A REFERENCE DESIGN FOR LAMPF II

Henry A. Thiessen
Los Alamos National Laboratory, Los Alamos, New Mexico 87545

Summary

A reference design for the 32-GeV LAMPF II proton accelerator is proposed. This design consists of a 30-Hz rapid-cycling synchrotron with a dc stretcher. A superperiodicity 5 design with dispersion-free straight sections is suggested for both machines. Beam-dynamics calculations are partially complete and rf requirements are given. Apertures are calculated for 2×10^{13} protons per pulse (100 μA average current). No significant problems are observed at any time in the cycle in a longitudinal beam-dynamics simulation including space charge.

Introduction

LAMPF II is to be a high-intensity proton accelerator for use as a neutrino, muon, pion, kaon, hyperon, and antiproton factory. An energy of 32 GeV and a beam current of 100 μA were chosen as design targets. Users of the machine fall into two classes, those requiring short spills and those requiring nearly 100% duty factor. A solution that includes a synchrotron and a stretcher ring in the same tunnel provides both types of beams simultaneously.

The high current naturally leads to a number of design constraints. The most important of these is to minimize losses. Our design goal is losses of less than 0.5% from all causes, with all but 0.1% spilled on collimators that are designed for easy remote handling.

The requirement for efficient slow extraction leads naturally to long straight sections in the stretcher. To fit the accelerator and stretcher into one tunnel, the same shape is required of both rings. The straight sections can be used for the rf system of the accelerator if the superperiodicity is high enough and if the dispersion in these straight sections is low enough. Dispersion-free straight sections should eliminate the problem of synchrotron-betatron oscillations in the accelerator.

Many of the low-energy secondary beam lines require a microstructure of the proton beam to be used for particle identification. We require a basic microstructure of 1 ns with 16-ns spacing for the output of the stretcher. The LAMPF II machines are designed to be injected by the existing LAMPF 797-MeV H^- beam and to fit on the LAMPF site. A layout drawing is shown in Fig. 1.

The Lattice

The most straightforward way to obtain zero-dispersion straight sections is to use arcs that have integer tune. Such arcs can be made with the second-order achromats of K. Brown.[1] The straight sections determine the tune and also the matched beta functions of the lattice. If, in addition, the beta functions of the straight sections match the beta functions for a single cell of the arcs, then efficient use is made of the magnets of the arcs. The chromaticity of the ring is adjusted by sextupoles in the arcs. Two families of sextupoles in the arcs were found to be sufficient for correcting the chromaticity of the complete machine.

The reference design for the accelerator has a superperiodicity of 5. The arcs are made up of combined-function dipoles. All cells are symmetric about their midpoints so that alpha is zero at the entrance and exit of each cell by symmetry. Each arc consists of 10 cells, with a tune of 1/5 per cell. Each cell consists of four dipoles in a -D-F--F-D- arrangement. A 1.2-T maximum field was chosen for all dipoles.

Each straight section of the accelerator consists of three cells; each cell is a quadrupole triplet. The tune of each cell is 0.169 horizontal and 0.109 vertical, resulting in an overall tune for the accelerator of 14.19 horizontal and 12.29 vertical. Matched beta and dispersion functions for one superperiod of the accelerator are shown in Fig. 2.

