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LATTICE FOR A 1.1-GeV 500-μA FAST-CYCLING PROTON SYNCHROTRON*

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Summary

A very-high-intensity proton synchrotron lattice has been designed for a spallation neutron-source system. The synchrotron is to accelerate a beam of 6.25 × 10^{13} protons from 200 MeV to 1100 MeV in 15 msec. A detailed discussion on the synchrotron is described elsewhere[1]. The proposed lattice is in modular form of storage-ring type consisting of normal cells, dispersion-suppressor cells, and matching and straight-section cells. Due to the fast repetition rate, the maximum required energy gains per turn is approximately 100 keV, and this in turn needs approximately 20 meters or more of straight sections for the acceleration cavities. Such spaces for the cavities are to be provided by the insertion straight section.

One of the important concerns for high-intensity, high-rep-rate (50 pulses/sec) machines is stability of the beam. Considerations of the transverse space-charge limits and the transverse-stability criterion favor a high-tune machine over a low-tune machine of the same circumference. This high-tune concept makes the average beta function throughout the lattice smaller and at the same time the momentum dispersion function smaller compared to a low-tune machine. The smaller dispersion functions enables operation of the machine with a larger momentum bite, and a large momentum spread to alleviate the longitudinal instability. For these reasons, we made the tune as high as possible by making the cell length as short as possible.

The lattice proposed here consists of four sectors, and each sector is made up by three FODO normal cells, four dispersion suppressor cells, and four matching and straight section cells. Then the total of 44 cells with approximately 90°/cell phase advance would make the natural tune of the machine to be near 11. However, a working-point consideration prefers ν_x = 10.3 and ν_y = 11.3.

Lattice

Normal Cell:

A standard FODO cell at ~ 90° phase advance/cell is shown in Figure 1. The polarities of the focussing elements can be changed depending on the plane of extraction. The lattice elements description is given in Table I.

Dispersion Suppressor Cell:

Since the normal cells would have a phase advance of ~ 90°/cell, a set of two cells with a half of bending magnet strength would eliminate the momentum dispersions. The beta and the eta function variations through these cells are shown in Figure 2. The bending magnets M1's are the half-length magnets.

Matching and Straight Section Cells:

The optical properties of beam entering these cells would have the momentum dispersion function suppressed, therefore the minimum requirement for the matching cells for sufficient straight sections per sector is to match the beta functions to the sector which follows. However we have opted to make the beta-functions through the straight sections relatively small compared to the average beta-function. This is to alleviate the transverse instability criterion. Up to this point the focussing elements in the normal and dispersion suppressor cells have the same strengths in each polarity. That is to say all F-type quadrupoles have some gradient and all D-type quadrupoles have the same strength. To facilitate the matching, we remove this constraint for the quardupoles in the insertion area. We define the insertion quardrupoles starting from the last quad in the dispersion supressor cell, and the notations used to signify these are the use of numerical nomenculture. Figure 2 shows the elements layout of a half of a sector, it shows that the matching cell is made of a doublet and the straight section cells is made of a triplet. In case the accelerator needs more straight sections for the rf system, then the triplet cell can be repeated as many times as required.

Injection and Extraction Optics:

If the transverse phase space acceptances are assumed to be ϵ_H = 500 π mm mr and ϵ_V = 300 π mm mr, then extraction and injection favor in the vertical direction. This is to take advantage of the smaller vertical acceptance which results in a smaller vertical beam size. The straight sections suitable for the injection and extractions are the matching cell near the end of a sector and its following straight section for the injection. For the extraction the prefered straight sections are the mirror image of the injection region located at the beginning of a sector.

In order to match the injection orbit and the transverse phase space of the incoming beam and the synchrotron, we distort the central orbit of the machine to place the acceptance phase space ellipse at the H^- stripper as shown in Figure 3. To do this, we employ a set of four hamper magnets. Figure 3 also shows the distorted orbit and the apertures needed to contain the injection beam. The injection septum magnet places the incoming H^- beam such that when the H^- ions are stripped to make proton beams, the proton beam orbit is to coincide with the circulating beam.

For the extraction, the ejection septum magnet is to be placed in the matching straight section at the beginning of a sector, and a set of kicker magnets is to be located in a straight section cell preceeding the matching cell. Figure 4 shows the extraction orbit and its associated beam envelope assuming the full aperture extraction. The total length of the kicker magnet is 2.5 m and its strength is about 700 Gauss which results to about 30 milliradian kick at 1.1 GeV. A 2.1 m septum magnet with the field strength of 8 kG would result in a bending of 278 milliradians, and would enable to clear the next lattice element by displacing the orbit by 60 cm.

Reference

1. Y. Cho, et. al "Conceptual Design of a 1.1 GeV 500 μA Fast Cycling Proton Synchroton" in these proceedings.

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