gun pulse. Figure 1 is a schematic of the accelerator. Using the beam generated by this accelerator as an injector to a modified betatron is investigated.

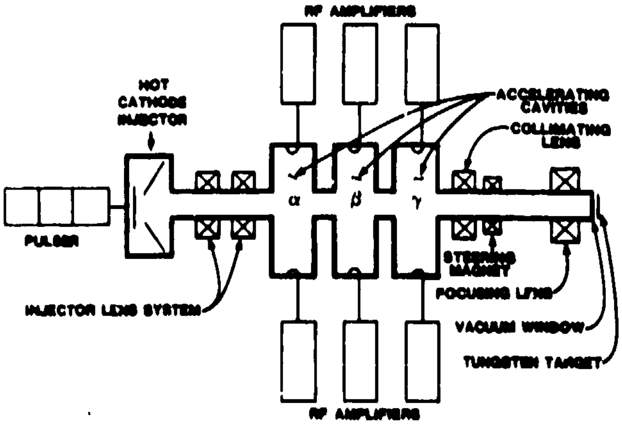

Fig. 1. Schematic of PHERMEX accelerator.

PHERMEX Beam Parameters

A single electron gun pulse produces a beam at the exit containing a train of micropulses. Micropulse width is primarily determined by the rf accelerating phase. Recent data indicate that it also depends on electron gun-pulse voltage. Injected beam energies of 0.5 MeV yield micropulse widths of 3.3-ns FWHM. An initial energy of 0.9 MeV produces a 5-ns FWHM pulse. Figure 2(a) shows a micropulse envelope that results from a 0.9-MV, 40-ns pulser. Figure 2(b) shows a single micropulse from the same envelope. Typical peak currents of a micropulse depend on the gun voltage. Applied pulse voltage of 0.5 MV results in a peak current of 350 A; for 0.9 MV the peak current is 850 A. (The electron gun perveance is 1 μP.[3])

The energy of the beam depends on the cavity field strength. Typical machine parameters produce a maximum beam energy of 30 MeV. Detailed presentation of the time resolved beam momentum measurements are in Ref. 4. Within the macropulse

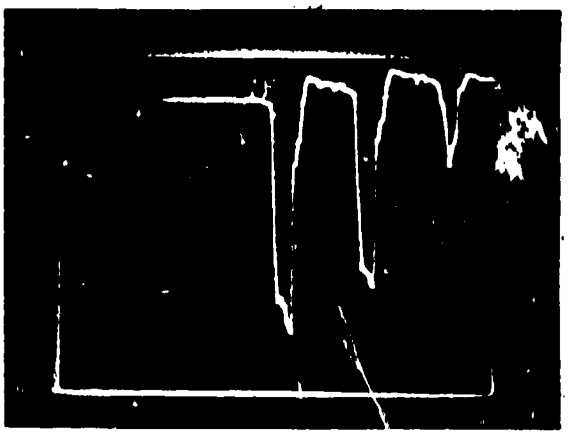

Fig. 2(a). PHERMEX 40-ns pulse envelope.

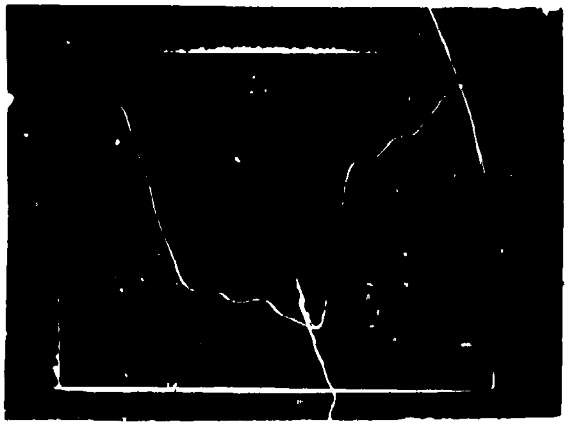

Fig. 2(b). A single 5-ns FWHM PHERMEX micropulse.

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envelope, peak beam energy decreases 0.7% per micropulse; for 10 micropulses, the tenth pulse will be 7% lower in energy. In a single micropulse, the beam energy spread is ±3%; however, 80% of the charge appears in a ±1% energy band shown in Fig. 3. This band is contiguous in time (~2 ns), contains the peak current, and has minimum emittance of 260 π mm-mrad.[5]

For modified betatron injection it is desirable to deliver maximum charge. It may be possible to extend the length of the PHERMEX gun pulse to 2 μs at 0.5 MV, thereby generating a 2-μs pulse train containing 100 micropulses. Peak-injected and transported current would be about 350 and 300 A. The beam energy would vary from 30 MeV to 10 MeV front to rear of the 2-μs pulse. Each micropulse would contain an average charge of 1 μC. When injected into a modified betatron, the total charge would add to 100 μC.

