AN ANTI-SYMMETRIC LATTICE FOR HIGH-INTENSITY RAPID CYCLING SYNCHROTRONS *

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Abstract

Rapid cycling synchrotrons (RCSs) are used in many high power facilities like spallation neutron sources and proton drivers to accumulate and accelerate proton beams. In such accelerators, beam collimation plays a crucial role in reducing the uncontrolled beam loss. Furthermore, injection and extraction sections often need to reside in dispersion-free regions to avoid couplings; sizeable drift space is needed to house the RF accelerating cavities; long, uninterrupted straights are desired to ease injection tuning and to raise collimation efficiency. Finally, the machine circumference needs to be small to reduce construction costs. In this paper, we present a lattice satisfying these needs. The lattice contains a drift created by a missing dipole near the peak dispersion to facilitate longitudinal collimation. The compact FODO arc allows easy orbit, tune, coupling, and chromatic correction. The doublets provide long uninterrupted straights. The four-fold lattice symmetry separates injection, extraction, and collimation to different straights. This lattice is adopted for the China Spallation Neutron Source (CSNS) synchrotron [1].

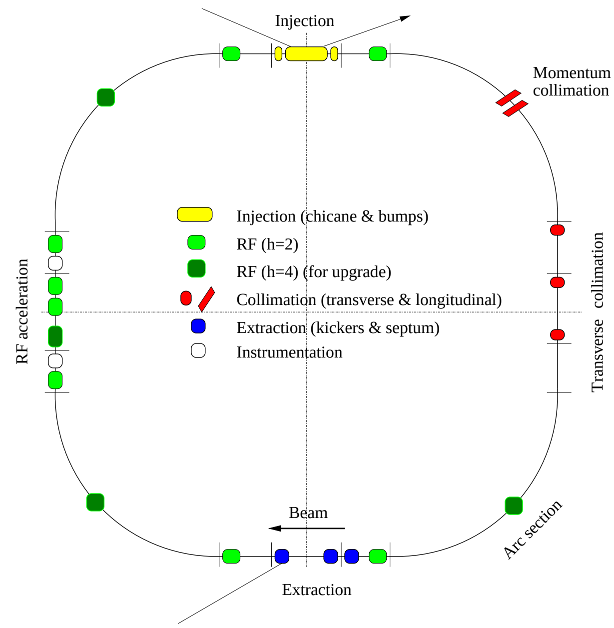

Figure 1: Schematic layout of the CSNS synchrotron.

INTRODUCTION

The backbone of a synchrotron is its lattice, the periodic magnetic structure encountered by the circulating beam [2]. For high-intensity, high-power applications like pulsed spallation neutron sources, the machine lattice must accommodate injection, collimation, RF acceleration, extraction, diagnostics, and possible upgrades (Fig. 1).

In this paper, we first review the lattice choices of some recently designed high-intensity rings including the Spallation Neutron Source (SNS) [3], the Japan High Intensity Proton Complex (J-PARC) [4], and the European Spallation Source (ESS) [5]. Then, we introduce the lattice of the CSNS synchrotron and discuss its properties [1].

LATTICE DESIGN OPTIONS

General Layout

Lattices of high periodicity are preferred to reduce the impact of lower-order resonances on the transverse motion of particles excited by magnetic imperfections. On the other hand, for a ring of moderate circumference, high-periodicity lattices also imply a lack of long, uninterrupted straights to accommodate dedicated functions. As a compromise, modern synchrotrons for high-intensity protons often have a lattice periodicity from 2 to 4. The SNS accumulator ring (AR) has a periodicity of 4 with each straight dedicated to injection, RF, collimation, and extraction, respectively [3]; The J-PARC RCS adopts a periodicity of 3 with injection and collimation sharing a specially shielded straight [4]; The ESS AR plans a periodicity with 3 of injection located in the dispersive arc [5].

