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FODO/DOUBLET LATTICE FOR THE SNS ACCUMULATOR RING*

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Abstract

Requirements of minimum beam loss for hand-on maintenance and flexibility for future operations are essential for the lattice design of the Spallation Neutron Source (SNS) accumulator ring. In this paper, we present a hybrid lattice that consists of FODO arcs and doublet straights, emphasizing injection and collimation optimization and flexibility, split tunes for coupling control, sextupole families for chromaticity control, and compatibility to future upgrades.

1 INTRODUCTION

As a key component of the Spallation Neutron Source (SNS) Project, the accumulator ring will collect the proton beam from the SNS linac at an intensity of 2×10^{14} per pulse at 60 Hz for a total power of 2 MW, far exceeding existing facility performance. Requirements of minimum beam loss for hand-on maintenance and flexibility for future upgrade are essential for the lattice design [1].

Lattices used in typical high-intensity proton rings have either a FODO structure (AGS Booster [2], IPNS Upgrade [3], Japanese Hadron Facility (JHF) ring [4], previous SNS ring [5], etc.) or a doublet/triplet structure (ISIS [6], ESS [7], etc.). A FODO lattice structure has the advantage of relatively low quadrupole gradients, relatively smooth lattice function variations, and easily implemented chromatic and resonance corrections. However, the uninterrupted drift space is often short and not desirable for injection and collimation arrangements. Moreover, possible lattice mismatch caused by unequal FODO cell lengths can reduce machine acceptance. On the other hand, a doublet/triplet lattice structure has the advantage of long uninterrupted drift spaces for injection and collimation optimization.

In this paper, we present a hybrid lattice that consists of FODO arcs and doublet straights. Section 2 introduces general layout and functions. Section 3 discusses lattice function, working point comparison, and alternative candidates. Section 4 describes injection and extraction design. Section 5 discusses compatibility with future upgrades. A summary is given in Section 6. Table 1 lists major parameter of the SNS accumulator ring.

Table 1: Major parameters for the hybrid-lattice SNS ring.

Quantity	Value	Unit
Circumference	248.0	m
Kinetic energy	1	GeV
Beam power	2	MW
Repetition rate	60	Hz
Number of protons	2.08	10^{14}
Ring dipole field	0.792	T
RF harmonics	1, 2	
Peak RF voltage, $h = 1$	40	kV
Peak RF voltage, $h = 2$	20	kV
Unnormalized emittance (99%)	160	$\pi\mu$m
Betatron acceptance	480	$\pi\mu$m
Momentum acceptance (full beam)	± 2	%
Magnetic rigidity, $B\rho$	5.6574	Tm
Horizontal tune	5.8 – 6.8	
Vertical tune	4.8 – 5.8	
Transition energy, γ_T	5.25	GeV
Natural chromaticity	−7.7, −6.4	
Number of super-periods	4	

2 LAYOUT AND FUNCTIONS

The newly optimized SNS ring lattice has a hybrid structure with FODO bending arcs and doublet straight sections [8]. The lattice combines the FODO structure's simplicity and ease of correction with the doublet structure's flexibility. As shown in Fig. 1, the accumulator ring has a four-fold symmetry comprising four FODO arcs and four dispersion-free straights. The four straight sections house injection, collimation, radio-frequency (RF) systems, and extraction systems, respectively. Each straight section consists of one 12.5-m and two 6.85-m long dispersion-free drifts.

Figure 2 shows the layout and content of one of the four super-periods. Each arc consists of four 8-m long FODO cells. Five of the arc quadrupoles, at sites of large disper-

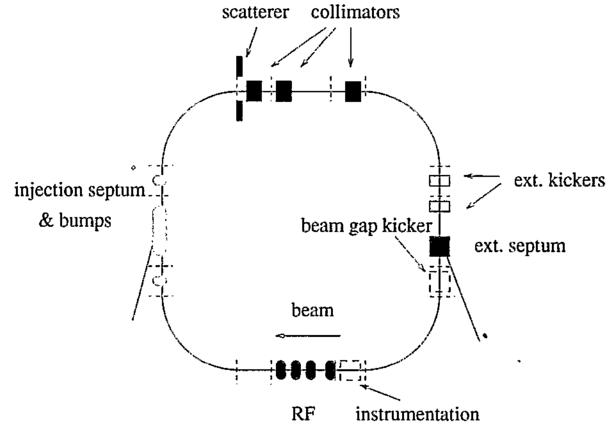

Figure 1: Schematic layout of the SNS accumulator ring. The four straight sections are designed for beam injection, collimation, extraction, and RF systems, respectively.

