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TITLE SIMULATION OF TRANSITION CROSSING IN LAMPF II

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SIMULATION OF TRANSITION CROSSING IN LAMPF II*

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Summary

LAMPF II is the proposed rapid-cycling synchrotron that will take 0.8-GeV protons from the LAMPF linear accelerator and raise them to 32 GeV. Early design models were based on a 60-Hz cycle with 10^{13} protons to be accelerated per cycle. Any reasonable magnetic lattice results in the proton beam going through a phase transition. A general accelerator-simulation code that includes the effect of longitudinal space charge, ARCHSIM, has been used to study the transition in a typical achromatic lattice. The beam remains stable through the transition.

Introduction

A proposal is in preparation for a 32-GeV rapid-cycling proton sychrotron (LAMPF II) that will be injected with 0.8-GeV protons from LAMPF. Details of the proposed accelerator are given elsewhere in these proceedings.[1] LAMPF is a 120-Hz machine. LAMPF II is being designed for ~6 x 10^{14} protons/s, which means either 10^{13} at 60 Hz or 2 x 10^{13} at 30 Hz. Either would result in roughly 200-300 bunches spread around an ~170-m-radius ring. Each bunch would contain ~10^{11} protons. Space-charge effects could be important, especially near the phase transition. Bunch-length oscillations and longitudinal emittance growth can occur just after transition and could limit the beam intensity.[2] All of the magnetic lattices studied so far result in a phase transition near 12 GeV. It is probably not reasonable to design a machine without a transition because, even if transition causes problems, there exist several known cures.[2]

In the process of studying various acceleration schemes, a simulation code called ARCHSIM was developed. This code also includes longitudinal space-charge forces in the kick approximation.

The formula for the energy kick in terms of the rf phase φ is

$$\Delta W = -\frac{r_p mc^2}{\gamma^2}\left(\frac{h}{R}\right)^2 [1 + 2\ln(b/a)]\frac{d\lambda(\varphi)}{d\varphi} L \quad , \qquad (1)$$

where r_p is the classical proton radius, mc^2 the rest mass energy, $mc^2\gamma$ the proton energy, h the harmonic number, $2\pi R$ the machine circumference, b the beam pipe radius, a the beam radius, $\lambda(\varphi)$ the linear density of charge along the beam, and L the distance along the ring since the last kick.[3]

ARCHSIM turned out to be ideally suited to studying the effect of phase transition. This paper gives a short description of ARCHSIM and shows an example of transition crossing in an early design model of LAMPF II. In this example no emittance growth was observed.

Description of ARCHSIM

Figure 1 is a simplified flow chart. The input subroutine loads the computer with general control parameters such as the time to complete an acceleration cycle, number of particles to be used in the simulation, print and plot controls, etc. The emittance of the injected beam is simulated by associating a random 6-D phase-space vector with each injected particle and requiring that vector to be in a certain phase-space ellipsoid. The ellipsoid can be offset from the center of phase space in an oscillatory manner to simulate bumping of the incident beam to increase its emittance and decrease space-charge-force effects. The synchrotron is simulated by a ring with a certain number of nodal points (Fig. 2). At these

