LATTICES FOR HIGH-POWER PROTON BEAM ACCELERATION AND SECONDARY BEAM COLLECTION AND COOLING*

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Abstract

Rapid cycling synchrotrons are used to accelerate high-intensity proton beams to energies of tens of GeV for secondary beam production. After primary beam collision with a target, the secondary beam can be collected, cooled, accelerated or decelerated by ancillary synchrotrons for various applications. In this paper, we first present a lattice for the main synchrotron. This lattice has: a) flexible momentum compaction to avoid transition and to facilitate RF gymnastics b) long straight sections for low-loss injection, extraction, and high-efficiency collimation c) dispersion-free straights to avoid longitudinal-transverse coupling, and d) momentum cleaning at locations of large dispersion with missing dipoles. Then, we present a lattice for a cooler ring for the secondary beam. The momentum compaction across half of this ring is near zero, while for the other half it is normal. Thus, bad mixing is minimized while good mixing is maintained for stochastic beam cooling.

INTRODUCTION

To produce and accumulate high-power secondary beam, such as antiproton and rare nuclear isotopes, a main rapid cycling synchrotrons is often used to accelerate high power proton or heavy ion beams to energies of tens of GeV to strike a target [1,2]. Subsequently, ancillary synchrotrons are used to collect, accumulate, cool, accelerate or decelerate the secondary beams [3,4,5]. In this paper, we present lattices for the main proton synchrotron and ancillary secondary-beam synchrotrons.

MAIN SYNCHROTRON

A high-power synchrotron of several tens of GeV is challenged by issues like transition crossing, collimation and loss control, and fast acceleration [1]. We choose a Flexible Momentum Compaction lattice (FMC) [6,2] with adequate straight space to house collimation, RF, injection, extraction, and diagnostics.

FMC Module Structure

A FMC lattice without negative bending requires negative dispersion at part of the bending dipoles. Fig. 1 shows the lattice module consisting of three FODO cells with missing dipole in the middle cell. The horizontal phase advance of about 90^o per cell excites dispersion oscillation so that high dispersion occurs at locations of missing dipole.

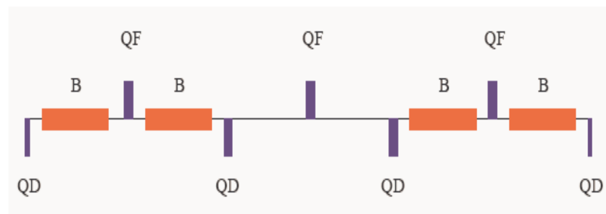

Figure 1: FMC lattice module with missing dipoles.

Lattice Layout and Functions

Lattice for a 800 MeV to 25 GeV proton synchrotron is designed by using the module shown in Fig. 1. The lattice has a super periodicity of 4. Each arc section consists of four modules. The horizontal (H) phase advance is near but not equal to 270^o across each three-cell module. The H phase advance across the four-module arc is exactly 6π, so that the dispersion is completely suppressed outside of the arc. The momentum compaction factor can be easily adjusted by varying the strength of the quadrupole families in the arc.

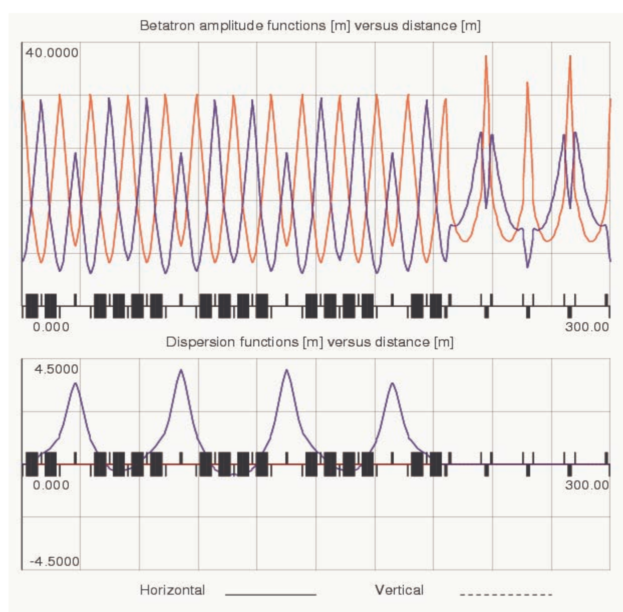

Figure 2: Main synchrotron lattice functions for one super-period.

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Fig. 2 shows the optical functions in a super-period. The FODO structure easily accommodates optical correction including closed orbit, transverse coupling, chromaticity, and high-order corrections. Momentum collimation is performed in the high-dispersion missing-dipole region.

