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BEAM TRANSFER AND EXTRACTION AT LAMPF II

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Summary

Protons will be single-turn extracted from the LAMPF II synchrotron at 30 Hz. On alternate pulses they will be single-turn injected into a storage ring. Both processes utilize fast kickers and Lambertson septum magnets. Half-integer resonant extraction will be used to slow-extract the beam from the storage ring over a time spread of 1/15 s. The slow extraction occurs using electrostatic wire and iron septa.

I. Introduction

The current reference design[1] for the LAMPF II project is based upon the requirement of producing an intense (I ~ 100 μA) proton beam. These protons would be used to produce intense beams of kaons, hyperons, and neutrinos. A rapid-cycling synchrotron would be used to accelerate 800-MeV protons from the LAMPF linac to a peak energy near 32 GeV. The desired current can be obtained using 30 Hz with 2×10^{13} ppp. The reference design for the accelerator is a superperiod five machine. The total betatron tunes are $\nu_x = 14.19$ and $\nu_y = 12.29$; the circumference is 1082.69 m (harmonic number 216). Figure 1 shows a layout with the machine inscribed within a pentagon. The machine is composed of five arcs A_i and five straight sections S_i.

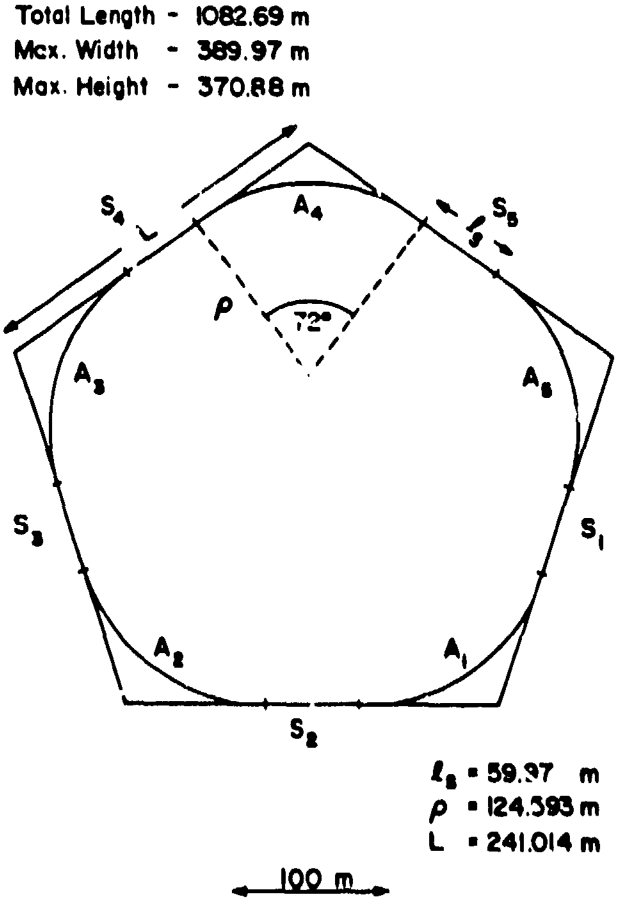

Fig. 1. Geometry of five-sided machines for LAMPF II.

On alternate pulses the beam is single-turn extracted and sent to a DC storage ring for slow extraction to experiments. This ring has been designed to also be five sided and to be positioned, for example, directly above the accelerator. On intervening pulses the beam is sent directly to a neutrino experiment area. The storage ring has a unit superperiod and has a high beta section in one of its straight sections in order to locate an electrostatic extraction septum. This machine has a tune of $\nu_x = 13.45$ and $\nu_y = 12.95$.

In Sec. II we describe the accelerator extraction, beam transfer, and injection into the storage ring. The storage-ring extraction is discussed in Sec. III. Concluding remarks are given in Sec. IV.