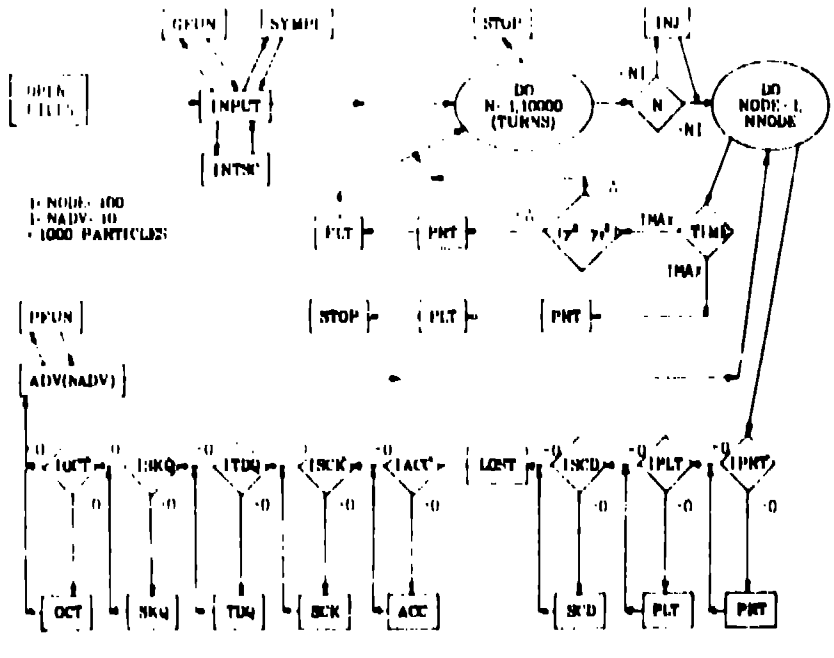

Fig. 1. Flow chart for ARCHSIM.

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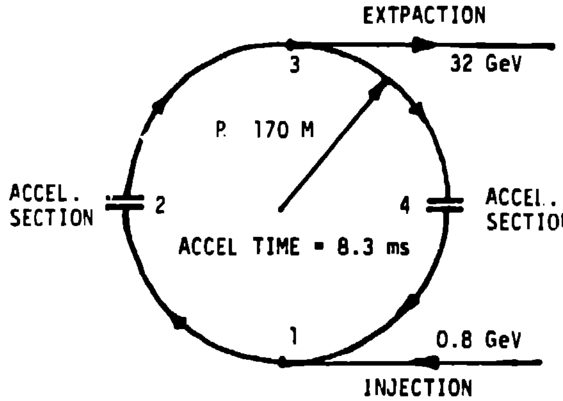

Fig. 2. Example of accelerator with four nodes.

nodal points a number of things can occur. The particles may be: accelerated (ACC); given a space-charge-force kick (SCK); and/or given a kick from a time-dependent quadrupole (TDQ), a skew quadrupole (SKQ), or an octupole (OCT). At a node, one can make phase-space plots such as those shown in Figs. 3 through 5 (PLT). One also has the option of printing out various kinematic parameters such as turn number, time, momentum, rf voltage, rf phase, relative Laslett tune shifts, etc. (PRT). The linear space-charge distribution used to calculate the space-charge kick also is updated at a node (SCD). Particles that have moved outside the admittance of the beam are also tagged at nodes (LOST). Particles are transported between nodes, using matrices calculated from a second-order transport code such as DIMAT[4] or TRANSPORT (ADV).[5] The code presently handles 1000 particles, 100 nodes, and up to 10 different transport matrices between nodes. It could be expanded if installed on a faster, larger computer.

The input subroutine also loads all the transport matrices and makes minor adjustments in the matrix elements to insure that they are symplectic (SYMPL). This is important because small errors grow large after 12 000 turns around the ring. A Los Alamos internal report describing this symplectification process is in preparation.[6] The input subroutine

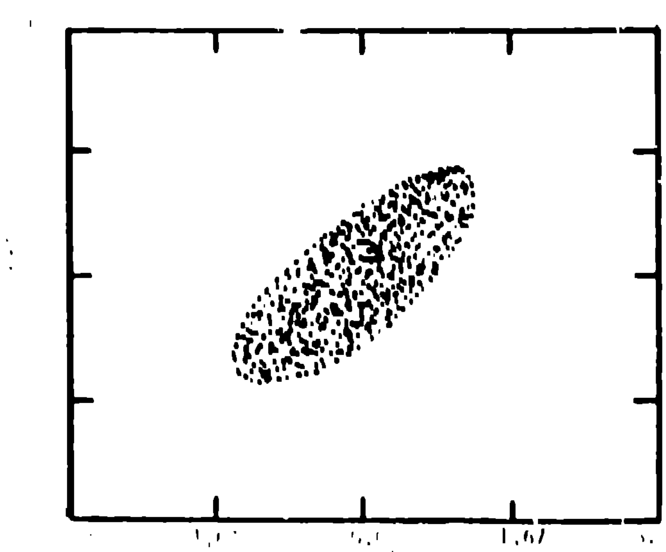

Fig. 3. Radial phase space after 50 turns, at end of injection.