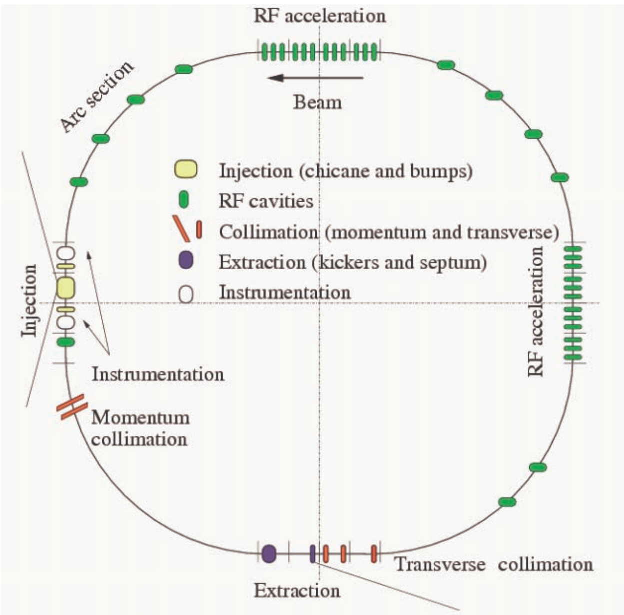

Figure 3: Schematic layout of the main synchrotron.

Table 1 Primary parameters of the main synchrotron.

Ion type	Proton
Kinetic energy(GeV)	0.8-25
Ring circumference(m)	1200
Lattice	FMC FODO/triplet
Arc lattice	4 FODO modules
Arc module lattice	3-cell / missing dipoles
Arc length (m)	218.8
Arc horizontal phase advance (degree)	3x360
Arc module length (m)	54.7
Straight section lattice	4 triplets
Straight section length (m)	81.3
Uninterrupted drift length in straight (m)	15
Uninterrupted drift length in arc gap (m)	4.6
Nominal betatron H tune	15.85
Nominal betatron V tune	13.80
Transition gamma	31.6
Natural H chromaticity	-17.9
Natural V chromaticity	-19.4
Maximum dispersion (m)	4.0
Maximum H/V β (m)	31.6/38.0

Each dispersion-free straight contains four quadrupole triplets and four uninterrupted drifts of 15 m each, facilitating low-loss injection and efficient collimation (Fig. 3). Table 1 indicates the primary lattice parameters.

Tune-space Working Point

With a 4-fold symmetry, Fig. 4 indicates the working point along with resonance lines up to the 4th order. Space-charge tune spread of up to 0.2 can be accommodated.

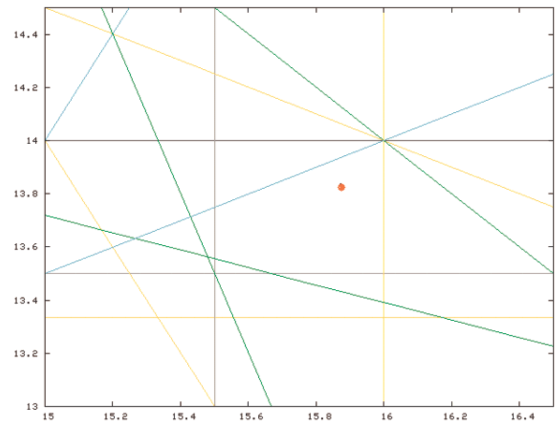

Figure 4: Tune diagram (ν_x,ν_y) with resonance lines up to the 4^{th} order.

SECONDARY-BEAM COLLECTION

The energy of the secondary beam produced at the target is assumed to be 3.5 GeV. This beam is transported to the collector ring, injected and stacked in the horizontal phase space. The circumference of the collector ring shall be such that the revolution period of the collector ring is equal to a quarter of the main ring's (i.e. 291.55 m). The collected beam can then be injected into and stacked in a cooler ring of the same circumference.

Collector and Cooler Ring Requirements

By choosing the horizontal tune of the ring close to 1/4 integer one can efficiently stack 4 turns into the four corners of the transverse phase space. Since the revolution period is 1/4 of the main ring's, 12 bunches of the secondary beam are coalesced into three buckets of the collector ring.

Fast cooling is needed to reduce the emittances of the secondary beam. To facilitate stochastic cooling, a split-function lattice is adopted for the ancillary synchrotrons: the phase slip is near-zero between the cooling pick-ups and kickers to minimize the bad mixing, and is normal between the kickers and the next-turn pick-ups [5].

Ring Lattice Structure

To minimize bad mixing, the half ring from the pickups to kickers of the stochastic-cooling system shall adopt FMC lattice structure. As shown in Fig. 5, the right-hand-side of the ring contains four modules of three FODO cells with missing dipoles in the middle cell, same as those used in the main synchrotron. The momentum compaction across this 180^{o} bend is near zero, thus minimizing the bad mixing. The left-hand-side of the cooler ring contains two bending arcs, each containing four FODO cells. The dispersion in the straights between these three arcs is zero. Fig. 6 shows the schematic layout of the cooler ring.

