DIPOLE AND QUADRUPOLE SORTING FOR THE SNS RING *

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Abstract

The Spallation Neutron Source (SNS) accumulator ring is a high intensity ring that demands low uncontrolled loss for hands on maintenance. To achieve these low loss one needs a tight tolerance on magnet field accuracy. These tight tolerances have been achieved through shimming the magnets and sorting. Typically, sorting is done to minimize linear effects in beam dynamics. Here, sorting of quadrupoles was done according to a scheme, which allows reducing unwanted strength of nonlinear resonances. As a result, the strength of sextupole resonances for our base line tune-box was strongly reduced which was confirmed by a subsequent beam dynamics simulation.

INTRODUCTION

The Spallation Neutron Source (SNS) accelerator complex [1] will initially provide 1 .44 MW of protons on target at 1 GeV, but all the components of the ring are designed to operate up to 1.3 GeV for future upgrade. A major requirement of all parts of this accelerator is to have low uncontrolled beam loss (≤ 1 Watt/m), to allow hands on maintenance. In order to achieve this goal, the expected magnetic field error is 10^{-4} for the main dipole and quadrupoles.

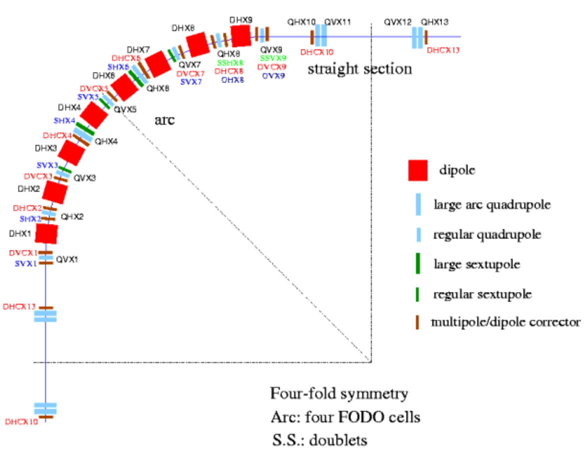

Figure 1. Schematic layout showing dipole, quadrupole, sextupole, and corrector magnets of one lattice superperiod.

SNS ring lattice has a hybrid structure with FODO bending arcs and doublet straight sections. The accumulator ring has a fourfold symmetry comprising four FODO arcs and four dispersion-free straight. Figure 1 shows the layout and content of one of the four superperiods.

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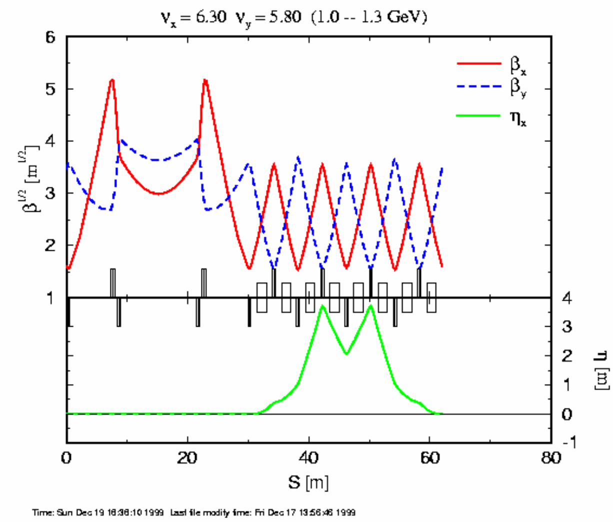

Figure 2. Lattice functions of one lattice superperiod consisting of a FODO arc and a doublet straight. The horizontal phase advance across the arc section is 2 π rad. The dispersion in the straight section is zero.

Each arc consists of four 8-meter FODO cells; Figure 2 shows the lattice functions in one lattice superperiod.

DIPOLE SORTING

The 248 m compact accumulator ring contains 32-sector dipole with 1.44 m effective length and a large aperture of 170 mm. The specification for the integral transfer function and magnet field quality is 0.01%.

These 32 dipole magnets are built from potted coils and machined pieces of solid iron and powered by a single power supply. When first assembled, the dipoles met the requirements for the field uniformity, but the rms variation of the ITF was much larger than the design values at both proton energies of 1.0 GeV and 1.3 GeV [2]. Based on measurements, shims have been added to the return legs or poles as appropriate, in order to bring the rms variations of the 1.0 GeV ITF to the specification, 0.01%. But the value of the ITF rms variation at 1.3 GeV for the shimmed magnets is 0.033% due to iron properties in solid magnets. Since at 1 GeV shimmed magnets meet all the requirement, dipoles were sorted for 1.3 GeV operation according to the following rule: (1) Pairing out of range dipoles magnets. (2) Place two dipoles of equal errors 180° apart in phase for cancellation, (3)Or place two dipoles with opposite errors 360° apart.The maximum closed orbit distortion (COD) at 1.0 GeV with sorted magnet is 1.2 mm, which is well within the corrector strength. After sorting the maximum COD for 1.3 GeV operations is reduced to 2.5 mm from 7 mm.