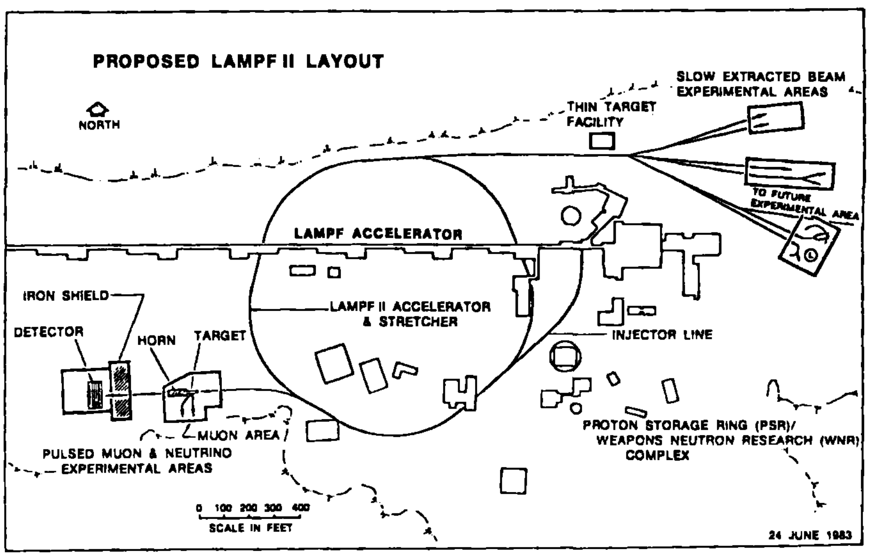

Fig. 1. LAMPF II site layout.

The stretcher consists of dipoles that are identical (except for aperture) to the dipoles of the accelerator. The straight sections of both machines are the same length (60 m). The basic superperiodicity of the stretcher is 1. One of the straight sections of the stretcher has a high-beta section designed for the electrostatic septum of the extraction system; one has a layout appropriate for a Lambertson-type septum for the extraction system; and the remaining three straight sections are identical and determine the tune and matched beta functions for the stretcher. The slow-extraction system is of the 1/2-integer resonance type and is described in more detail in a report by E. Colton.[2]

The aperture of the accelerator is safely larger than the minimum needed to transport the phase space. We chose the aperture on the basis of a Laslett tune shift of 0.25, with a ratio of 2:1 between horizontal and vertical phase space, and then doubled the phase space in both planes as a safety factor. In addition we included an allowance, ±0.5 cm vertical and ±1.0 cm horizontal, for closed-orbit distortion. In the vertical dimension, an additional 0.5 cm has been allowed for a vacuum chamber or rf shield. The resulting good field region required is 5.7 cm vertical and 9.2 cm horizontal. A cross-section drawing of an F dipole is shown in Fig. 3.

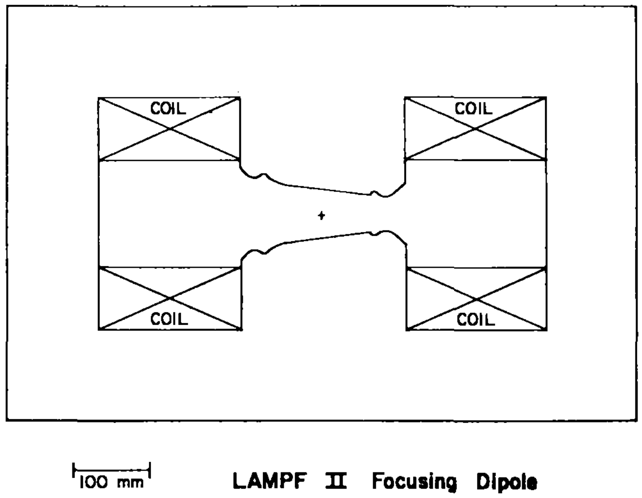

Fig. 3. LAMPF II focusing F dipole.

Magnet and rf Power Systems

A number of possibilities for a resonant power supply for the accelerator magnets are under consideration. We require a constant field for 1 ms for injection. One possibility provides 30 Hz with 4% of 150 Hz to give a flat bottom and flat top to the magnet field. A second possibility, suggested by W. Praeg,[3] uses switching to provide a constant field for injection, a 20-Hz rise, and a 60-Hz fall. This field program minimizes rf requirements.

The rf system must be tunable from 50.31 MHz at injection time to 59.74 MHz at full energy. The harmonic number for the reference design is 216 (the circumference is 1082.7 m). The rf requirement for acceleration is shown in Fig. 4. For a 30-Hz plus fifth-harmonic magnet power supply, a peak voltage of 14 MV per turn is required.