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sion, are sandwiched by a chromatic sextupole and an orbit correction dipole. The other quadrupoles are sandwiched by corrector packages containing both linear elements for orbit correction and decoupling, and nonlinear elements for amplitude detuning and resonance correction.

3 LATTICE

3.1 Lattice functions and matching

Figure 3 shows the lattice functions in one lattice super-period, consisting of a FODO arc and a doublet straight. The arcs and straight sections are optically matched to ensure maximum betatron acceptance. A horizontal betatron phase advance of 2π radians across each arc makes each arc an achromat. The dispersion vanishes in the straight sections. Each dipole is centered between two quadrupoles so as to maximize the vertical acceptance of the dipoles.

3.2 Working points

The horizontal and vertical tunes can both be adjusted by more than one unit without significant optical mismatch. The vertical tune is adjusted using two families of arc quadrupoles, and the horizontal tune is adjusted using three families of straight-section quadrupoles.

Working points in tune space are chosen mainly to avoid the major low-order structure resonances. Working points with tunes split by more than an half integer avoid possible strong coupling caused by space-charge forces and systematic magnet errors, thus preserving the painted beam distribution for the target. Table 2 compares four candidates in (Q_x, Q_y) tune space. A more detailed working-point comparison based on resonance analysis is currently under study.

3.3 Alternative lattices

Several alternative lattices have been studied and compared with the nominal lattice. One alternative reverses the polarity of the quadrupoles. In that case, the maximum dispersion is increased by about 10%. Another alternative [3] uses missing-dipole dispersion suppressors, instead of the achromats, to reduce dispersion in the straights. In this case, dispersion matching can reduce the maximum dispersion of the ring by about 40%, and the horizontal phase advance in the arc is more flexible. However, the addition of 8 FODO half-cells with missing dipoles increases the ring circumference by about 15%.

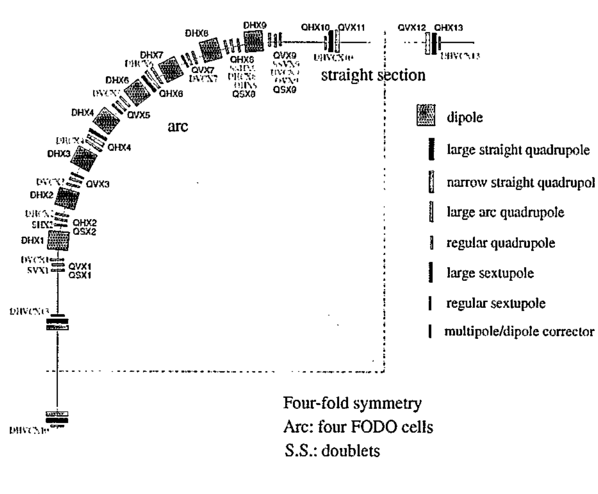

Figure 2: Schematic layout of one lattice super-period.

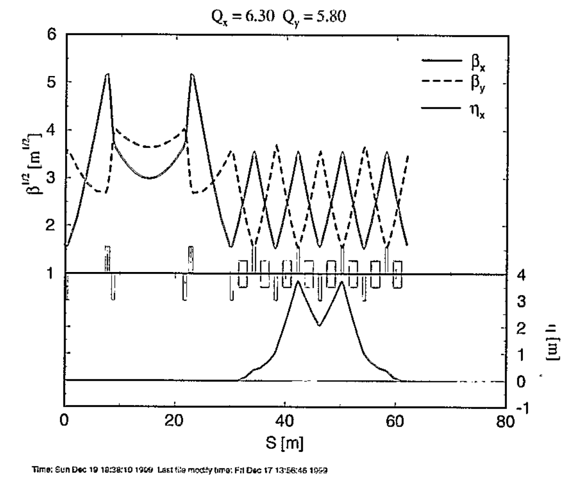

Figure 3: Lattice functions of one lattice super-period consisting of a FODO arc and a doublet straight. The horizontal phase advance across the arc section is 2π radian. The dispersion in the straight section is zero.

Table 2: Comparison of SNS ring working points in the tune space.