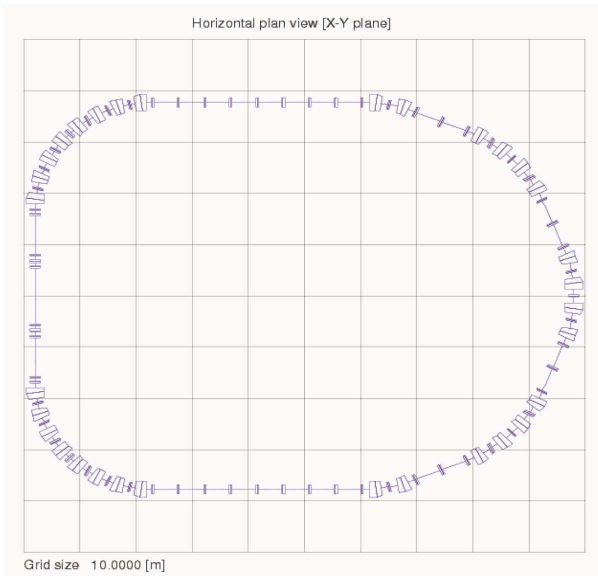

Figure 5: Main magnet layout of the collector and the cooler ring.

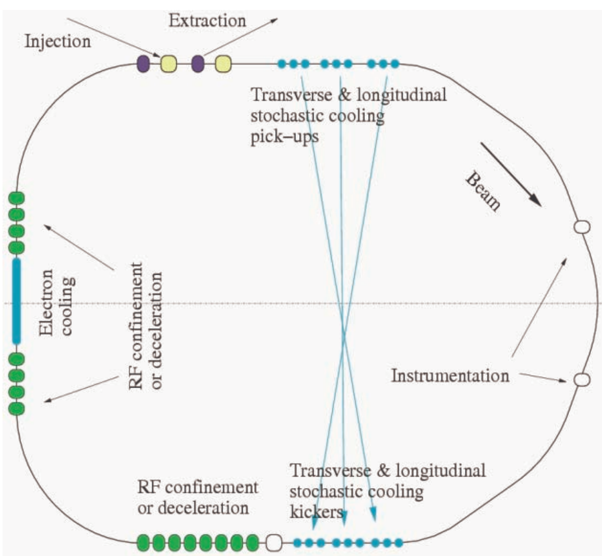

Figure 6: Functional layout of the cooler ring.

Layout and Functions

Fig. 7 shows the lattice of the entire cooler ring. The circumference is 291.55 m. The maximum β– function is less than 16 m across the FODO cells, and is less than 23 m in the triplet section. The lattice super-periodicity is 1. The horizontal phase advance in the arc FODO cell is near but not necessarily equal to 90^{o}. The horizontal phase advance is exactly 6π across the near-zero momentum compaction arc, and is exactly 2π across each of the two normal arcs. Between two arcs of normal FODO cells, there is a long dispersion-free straight section. The Focusing structure in the straight section is triplet, providing long drift space with small beam envelope to accommodate electron cooling devices, and allowing for circumference matching. The two straight sections between the arc with normal and FMC modules are used to house stochastic-cooling pickups and kickers, and to accommodate injection, extraction, and RF systems.

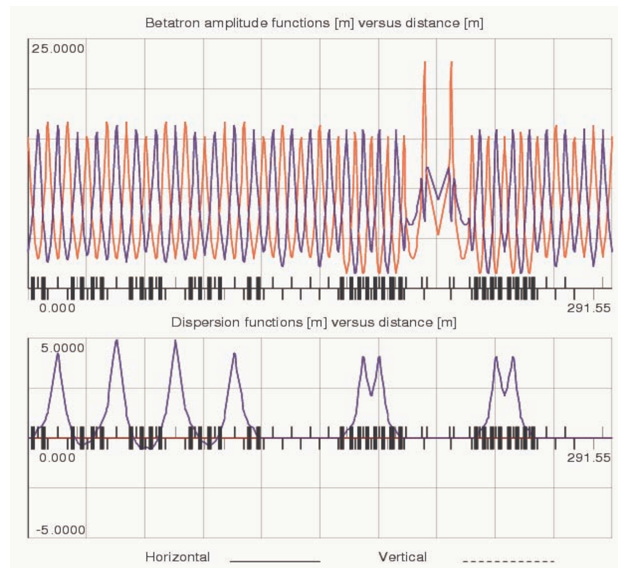

Figure 7: Lattice function of the entire cooler ring.

SUMMARY

Based on arcs of the Flexible Momentum Compaction lattice modules and straights of triplets, we designed the lattice for a high-power rapid cycling synchrotron capable of delivering MW level of proton beam to 25 GeV, addressing major issues like transition crossing and beam loss control. For the subsequent collector and cooler rings for the secondary beams, we designed split-function machines that facilitate beam cooling. An accelerator complex consisting of the main proton synchrotron and several ancillary synchrotrons for secondary-beam collection, accumulation, acceleration and deceleration serves as a powerful secondary-beam factory.

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