RANDOM AND SYSTEMATIC FIELD ERRORS IN THE SNS RING: A STUDY OF THEIR EFFECTS AND COMPENSATION

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Abstract

The Accumulator Ring for the proposed Spallation Neutron Source (SNS) [1] is to accept a 1 ms beam pulse from a 1 GeV Proton Linac at a repitition rate of 60 Hz. For each beam pulse, 10^{14} protons (some 1000 turns) are to be accumulated via charge-exchange injection and then promptly extracted to an external target for the production of neutrons by spallation. At this very high intensity, stringent limits (less than two parts in 10,000 per pulse) on beam loss during accumulation must be imposed in order to keep activation of ring components at an acceptable level. To stay within the desired limit, the effects of random and systematic field errors in the ring require careful attention. This paper describes our studies of these effects and the magnetic corrector schemes for their compensation.

1 INTRODUCTION

The Accumulator Ring for the proposed Spallation Neutron Source (SNS) [1] is designed to operate with horizontal and vertical tunes (Q_x and Q_y) between 5 and 6. Several second, third and fourth-order resonance lines cross this region, and, because the ring will operate at very high intensities for which stringent limits on losses will be imposed, the possibility of beam loss due to the presence of these resonances must be considered. Although the space-charge tune spread of the beam is expected to be small (at most 0.1), a number of lines are sufficiently close to the nominal working point ($Q_x = 5.82$, $Q_y = 5.80$) to be of concern. Other lines not as close to the working point must also be considered as they may cause unfavorable distortions of the beam phase space. The second, third and fourth-order lines between tunes of 5 and 6 are shown in Figure 1.

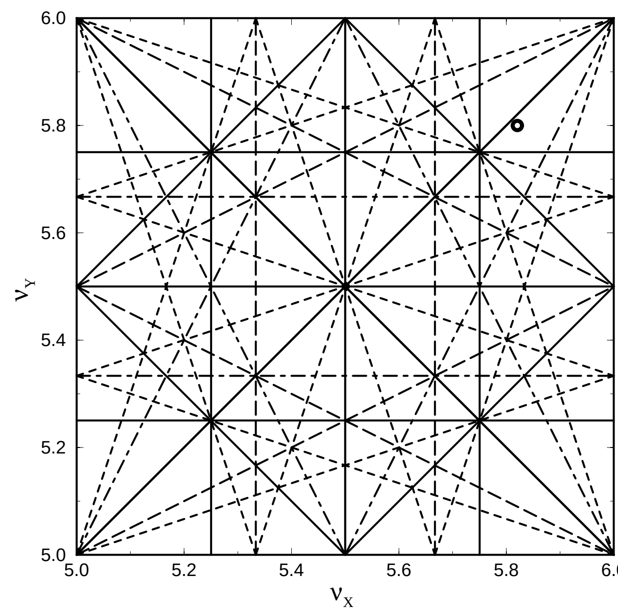

Figure 1: Accumulator Tune Chart. The circle shows the working point. Solid and short-dashed lines indicate second and fourth-order resonances; long-dashed and dot-dashed lines indicate third-order.

2 THE RING LATTICE

The layout of the ring is shown in Figure 2. The lattice [2, 3, 4] consists of four superperiods, each containing a $90°$ arc and a long straight section. The superperiods are labeled A (Injection), B (Collimation), C (RF Cavities), D (Ejection) and run sequentially along the beam direction from the beginning of one arc to the next. The order of magnets in each superperiod X is DHX1, QVX1, DHX2, QHX2, ..., DHX8, QHX8, QVA9, QHX10, QVX11, QHX12, where D and Q denote dipoles and quadrupoles, and H and V refer to the horizontal and vertical planes. The long straight section in each superperiod runs from QHX8 through QHX12.

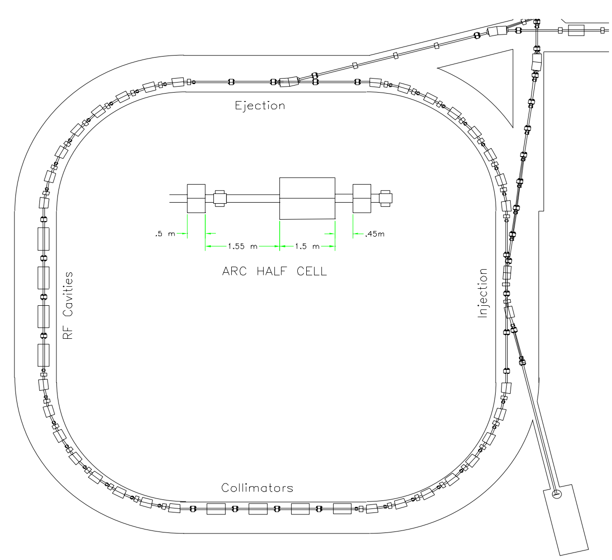

Figure 2: Accumulator ring layout.