(Q_x, Q_y)	Advantages	Disadvantages
(6.30, 5.80)	perfect matching split tune high tunes	near $2Q_x + 2Q_y = 24$ near $2Q_x = 12$
(6.30, 5.27)	perfect matching split tune	near $3Q_y = 16$ near $2Q_y - Q_x = 4$ near $2Q_x = 12$
(5.82, 5.80)	coupled painting away from integer	large β_{max}/β_{min} coupling & growth near $2Q_x - 2Q_y = 0$
(5.82, 4.80)	split tune away from integer	large β_{max}/β_{min} near $2Q_y - Q_x = 4$

4 INJECTION AND EXTRACTION

4.1 Dispersion-free injection

One of the key features of the SNS ring is that the beam is injected at a dispersion-free section. This design allows independent adjustment of the transverse and longitudinal beam distribution using transverse phase-space painting [9] and longitudinal energy spreading [10], and reduces the requirements on injection beam momentum spread.

The H^- beam is transferred from the linac, stripped by the foil, and then injected into the ring. A maximum field of 0.3 T in the transport line and injection magnet keeps premature H^- stripping below 10^{-6} per meter. As shown in Fig. 4, a 12.5-m drift between quadrupole doublets houses the fixed chicane that assures adequate clearance for injection. The two 6.85-m drifts accommodate the symmetrically placed horizontal and vertical dynamic kickers used for injection painting. The β-function perturbation caused by the injection chicane and the orbit bumps is about 2%. The maximum residual dispersion is about 0.2 m.

The fixed chicane does not overlap ring lattice magnets. When the lattice is tuned, the strengths of the dynamic kickers will be adjusted so that the fixed chicane remains constant. The injection system is thus decoupled from the lattice tuning.

4.2 *Extraction*

The beam accumulated in the SNS ring forms a single bunch of 650 ns with a gap of 250 ns. Extraction is a two-step process: kick the beam vertically with the 14 fast ferrite kickers into the Lambertson-type septum magnet, then deflect the beam horizontally with the septum magnet, as shown in Fig. 5. The lattice of the Ring-Target-Beam-Transport line is matched to the ring straight section to avoid emittance growth [11].

5 ENERGY COMPATIBILITY

Although designed for 1 GeV energy, the present lattice is capable of accepting various injection beam energy up to 1.3 GeV. In order to minimize uncontrolled stripping loss of H^- and H^0 ions, the middle pair of injection dipoles needs to be replaced for optimum field value when the injection energy exceeds a ±5% window. At 1.3 GeV, additional two kickers (Fig. 5) will be used for extraction.

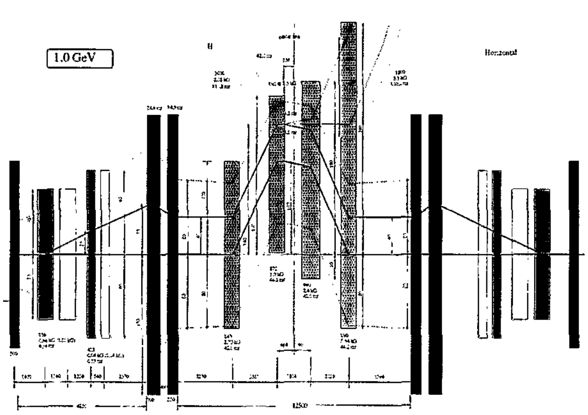

Figure 4: Schematic layout of the injection straight section. The red elements are the fixed injection chicane, the blue elements are ring lattice quadrupoles, and the yellow and green elements are the vertical and horizontal dynamic kickers, respectively.

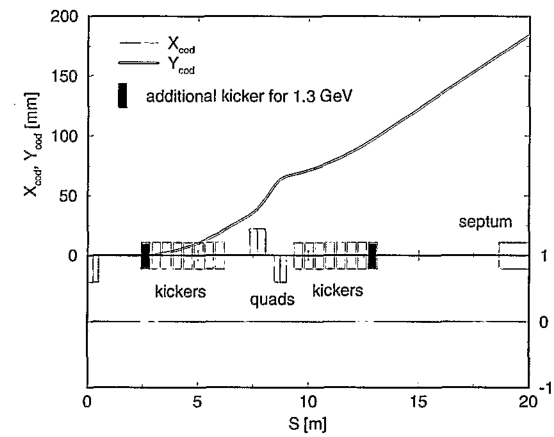

Figure 5: Ring extraction layout and orbit. Two additional kickers for 1.3 GeV operation are marked in dark.

6 SUMMARY

The long uninterrupted straights not only simplify injection, but also allow flexible arrangement of collimators and thus significantly improve collimation efficiency [12]. On the other hand, the FODO arcs allow easy arrangement of chromatic sextupoles and resonance-correction [13] elements. In conclusion, a hybrid lattice with FODO arcs and doublet straights is ideal for achieving the low-loss design goal of the SNS accumulator ring.

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