The machine's circumference largely is determined by the magnetic rigidity and the space required to accommodate injection, collimation, RF, extraction, diagnostics, and possible upgrades. A large circumference also entails fewer injection turns, reduced foil scattering for H^- injection, and a lower particle-density for better beam stability. Due to economical reasons, the ring is required to be compact. The circumference of the SNS, J-PARC RCS, and ESS rings range from about 250 to 350 m.

FODO structures require modest quadrupole gradients, and the alternating amplitudes of the transverse beam easily accommodate magnetic-correction systems acting selectively on the two transverse directions. A FODO lattice also is relatively insensitive to errors in quadrupole tuning. On the other hand, a lattice consisting of dou-

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blets/triplets has the advantage of encompassing long, uninterrupted straights for flexible injection and optimal collimation. Synchrotrons of this structure also have vacuum chambers with fewer segments and joints [5]. The J-PARC RCS contains FODO cells of different lengths at different sections of arcs and straights [4]; The ESS uses triplets across the entire ring; The SNS ring uses FODO arcs and doublet straights [3].

Dispersion Suppression

Dispersion-free regions are preferred to house RF cavities, transverse collimation, extraction, and sometimes injection systems. Dispersion in the straight can be suppressed either by judiciously choosing the horizontal phase advance in the arc, or by dedicated dispersion-suppression insertions. The SNS AR suppresses dispersion by evenly filling 2π horizontal phase with dipoles (Fig. 2). Each arc consists of four FODO cells each with 90° horizontal phase advance. The advantage of this scheme is that the arc is compact. Its disadvantage is that the peak dispersion in the arc is higher than the matched value [2].

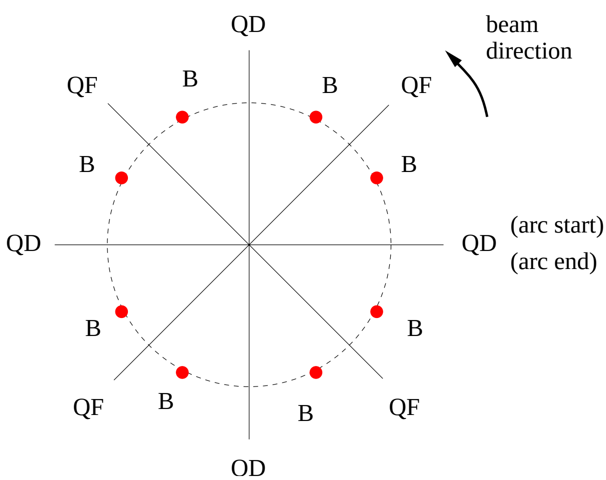

Figure 2: Magnet arrangement in the horizontal phase space for the SNS ring to suppress dispersion.

The J-PARC RCS suppresses dispersion using three-cell modules with two missing-dipole gaps in the middle (Fig. 3). The primary scrapers for longitudinal collimation are located in the middle of the module where the focusing quadrupole (QF) is split and the dispersion is the maximum. The momentum compaction is also low raising the transition energy of the machine [4].

Injection Arrangement

ISIS and ESS inject at a high-dispersion region [5]. The injection dipole, part of the periodic lattice structure, separates the injecting and circulating beams without using a septum. Thus, the arrangement of the injection magnets is simplified. The high dispersion at injection also facilitates the collection of the momentum halo. Contrastingly, SNS and J-PARC inject in a zero-dispersion straight region

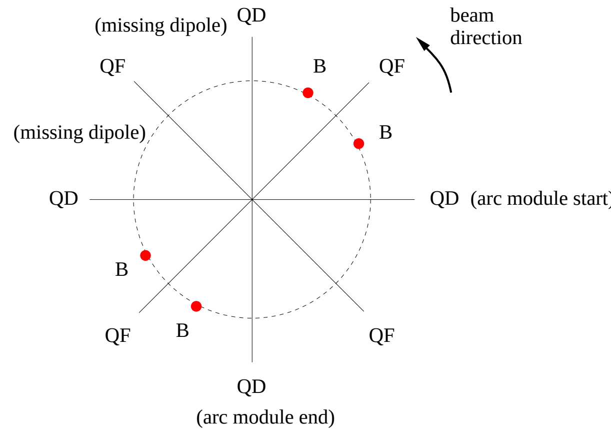

Figure 3: Magnet arrangement in the horizontal phase space for the J-PARC RCS to suppress dispersion.