II. Single-Turn Manipulations

Figure 2 shows a plan view of the accelerator. Beam is extracted in a single turn by energizing two fast horizontal kickers to deflect the beam into a Lambertson extraction septum. Kicker (K_1) bends the beam 1.5 mr inward, while the second kicker (K_2) gives an identical but outward deflection. We assume a length of 5.5 m for the kickers and field of 300 gauss. Figure 3 shows the kicked orbit from K_1 through the extraction Lambertson L_1. The maximum displacement is ±20 mm through arc 2, well within the aperture. At the Lambertson Center we have $x_L = 24.2$ mm, $x_L' = 0.8$ mr.

Identical extraction can take place through kickers 3 and 4 and the extraction Lambertson 2 (see Fig. 2). In this case the beam would be transported to another area (neutrino experiments). The kickers must be capable of at least 300 gauss with a short rise time (100-200 ns). They are separated by 190.2 m so K_2 (K_4) must be delayed by 634.8 ms relative to K_1 (K_3) when transporting 32.977 GeV/c protons. The Lambertson extraction septa will bend the horizontally displaced beams up. A length of 5.0 m should allow for efficient extraction and transport, assuming a maximum 1.0 T field.

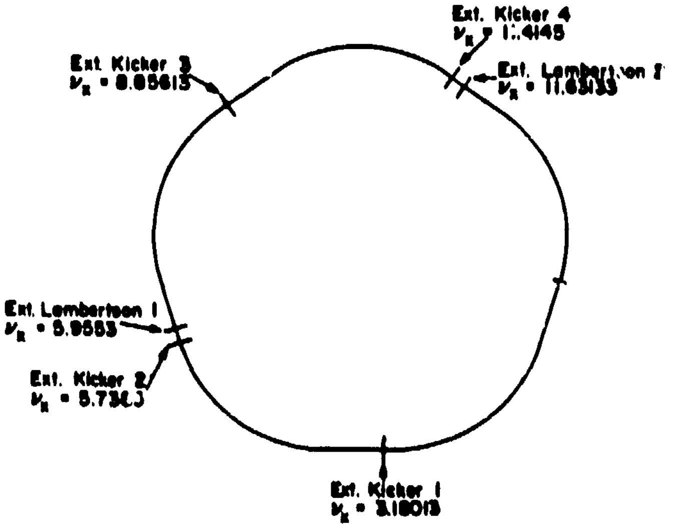

Fig. 2. Plan view of the accelerator ring showing the locations of the extraction components.

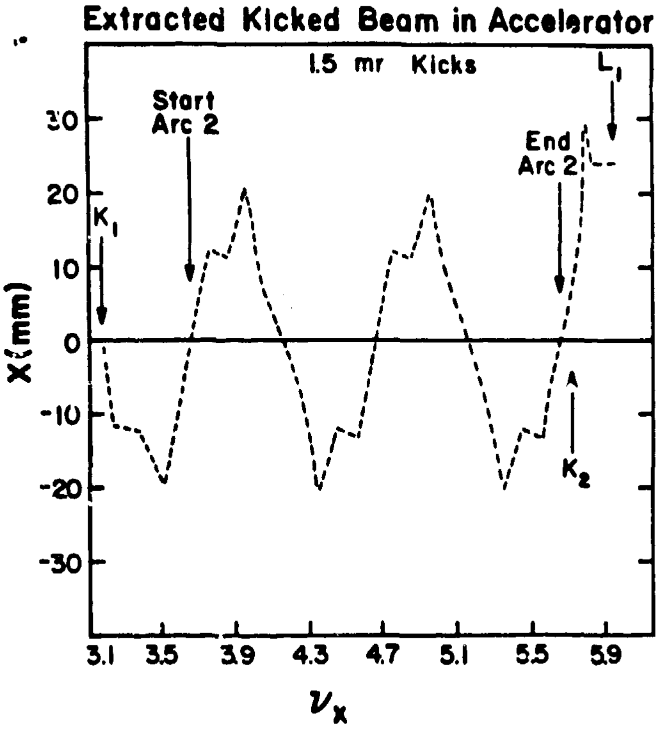

Fig. 3. Closed orbit for monoenergetic kicked beam in accelerator from kicker K_1 through the extraction Lambertson L_1.