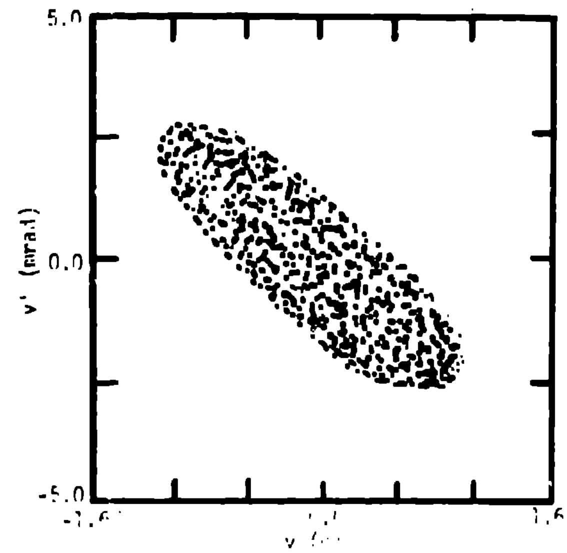

Fig. 4. Vertical phase space after 50 turns, at end of injection.

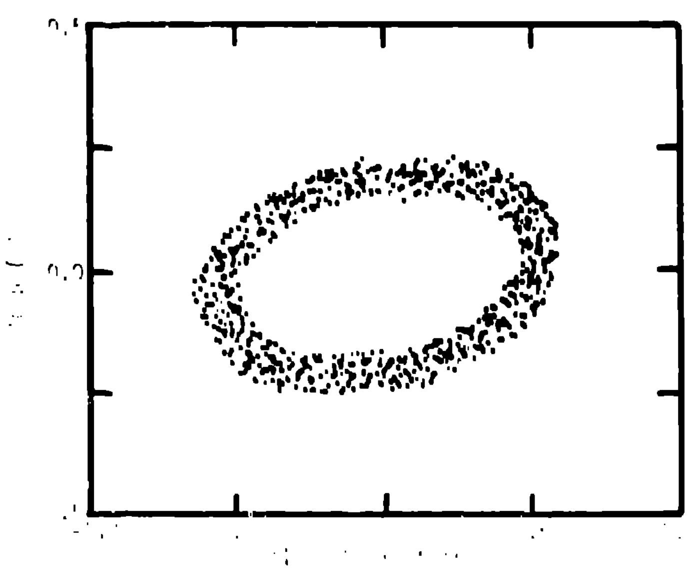

Fig. 5. Longitudinal phase space after 50 turns, at end of injection.

also calculates the transition-γ (GFUN) and initializes arrays used in the space-charge calculation (INTSC). One can see from Fig. 1 that the program has provision to examine more closely the region around transition. The rise of the magnetic field during the acceleration cycle is simulated by specifying the synchronous momentum at the end of each advance between nodes (PFUN). The transport matrices do not depend on momentum.

Typical simulations such as the one summarized in the next section take about four hours on the VAX 11/750 system.

Results of a Typical Simulation

Figures 3-5 show the injected beam of 1000 particles with total electric charge of 10^{11}e. The ring being simulated is shown in Fig. 2. Initially the rf voltage and phase were varied in such a way to prevent a rise in Laslett tune shift at low energies. By 500 turns, the voltage/turn had risen to 14.25 MV, The phase φ changed slowly until transition where it was switched to (π - φ).

The longitudinal space-charge distribution and kick are shown in Fig. 6 at 500 turns. The maximum space-charge kick represents ~0.4% of the rf kick. Transition occurred during the 1330th turn. The longitudinal phase-space distribution becomes quite narrow (Fig. 7). Maximum space-charge kick rose to 1.1% of the rf kick. After transition, the rf phase increased slowly toward π at the end of the cycle. Nothing dramatic happens. Figure 8 shows longitudinal phase space at 2000 turns (E = 16.9 Gev).