thereby allowing independent control of phase-space painting both transversely and longitudinally [2]. The injection process is more tolerant to deviations in linac energy. SNS, with dc magnets, uses the doublet structure to create a 12.5 m long uninterrupted straight to contain the injection chicane for the 1 GeV beam [3]. A combined dipole-quadrupole magnet focuses two waste beams (H^0 and H^-) to the injection dump. J-PARC RCS uses split-cores ramping dipoles for the chicane bump where, in between the split cores, the second foil is placed to strip and combine the H^0 and H^- beams to the dump [4].

Longitudinal Collimation Arrangement

Longitudinal collimation is crucial to an RCS where significant beam loss is expected at the beginning of the ramp. At ISIS, a highly efficient (about 95%) momentum collimation is performed by collimators located in a 5 m section [6]. J-PARC RCS uses a primary scraper located at the maximum dispersion area and secondary collectors in the dispersion-free straight. SNS, where the ring does not ramp, uses beam-in-gap kicker for longitudinal cleaning.

CSNS ANTI-SYMMETRIC LATTICE

The CSNS is designed to accelerate proton beam pulses from 81 MeV (higher for phase II) to 1.6 GeV kinetic energy at 25 Hz repetition rate. The accelerator is designed to deliver a beam power of 120 kW with the upgrade capability of up to 500 kW (230 MeV linac energy) [1].

As shown in Fig. 4 and Table 1, the CSNS adopts a hybrid structure with FODO arcs and doublet straights. The lattice superperiodicity is 4 (Fig. 1). The 9 m long uninterrupted drift houses the entire injection at 81 MeV.

As shown in Fig. 5, the dispersion is suppressed by using two groups of 3 half-cells (90° horizontal cell phase-advance) located on each side of a missing-dipole half-cell. The arc is compact, and the single missing-dipole gap near the maximum dispersion location is ideal for placing momentum collimators (Fig. 6). The straight optics is anti-symmetric with respect to its center (Fig. 4). With four

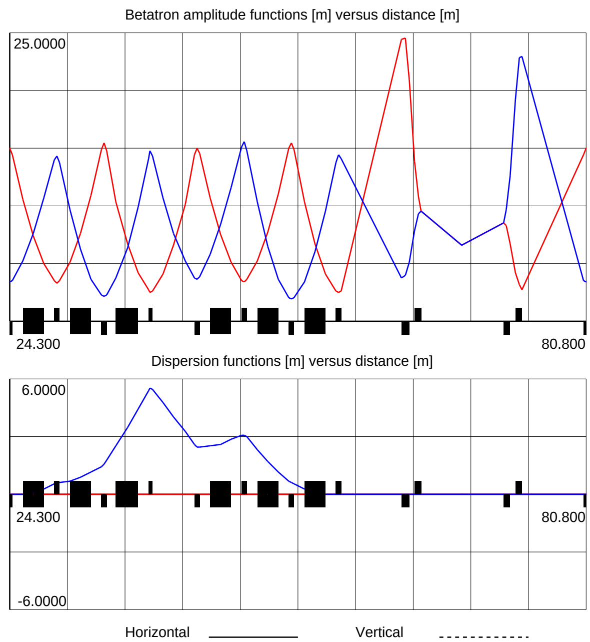

Figure 4: CSNS synchrotron lattice functions.

Table 1: CSNS primary lattice parameters.