3 CORRECTION ELEMENTS

To compensate for the small field imperfections and magnet alignment errors that can lead to beam loss, the ring

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will have a set of correction elements consisting of horizontal and vertical dipoles, skew quadrupoles, sextupoles, skew sextupoles and octupoles. Trim windings on the lattice quadrupoles will allow for any necessary quadrupole corrections. Correction dipoles and skew quadrupoles will be mounted downstream of the position monitor at each quadrupole with the dipole and skew quadrupole windings wound on the same core. Sextupole correctors (SVX11 and SHX12) will be located downstream of the dipole correctors at quadrupoles QVX11 and QHX12 in each superperiod. Skew Sextupole correctors (SSHX8 and SSVX9) will be wound on the same cores as the correction dipoles DHCX8 and DVCX9 in each superperiod. Octupole correctors (OVX11 and OHX12) will be located downstream of quadrupoles QVX11 and QHX12 in each superperiod. This placement of correctors ensures that appropriate harmonics (in azimuth θ) can be produced for the correction of resonances.

4 COMPENSATION OF ERRORS

4.1 Dipole Errors

Using the MAD code [5] we analyzed the effects of dipole-field errors due to random errors in (1) the placement of the lattice quadrupoles; (2) the guide field of the lattice dipoles; and (3) the roll of the lattice dipoles about the beam axis. We assumed Gaussian distributions of errors with RMS values of $\sigma_x = \sigma_y = 2.5 \times 10^{-4}$ m for the horizontal and vertical placement of the quadrupoles, $\sigma_B/B = 2.5 \times 10^{-4}$ for the guide field, B, and $\sigma_\theta = 2.5 \times 10^{-4}$ for the roll, θ, of the dipoles. Some 100 such distributions were generated and the correction dipole strengths required to correct the resulting closed orbit distortion (COD) were calculated. Using both the method of harmonic correction and local three-bumps we found that dipole strengths of up to 2.3×10^{-3} Tm were required to correct the COD. The uncorrected COD was at most 16 mm from the design orbit for the entire set of distributions.

The correction dipoles may also be used to produce deliberate local three-bump distortions of the closed orbit. Three-bumps with an amplitude of 10 mm require dipole strengths of at most 5.0×10^{-3} Tm.

4.2 Quadrupole Errors

Random quadrupole errors can produce undesirable distortions of the dispersion and betatron functions as the tunes approach 6 and 5.5. We have modeled these effects with the MAD code and find that they can be corrected with the quadrupole trim windings. The currents required in the trim windings are at most 0.5 percent of the current in the main windings. Typical results are shown in Figures 3 and 4.

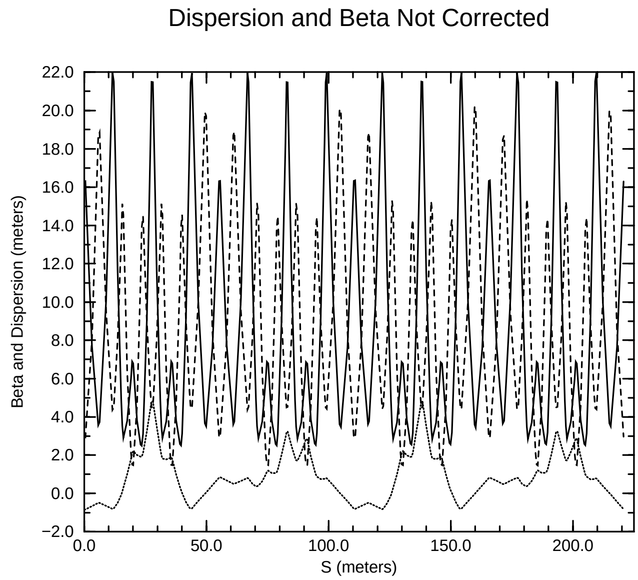

Figure 3: Dispersion and Beta distortion due to quadrupole errors with tunes near 6. Solid and dashed curves indicate hoizontal and vertical beta functions respectively; dotted curve indicates dispersion.

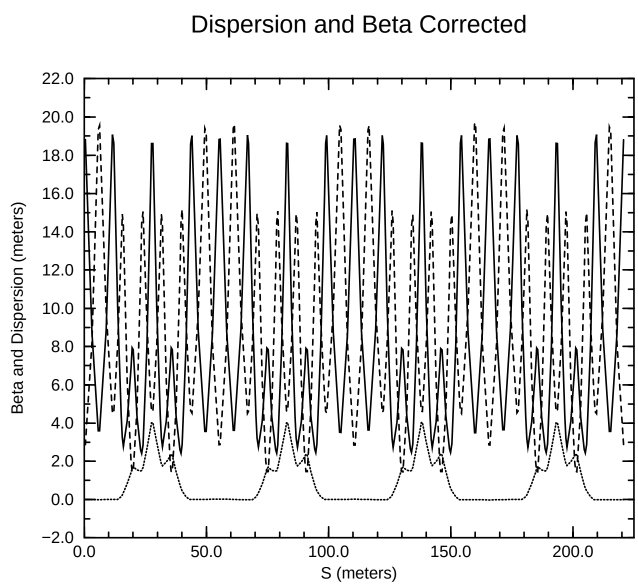

Figure 4: Same as above but with dispersion and beta corrected.