Injection will occur via a Lambertson (L_3) into the storage ring. Two symmetric quadrupole triplets will accomplish the matching of Twiss parameters and will be located in the line between the two Lambertsons L_1 and L_3. The height differential of the two rings h is given by 37.2 tan θ where θ represents the bend angle of the Lambertsons L_1 and L_3. Existing quadrupoles in the ring straight sections require a minimum angle near 40 mr and h > 1.5 m. This bend can be accomplished with $\int B d\ell$ = 4.4 T-m; for a 5.0-m Lambertson we require B_0 = 0.88 T (at $B\rho$ = 110 T-m).

Figure 4 illustrates the storage ring and transfer components. The injection Lambertson (L_3) renders the incoming beam horizontal; at this point the horizontal displacement of the beam is, for example, +15 mm and parallel to the central orbit. The injected beam undergoes a coherent betatron oscillation through the arc A_3 (see Fig. 1) and the straight S_4 before being acted upon by the injection kicker. The trajectory behavior between Lambertson and kicker is shown in Fig. 5. As before, the required kicker field is 300 gauss for a length of 6.33 m.

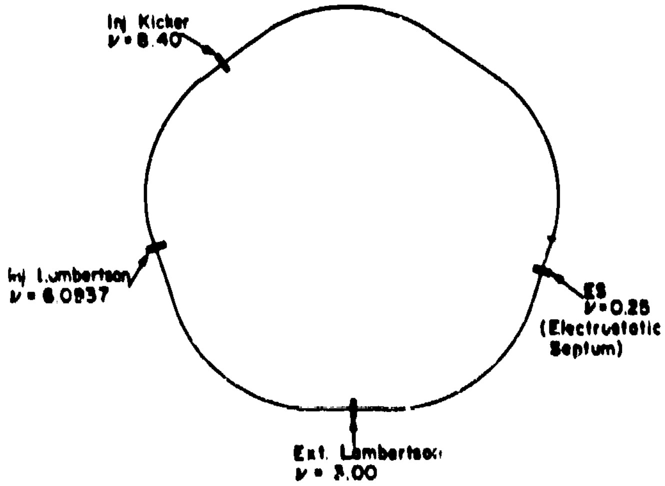

Fig. 4. Plan view of the storage ring showing the locations of the injection and extraction components.

III. Storage Ring Extraction

The unperturbed tune of the machine is ν_x = 13.45. We plan to extract the beam using half-integer resonant extraction in the horizontal plane. Time-dependent perturbing quadrupole(s) will drive the tune close to ν_x = 13.50. The separatrices will be defined by suitably placed octupole(s). As the resonance is approached, particles will arrive at the location of the electrostatic septum (see Fig. 4) with larger absolute displacements x_s on successive turns. The wire will be located at x_s = +40 mm. An electric field of greater than 50 kv/cm is sufficient for extraction. Assuming a septum length of 3.0 m, we will keep the step size less than 20 mm. Thus particles arriving at the septum with displacement +40 mm < x_s < +60 mm will receive a horizontal kick. Figure 6 shows the horizontal displacement for a test particle arriving at the electrostatic septum with x_s = +60 mm and zero angle x_s' = 0; the particle then traverses the following arc to the Lambertson location at ν_x = 3.0. The solid line represents the trajectory for no kick from the electrostatic septum. This curve is useful to show how the beam grows prior to extraction. Apertures can be inferred from their behavior as well as from the injection orbit in Fig. 5. The dashed curve in Fig. 6 results when the test particle receives an outward +0.45-mr kick in the electrostatic septum. The excursions grow to ±35 mm in arc 1; the displacement is −25 mm at the extraction Lambertson L_4, sufficient to then take out for experiments.