Figure 3 and 4 show COD for unsorted and sorted dipoles at 1.3 GeV respectively.

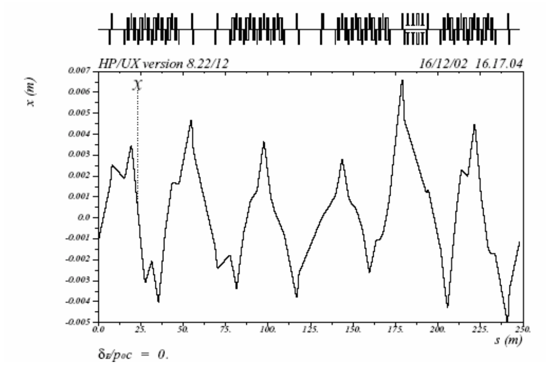

Figure 3: Closed orbit distortion for unsorted dipole at 1.3 GeV. Vertical scale [-0.005;0.007]meters.

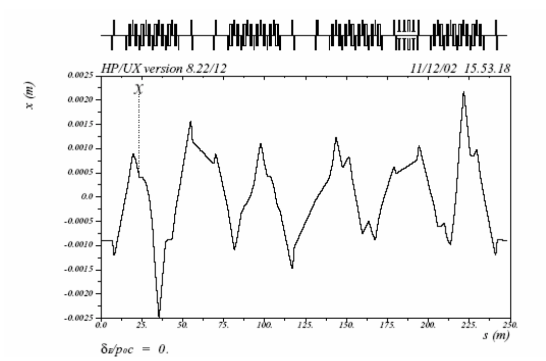

Figure 4: Closed orbit distortion for sorted dipoles at 1.3 GeV. Vertical scale [-0.0025;0.0025] meters.

QUADRUPOLE SORTING

There are 52 solid core quadrupole magnets powered by six power supplies as follows: two strings of eight 21Q40 (diameter 21 cm and core length 40 cm) quadrupoles, one string of twelve 21Q40 quadrupoles, one string of eight 26Q40 quadrupoles, one string of eight 30Q44 quadrupole, and one sting of eight 30Q58 quadrupoles. Table 1 shows rms values of sextupole and skew sextupole components for these quadrupoles.

Table 1: RMS values of sextupole and skew-sextupole components for 21Q40, 26Q40, 30Q44 and 30Q58 quadrupoles.

	21Q40	26Q40	30Q44	30Q58
b_2 (10^{-4})	1.13	1.35	3.0	3.25
a_2 (10^{-4})	1.18	3.27	1.0	1.35

Sorting for ITF

The field quality of 21Q40 quadrupole meets expected accuracy of 10^{-4} at an acceptance of 480 π mm mrad. The rms variation in the ITF was higher than 10^{-4} (rms) for 21Q40 quadrupoles. The 21Q40 quadrupoles were sorted in following steps, (1) choose 28 quadrupoles in string of 8, 8, and 12 magnets out of 58 quadrupoles, the rest quadrupoles to be used in the beam transfer lines where the field quality requirement is less demanding, (2) shim quadrupole to meet the specification (7 quadrupoles were shimmed), and (3) place quadrupoles having approximate equal errors at 180 degree of phase advance apart.

The higher order multipoles in the case of 26Q45, 30Q44, and 30Q58 were a slightly higher than the specification of 10^{-4}. The aim of the sorting for 26Q45, 30Q44 and 30Q58 was to reduce the impact of higher order multipoles on the resonances (discussed below). After sorting, the beta wave for all the quadrupoles is 0.5% and the tune shift is 0.001. Figure 5 shows the beta wave in x plane for ideal case, only 21Q 40 sorted according to ITF and when all the quadrupole were included.

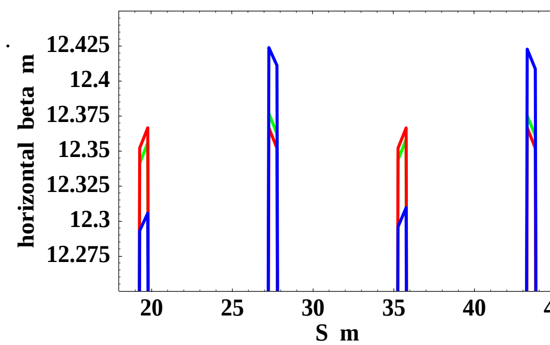

Figure 5: X- beta-wave (21Q40 ITF sorting; 26Q40 & 30Q44, 30Q58 sorting of multipoles without ITF). Red represents ideal lattice, green represents 21Q40 shorting and blue when all the 52 quadrupole included.