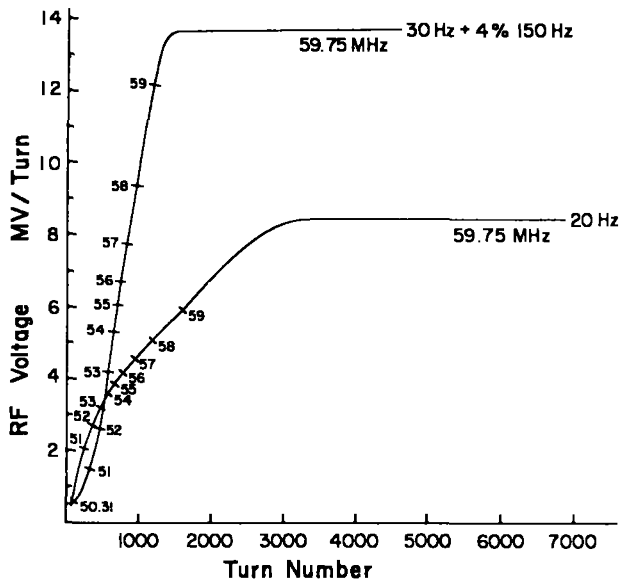

Fig. 4. rf voltage requirements for LAMPF II accelerator vs number of turns for two different magnet-field programs. The rf frequency is shown by tick marks on the curves.

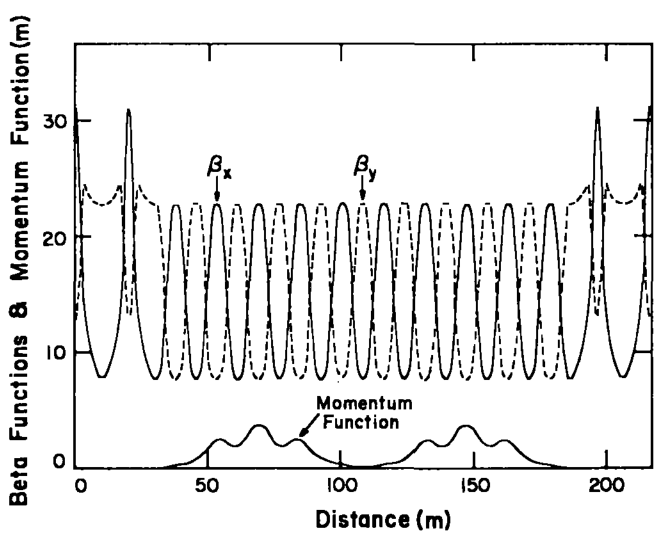

Fig. 2. Beta and dispersion functions for one superperiod of LAMPF II accelerator.

We propose to provide 60 rf cavities. This number was chosen on the basis of scaling the Fermilab booster rf system, with the assumption of the same energy stored in each tuner as in the Fermilab design. The required voltage per cavity is 240 kV. The lattice for the accelerator has room for up to 90 cavities, each 2 m long, so that up to one-third of the straight-section length may be used for injection, extraction, and diagnostics.

Experimental work on the ferrite tuning system is in progress. We reported that a prototype cavity with a tuner had achieved 8% tuning range with a Q of 1500 at the Santa Fe Conference.[4] A new, larger cavity with toroidal ferrite has been assembled. First results on the new cavity are to be reported by R. Carlini.[5]

Injection

We propose to use the existing 797-MeV H^- beam from LAMPF. To reach a Laslett tune shift of 1/4, we must increase the transverse phase space from 0.5 to 18 π mm-mrad. The longitudinal phase space also must be increased by a large factor. The method adopted is symmetric in the three planes, x-x′, y-y′, and E-ϕ. We will arrange for steering magnets to offset the injected beam from the closed orbit. By slowly adjusting the steering magnets and the rf phase of the synchrotron, it will be possible to fill the three two-dimensional phase ellipses uniformly, or with some other prescription if required. Some care must be taken to see that the horizontal betatron tune, the vertical betatron tune, and the synchrotron tune are not commensurate during injection. Also, the filling of phase space will be quasi uniform because only 112 turns are available for injection during the nominal 500-μs output pulse of LAMPF.