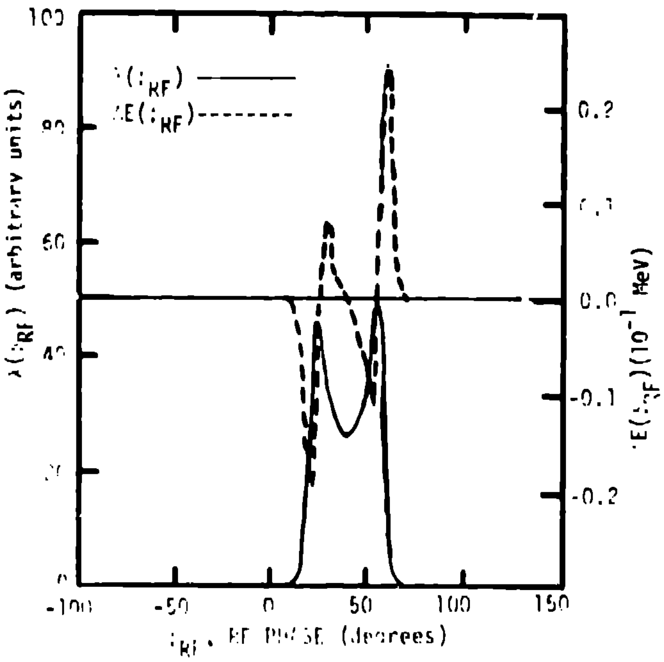

Fig. 6. Longitudinal space-charge density and space-charge energy kick vs rf phase after 500 turns.

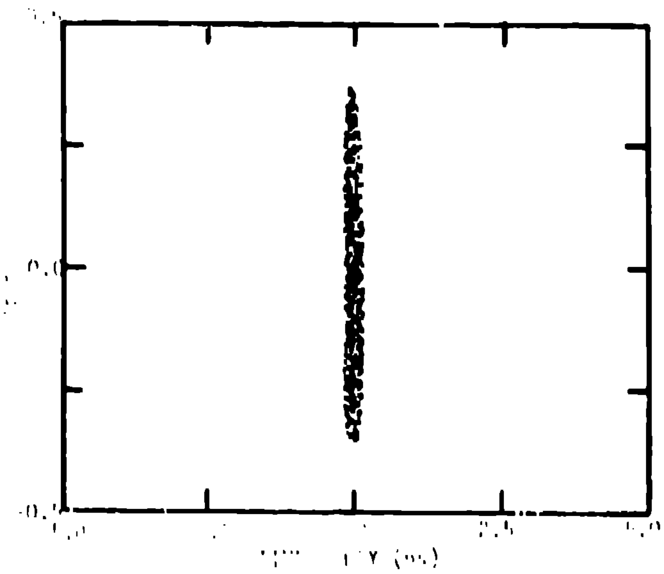

Fig. 7. Longitudinal phase space at transition, 1330 turns.

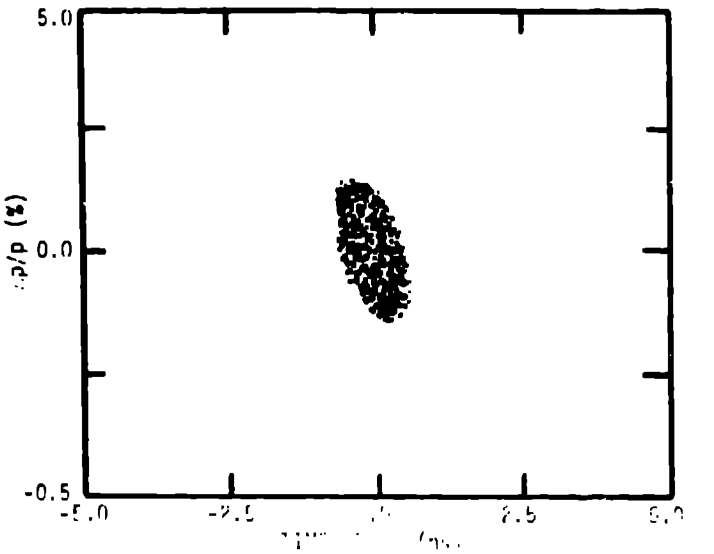

Fig. 8. Longitudinal phase space after 2000 turns.

Acknowledgments

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