Sorting for Multipoles:

For high-intensity operation of the SNS ring (> 1.5MW) one may need to place the working point above the present baseline tune of (Qx,Qy)=(6.23, 6.20), provided sufficient stop band corrections are instrumented to compensate the 3rd and 4th order resonances [3]. Ring quadrupoles were sorted to minimize impact of the 3rd order resonances for high-intensity operation when the zero-current tune may be chosen some where between Qx=6.25 and 6.4. Figure 6 shows the SNS tune-box (Qx,Qy) with the 3rd order resonances for high-intensity operation (Qx+2Qy=19; 2Qx+Qy=19, 3Qx=19; Qx-2Qy=6) and a full tune spread corresponding to a 2 MW beam.

The basic idea to avoid the 3rd order resonances is to place the quadrupoles with equal sextupole and skews sextupole multipoles in the four-fold symmetry. In case of 26Q40 quadrupoles which are in 4th and 6th half cell in each arc, quadrupole with approximately equal sextupole and skew sextupole were placed diagonally opposite which has π phase advance for 19 oscillations, pairs having approximately equal residual multipoles, were placed at π phase advance for 19 oscillations. Figure 7 shows the phase advance for 19 oscillations.

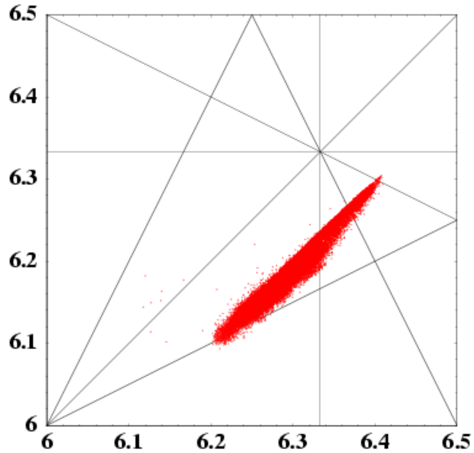

Figure 6. Resonances up to 3rd order and tune-spread due to the space charge and chromaticity for high-intensity operation of the SNS ring.

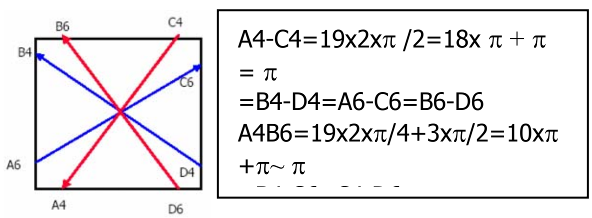

Figure 7: Schematic showing phase advances for the 19 oscillations.

A different sorting scheme was applied for 30Q44 and 30Q58 quadrupoles, which are in the straight section in doublet configuration. They were sorted for cancellation of the skew sextupole components in each doublet pair. Doublets having approximately equal sextupole component were place diagonally opposite to each other.

To test emittance growth due to the 3rd order resonances for quadrupole sorting, computer simulation were done using the UAL code with realistic non-linear magnet imperfections and space charge. The largest contribution to emittance growth came from measured multipoles of large quadrupoles in the straight sections (30Q44 and 30Q58). Figure 8 shows emittance growth due measured sextupole and skew-sextupole multipoles in all ring quadrupoles (red line), at the end of accumulation process with $N=1.5*10^{14}$ protons. After sorting of 26Q40, 30Q44 and 30Q58 impact of the 3rd order multipoles was substantially reduced (green line). Impact of nonlinear resonances (from other magnets and multipoles) can be further reduced applying resonance correction, as was shown for the high-intensity simulations of the SNS ring [4].

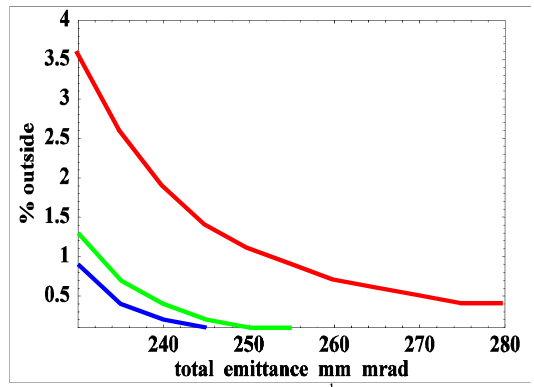

Figure 8. Beam halo due to 3rd order resonance caused by measured multipoles in ring quadrupoles: 1) red – no sorting 2) green – sorted 3) blue – ideal magnets without imperfection errors.

CONCLUSIONS

After shimming and sorting dipole magnets for 1.3 GeV operations, the variations in ITF met the specification of 10^{-4} (rms). The closed orbit deviation is 2.5 mm, which is well within the correct strength. Quadrupole sorting on the transfer function keeps the beta wave below 0.5% and tune shift below 0.001. Quadrupole sorting on the multipoles keeps the emittance growth less than 0.3% at 240 π mm mrad. Also it was demonstrated that this sorting scheme reduces unwanted strength of non-linear imperfection resonances.

ACKNOLEDGEMENTS

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