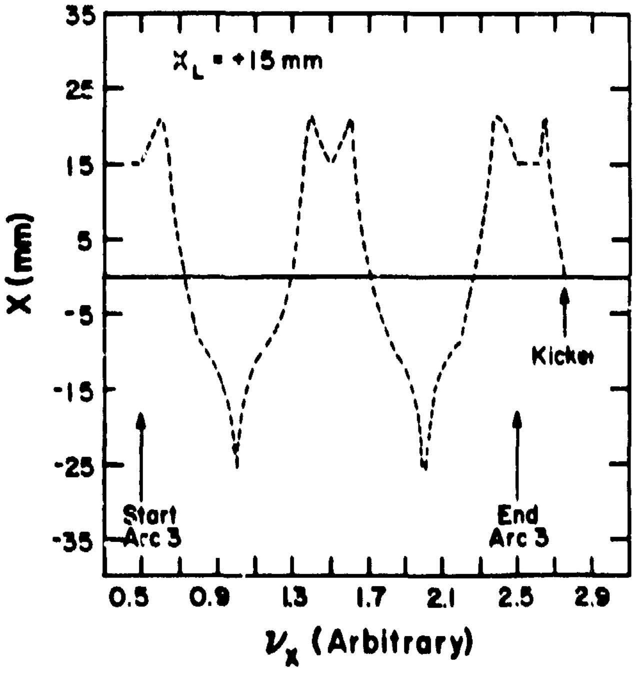

Fig. 5. Injection orbit in storage ring from injection Lambertson L_3 through the injection kicker.

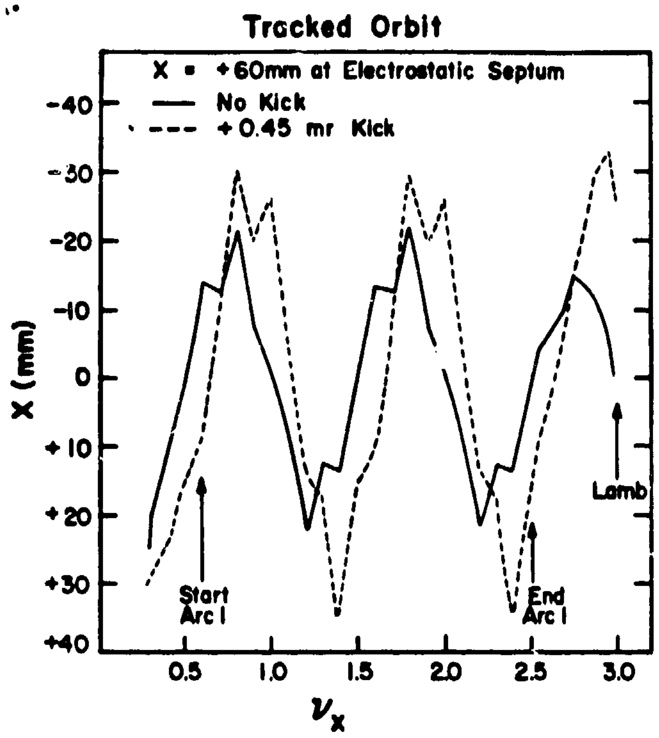

Fig. 6. Trajectory of a particle in the storage ring starting at the position of the electrostatic septum $x_s = 60$ mm.

The straight sections in the machines are dispersion free. In particular, the storage ring has a special high-beta straight section S_1 with $\beta_s^* = 156.9$ m at the electrostatic septum. The extraction Lambertson is located at the center of S_2 where $\beta^* = 21.278$ m. The three remaining straight sections S_3–S_5 are identical mirror-symmetric quadrupole systems with $\Delta\nu_x = 0.65$ and $\Delta\nu_y = 0.48333$. The peak β_x values are near 52 m in these sections. The high beta at the electrostatic septum is particularly useful to minimize the maximum excursions in the machine as well as to maximize the extraction efficiency. A good rule of thumb is to locate the septum wire at, for example, $x_s \sim 3\sqrt{\beta_s \epsilon}$, where ϵ is the transverse geometric emittance. We expect $\epsilon \sim (1.0\text{–}1.5) \times 10^{-6}$ πm so we choose $x_s = 40$ mm. The extraction efficiency is approximately given by[2]

$$r = 1 - \frac{t_s}{x_s + \Delta} \, \frac{1}{\log_e\left(\frac{x_s + \Delta}{x_s}\right)} \qquad (1)$$

for quadrupole-dominated extraction. In Eq. (1) t_s is the wire thickness and Δ is the step size. Given $t_s = 0.075$ mm we obtain $r = 0.993$ and $r = 0.997$ for $\Delta = 10$ mm and $\Delta = 20$ mm, respectively.