4.3 Skew Quadrupole Errors

Skew quadrupole errors, due to random rotations of the lattice quadrupoles about the beam axis, can produce unwanted coupling between horizontal and vertical planes, and can produce undesirable distortions of the betatron functions as the tunes approach the $Q_x + Q_y = 11(12)$ resonance lines. Vertical dispersion can also be produced as the tunes approach 6. Using the MAD code we have analyzed these effects assuming random distributions of quadrupole rotation angles, each distribution having an

RMS deviation of 1.0 milliradians. Skew quadrupole strengths of at most 1.0×10^{-2} T were required to correct these effects.

4.4 *Sextupole Errors*

The effect of random sextupole errors on particle motion in the ring was determined by examining phase-space contours obtained with the tunes near the $3Q_x = 17$ and $Q_x + 2Q_y = 17$ resonances. Figure 5 shows the con-

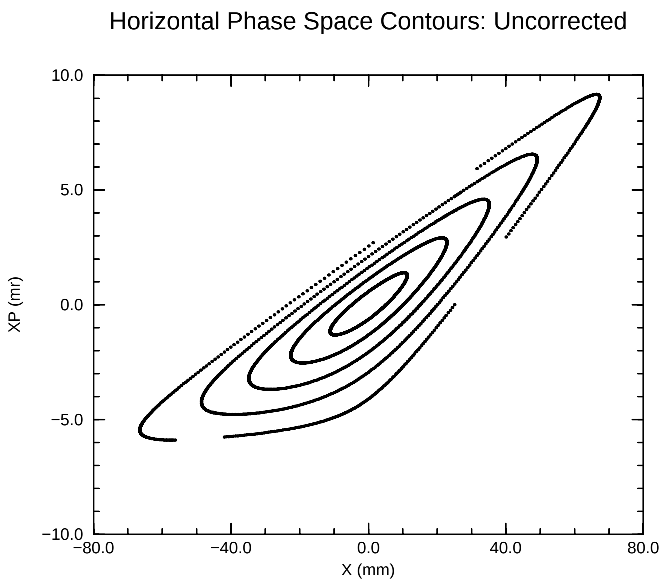

Figure 5: Horizontal phase-space distortion due to sextupole errors with tunes near $5 + 2/3$.

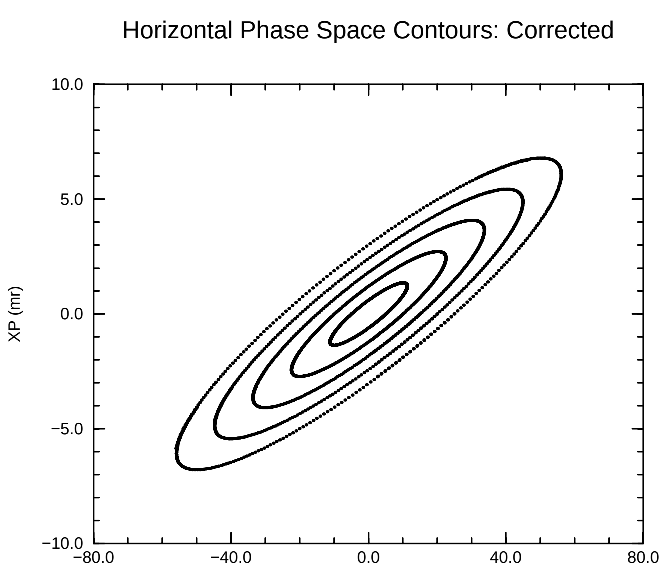

Figure 6: Same as above, but with sextupole corrections applied.

tours otained with a random distribution of sextupoles errors; Figure 6 shows the same with the correction sextupoles adjusted to correct the phase-space distortion. Correctors with a maximum integrated strength of 50×10^{-2} T/m were found to be more than adequate for the correction of several different error distributions.

4.5 *Skew Sextupoles and Octupoles*

Skew sextupoles are required for correction of the $3Q_y = 17$ and $Q_y + 2Q_x = 17$ resonance lines. Although one expects these lines to be relatively weak, experience in the AGS Booster [6] has shown that they can become quite important if there is any unexpected violation of the magnetic midplane symmetry. Skew sextupoles similar to those in the Booster will therefore be employed in the accumulator ring.

The lines in Figure 1 closest to the operating point are the fourth-order lines that pass through the point $Q_x = Q_y = 5 + 3/4$. These are excited by octupoles and are still under investigation.

5 REFERENCES

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