Circumference [m]	230.8
Injection energy [MeV]	81 – 230
Extraction energy [GeV]	1.6
Lattice superperiod	4
Lattice type	antisymmetric hybrid
Arc structure	single-gap, 7 FODO cell
Straight structure	2 doublets
Superperiod arc length [m]	32.4
Superperiod straight length [m]	25.3
Straight drift length [m]	9, 2×6
Transverse tunes	(5.82, 5.80)
Natural chromaticity	(−6.6, −7.3)
Transition energy, γ_T	4.9
Maximum dispersion [m]	5.5
No. of main dipoles	24
Dipole magnetic field [T]	0.16 – 0.98
Dipole gap height [mm]	178
No. of main quadrupole	48
No. of chromatic sextupole	16
No. of trim quadrupole	32
No. of multiple-coil correctors	32

families of chromatic sextupoles, the off-momentum optics is satisfactory. The beam-dynamics properties are discussed in Ref. [7].

SNS-type injection is planned with 4 chicane dipoles, 8 painting dipoles, and two septum magnets. We consider using dc chicane magnets for simplicity, and using programmable painting bump magnets to displace the orbit avoiding excessive foil hits [8].

Depending on the achievable gradient, some RF cavities

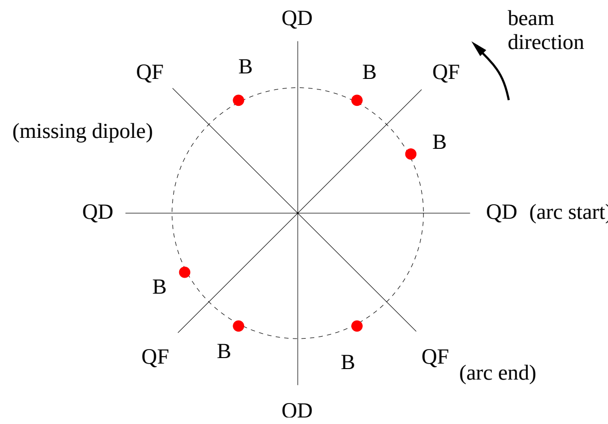

Figure 5: Dispersion suppression with a single missing dipole shown in the horizontal phase space.

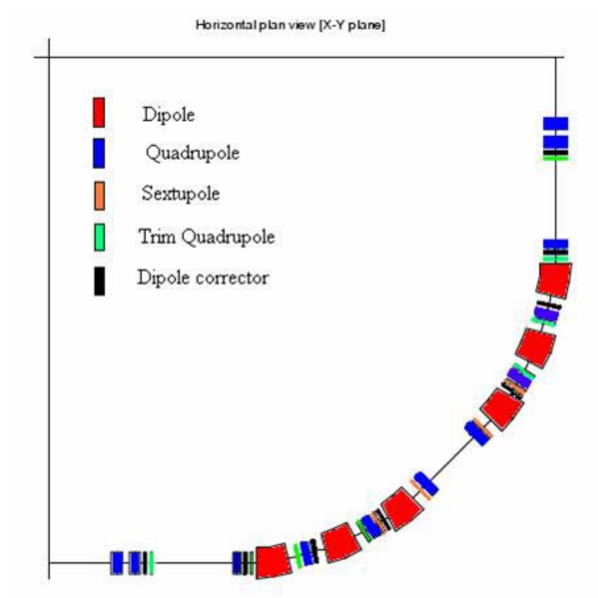

Figure 6: Magnet layout in the CSNS RCS superperiod.

planned for phase II may be placed in the missing-dipole locations of non-collimation sections. Due to the small synchrotron tune and distributed phase, we do not expect noticeable synchro-betatron coupling. However, the cavity bore radius must be large enough to avoid beam loss.

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REFERENCES

[1] CSNS Conceptual Design Report (IHEP, China, 2005)
[2] J. Wei, Rev. Mod. Phys. **75** (2003) 1383
[3] J. Wei et al, Phys. Rev. ST-AB, **3** (2000) 080101
[4] J-PARC Accelerator Technical Design Report (JAERI/KEK, Japan, 2002)
[5] ESS Project Technical Report (ESS Council, 2002)
[6] C.M. Warsop, AIP Conf. Proc. 448 (1998) 104
[7] S. Wang et al, these proceedings
[8] J.-Y. Tang et al; J. Wei et al, these proceedings