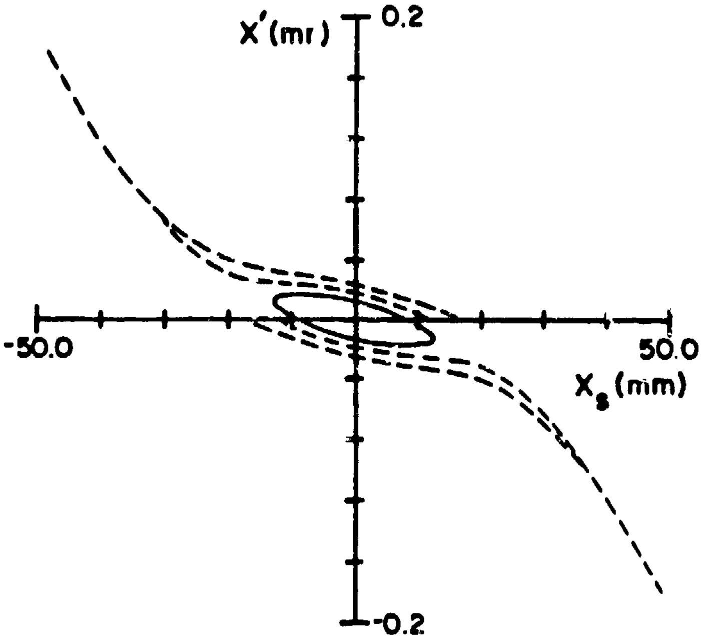

Fig. 7. x-x′ phase-space behavior at the electrostatic septum for three test particles with initial x′ = 0, $x_s = 8.85$ mm, $x_s = 12.52$ mm, and $x_s = 17.71$ mm.

In the simplest half-integer resonant extraction system one need include only a single 27th harmonic quadrupole and zeroth harmonic octupole. Achievement of a quadrupole-dominated extraction and large step size Δ is sometimes intractable for a given unperturbed tune and Twiss parameters at the electrostatic septum. We show in Fig. 7 the xx′ phase-space trajectories of three test particles at the location of the electrostatic septum. The outer two trajectories are outside the stable area and stream out along the separatrices—they would jump the septum at $x_s = 40$ mm. The perturbing quadrupole is located at $\nu_x = 1.20$ (in the first arc A_1) with $\beta_Q = 22.676$ m. It has a power $P_Q = 0.0135$ m^{-1} (HF). The octupole is located in the straight S_3 at $\nu_x = 3.6387$ with $\beta_O = 52.13$ m and has a power $B'''L/(6B\rho) = 1.667$ m^{-3}.

The step size in Fig. 7 is still too small for efficient extraction. Furthermore the separatrices need reorienting for actual extraction. In fact, an extensive search was performed in order to obtain more optimum quadrupole and octupole locations; an improved situation was not obtained. A slight redesign of the storage-ring lattice is needed. Octupole-dominated extractions are possible, but they necessarily introduce higher order nonlinearities; the extracted beam emittance depends strongly upon the strength of the perturbing quadrupole in these cases also.

IV. Conclusions

The actual design for LAMPF II is still evolving at this time. We have identified the major hardware and techniques for beam transfer. They are well within the present technology and should present no great problem. We are concerned with beam spill, however, especially at the electrostatic septum; further work will be aimed at reducing this effect.

References

1. H. A. Thiessen, Proc. of the XII Int. Conf. on High-Energy Accelerators, Fermi National Accelerator Laboratory, August 1983 (to be published).

2. M. Harrison, Fermi National Accelerator Laboratory report UPC-87 (1979).