The longitudinal injection requires further discussion. The LAMPF microstructure is 201.25 MHz, whereas we propose synchronous injection into a preexisting stable bucket in LAMPF II at 50.3125 MHz. To accomplish this, we propose to chop the LAMPF beam to one-fourth of the normal repetition rate and to prebunch at least 1.6 micropulses of charge into 1 micropulse in the Cockroft-Walton injector. This procedure will allow a 30-Hz repetition rate for LAMPF II at 100-μA average current. Since the normal LAMPF repetition rate is 120 Hz, three-fourths of the LAMPF beam will be available for other users when LAMPF II comes into operation. This will allow us to keep our commitments to the Proton Storage Ring (PSR)/Weapons Neutron Research (WNR) facility, to isotope production, and to a portion of the 800-MeV experimental program.

The stable bucket of LAMPF II is approximately ±0.12% dP/P by ±6 ns (7.5 π V-s). The output of LAMPF is approximately 0.15% dP/P by 0.05 ns. A bucket rotator that reduces significantly the momentum spread is required in order to allow fine control of the longitudinal phase space and to make the injection process insensitive to the occasional large momentum fluctuations of the LAMPF beam.

Tracking studies have been performed with the voltage program of Fig. 4. The transverse phase space at

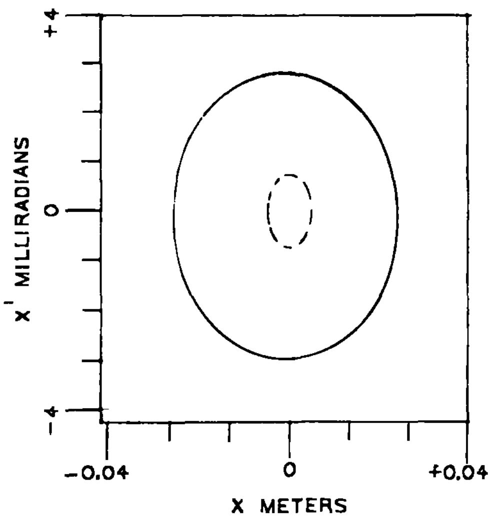

Fig. 5. The transverse phase space at injection (solid curve) and at extraction (dashed curve) using a 30-Hz − 0.04 × 150-Hz-magnet waveform and the rf program of Fig. 4.

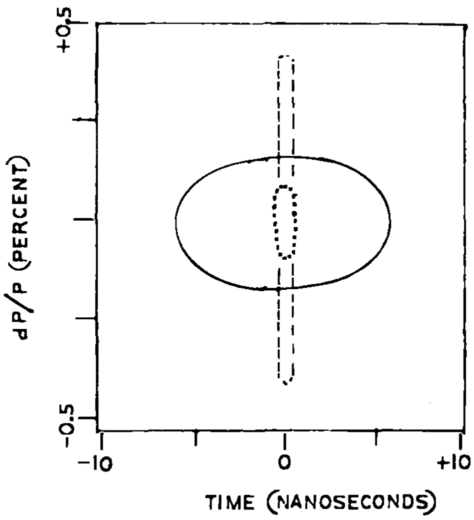

Fig. 6. The longitudinal phase space at injection (solid curve), at transition (dashed curve), and at extraction (dotted curve) using a 30-Hz − 0.04 × 150-Hz-magnet waveform and the rf program of Fig. 4.

injection and at 32 GeV are shown in Fig. 5. The longitudinal phase space is shown in Fig. 6. These studies were done in the absence of space charge. A simulation including longitudinal space charge is reported by J. Warren.[6]

Beam Dynamics

There are a number of beam-dynamics problems that must be handled in the LAMPF II design. The transverse space charge (Laslett tune shift) dominates considerations of aperture size. Synchrotron-betatron coupling can give trouble because of the high synchrotron frequency required early in the cycle. An rf program that minimizes the difficulties early in the cycle has been developed. The basic idea is to start at a low voltage and maintain the bucket area constant. There is some advantage to gradually increasing the bucket area when nonlinearity and space charge are included, so we have chosen to increase the bucket area by 0.1% per turn. The synchrotron phase increases as acceleration starts. After the phase reaches 1 rad, the phase is kept constant, and after the voltage reaches a maximum, the voltage is kept constant. The rf voltage requirements shown in Fig. 4 were calculated with this prescription.