PHERMEX Modified Betatron

Conceptual design for the injection and stacking of PHERMEX micropulses follows the design of Astron high-vacuum trapping experiments.[6] Figure 4 is a schematic of such a device. The beam is injected transverse to the solenoidal magnetic field containing a mirror field on both ends. The B_z field in the center is 0.6 T, and the mirror fields are 0.7 T. There is a variable toroidal field B_θ, such that $B_\theta \leq 0.5\ B_z$. The walls of the solenoid are resistive. The beam is injected at a slight angle relative to the normal of the solenoidal field and forms a ring with an initial axial velocity v_z. The v_z is damped by the resistive wall[7] and the ring equilibrates in the center of the mirror field as shown in Fig. 4. After equilibrium, the B_z field is increased by driving a separate set of coils, thus accelerating the beam. The B_θ field is kept at a constant fraction of the B_z field. During the latter stages of acceleration, the beam reaches an equilibrium between energy added and synchrotron radiation emitted. The final electron ring has a small energy dispersion relative to that of the initial ring.

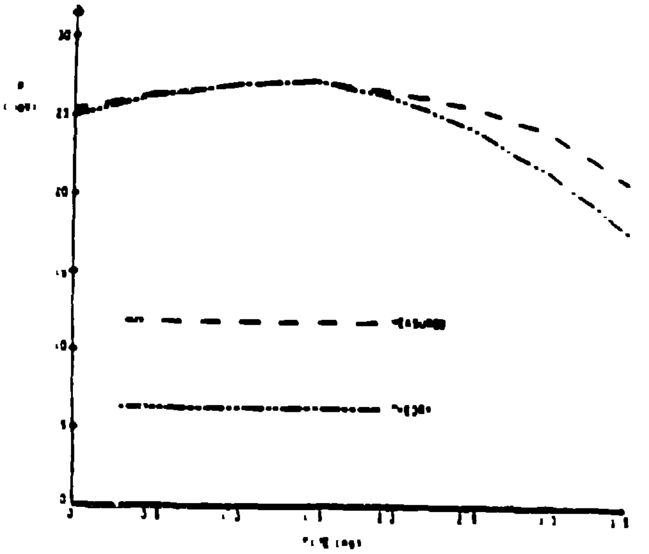

Fig. 3. PHERMEX beam energy spread as a function of time into the micropulse.

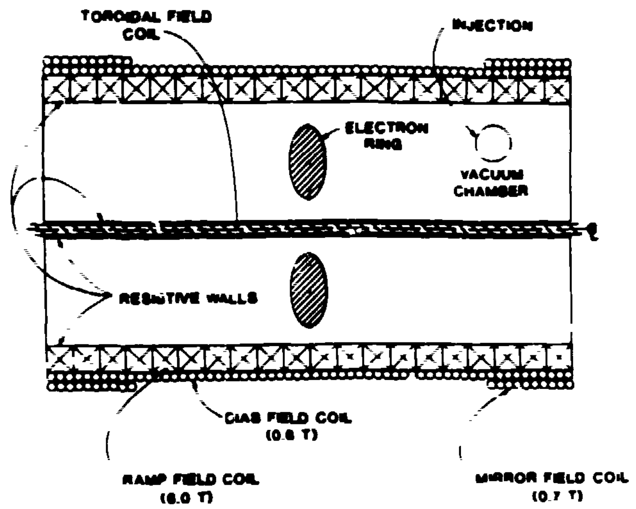

Fig. 4. Schematic of a PHERMEX modified betatron.

A summary of initial and final ring parameters is given in Table I. Injection, stacking, and ring stability have been examined extensively for the Astron experiments. Of the three, multiple-pulse stacking was the most difficult problem. Each stacked PHERMEX micropulse occupies a slightly different "phase space" because of beam envelope energy spread; therefore, there may not be the saturation effect observed in the Astron multiple-pulse experiment. Only a precessional instability was observed in the Astron experiments.[8] This was stabilized by the addition of a B_θ field. This field is included in our design.

Modified Betatron Simulations

Theoretical work on the ring accelerator can be divided into three portions: injection, acceleration, and extraction. The acceleration portion is best understood. We have run simulations of coil-driven ring accelerators using the 2 1/2 dimensional particle-in-cell code ISIS,[9] with parameters similar to the PHERMEX experiment under consideration. We have run simulations in both the r-θ plane (assuming

TABLE I

	Initial Parameters	Final Parameters
E (MeV)	20 (10-30)	63
B (T)	0.6	6.0
I (kA)	35	140
Q (μC)	100	100
r (m)	0.14	0.035
t (ns)	2.9	0.7
ΔE_{sync}/rev (eV)	3.5	450
ΔE_{gain}/rev (eV)*	5900	370

*Assumes a linear field ramp in 20 μs.

infinite axial extent) and the r-z plane (assuming axisymmetry) to look at stability of the ring to azimuthal and axial modes. While we can demonstrate the negative-mass instability for rings in a static external field, we find that the modest field ramping envisioned for the PHERMEX experiment will stabilize the ring.

The simulations assume an electron ring in equilibrium with an external solenoidal field of 20 kG magnitude. The ring radius is 5 cm, and the electrons have energies appropriate to a self-consistent equilibrium (approximately 30 MeV). The ring is diamagnetic but not field-reversing. On a time scale of 1 μs (10 μs is appropriate to the experiment, but much more expensive in computer time), the field is ramped by a factor of 10. The ring maintains its integrity and coherence throughout the ramp, and electrons gain a factor of $\sqrt{10}$ in energy. Simulations of the injection and extraction processes are in a very preliminary stage as yet.

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