In Fig. 7 we show the Laslett tune shift, the bunching factor, and the synchrotron frequency for the first part of the acceleration cycle. Tests of the stability of the longitudinal motion were made. It was demonstrated that no particles are lost with a longitudinal phase space twice as large as the nominal injection phase space.

Work in Progress

Tracking has been performed using the program DIMAT written by R. Servranckx.[7] Both the accelerator and stretcher lattices are stable for a few hundred turns with the injection phase space. However, if a noticeably larger phase space is used, or if we concatenate a large portion of the lattice and obtain a lumped second-order transformation, or if we use dipoles containing combined-function sextupoles, then an instability appears. We believe that all these troubles are not a fundamental problem with the lattice but result from truncation at second order. Tracking with

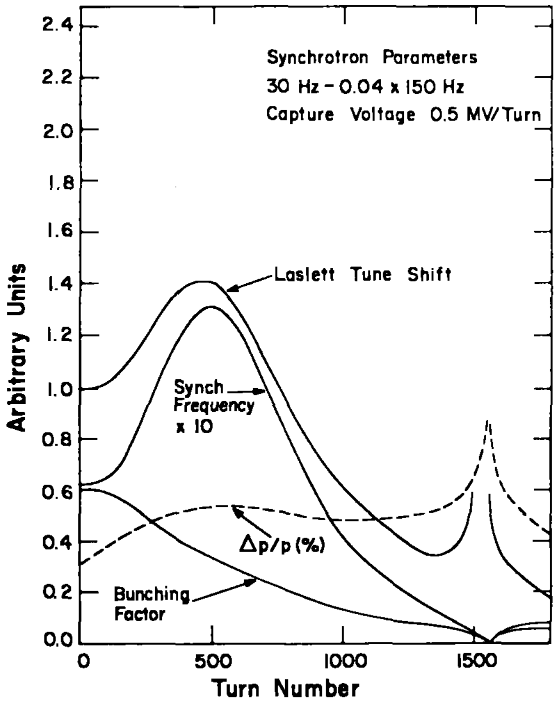

Fig. 7. Synchrotron parameters for the LAMPF II accelerator at 30-Hz with 4% fifth-harmonic program. The Laslett tune shift is normalized to 1 at turn 0. The synchrotron frequency, bunching factor, and momentum spread (full width) are given in the units indicated.

the symplectic formalism of A. Dragt,[8] or with a minimal set of third-order terms to make the formalism symplectic to one higher order, eliminates these problems. Publications on these subjects will be available in the near future.

A number of topics have not been covered because work has not progressed to the point where discussion is possible. These include transverse-space charge effects studied with the program MISAR,[9] bandwidths for nearby betatron resonances in the presence of field errors, and longitudinal coherent instabilities. Work in these areas will be reported as soon as possible.

Finally, there may well be substantial advantages for the rf system if a two-stage accelerator is adopted. This approach also may have political advantages. We presently favor a booster of the same circumference as the second-stage accelerator with single-turn extraction and injection between stages. A comparative study of the two approaches is under way.

Conclusions

We have shown that it is possible to design a 32-GeV 100-μA proton synchrotron that fits on the LAMPF site and makes use of the existing H^- beam. No problems have been encountered that would lead us to believe that significant losses of beam will occur. Our present design has conservative apertures and bucket area throughout the cycle. We have demonstrated that the accelerator will transmit beam with two times larger phase space than required in the x-x′, y-y′, or E-ϕ dimensions. This leads to a machine with apertures comparable to existing machines such as the Brookhaven Alternating Gradient Synchrotron (AGS) or the CERN Proton Synchrotron (CPS). Undoubtedly, we will be able to tighten the design and reduce costs as we gain confidence in our ability to calculate losses.

References

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