

PRELIMINARY EXPERIMENTAL INVESTIGATION OF QUASI ACHROMAT SCHEME AT ADVANCED PHOTON SOURCE*

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Abstract

Next generation storage rings require weaker dipole magnets and stronger quadrupole focusing to achieve very low emittance. To suppress the geometric and chromatic optics aberrations introduced by the strong sextupoles, achromat and quasi achromat schemes are applied in the lattice design to improve the beam dynamics performance. In this paper, some preliminary experimental investigation of the quasi achromat scheme at the Advanced Photon Source (APS) are presented. Three different operation lattices are compared on their beam dynamics performance. Although none of these operation lattices achieve ideal quasi achromat condition, they have certain relevant features. It is observed that fewer resonances are present in the nominal operation lattice which is most close to quasi achromat required conditions.

OVERVIEW

First-order and second-order achromats [1] have been applied in particle accelerators for a long time. The geometric and chromatic aberrations are eliminated by adopting integer betatron phase advance in certain beamlines. Similar third-order achromat design approaches were developed analytically and numerically [2] [3], where the concepts of repetitive identical cells and integer phase advance are used. For the next generation storage ring lattice designs, a third order geometric achromat is proposed with the assistance of harmonic sextupoles [4]. Quasi-achromat [5] is also proposed, which aims to minimize terms that are most relevant to the beam dynamics performance such as dynamic acceptance (DA) and lifetime. ESRF is proposing a hybrid multibend achromat (MBA) upgrade where the local cancellation scheme of $-I$ phase separation is employed [6]. Both quasi-achromat schemes and local cancellation schemes [6] are considered in the Advanced Photon Source (APS) MBA upgrade lattice design studies [5] [7].

In the lattice design studies, it is observed that fewer resonances are present in the achromat and quasi-achromat schemes. To investigate the beam dynamics performance of the achromat and quasi-achromat schemes, some preliminary experimental studies are performed at the APS storage ring. The APS storage ring is a third generation synchrotron-radiation light source, with a circumference of 1104 meters and an effective beam emittance of 3.13 nm. Three different operation lattices with different features have been compared. These lattices are the nominal lattice, hybrid lattice, and reduced horizontal beam size (RHB) op-

eration lattice. For the APS storage ring nominal lattice, the linear optics in one of 40 identical sectors is shown in Fig. 1 where the starting and ending point are the insertion device (ID) center. The betatron phase advance is 0.905 in horizontal plane and 0.481 in vertical plane, which are close to the quasi-achromat condition [5]. In the horizontal plane, the total betatron phase advance is equal to integer every 10 repetitive cells. In the following sections, some experimental results are discussed. The bunch fill pattern is 24 bunches that are evenly distributed in the storage ring.

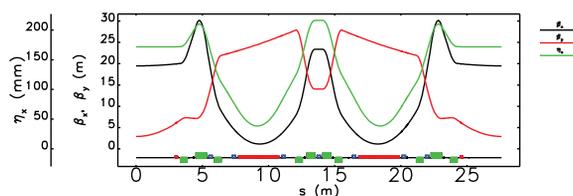


Figure 1: Twiss parameters in one arc section of APS storage ring. Green blocks represent quadrupoles, red blocks represent dipoles, and blue blocks represent sextupoles.

NOMINAL OPERATION LATTICE

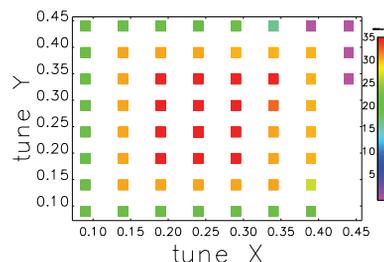


Figure 2: Stored beam current on ν_x - ν_y space during fractional tunes scan on nominal APS lattice.

The nominal APS operation lattice has 40 identical cells, with the optics in one such cell shown in Fig. 1. The standard operation mode of the APS storage ring has a total beam current of 102 mA, evenly distributed in 24 single bunches with top-up injection. Before the latest APS run, both the linear and nonlinear optics has a periodicity of 40. In the latest run, a smaller aperture ID vacuum chamber is installed at ID4, which has impact on injection efficiency and lifetime. It is noted that the minimum physical aperture of APS ring is located at ID4. The sextupoles in two sectors besides this ID chamber are optimized to manipulate the stored beam transverse phase space [8]. The nonlinear optics periodicity is slightly affected in these two sectors. The chromaticity is corrected to +2 in both horizontal and vertical planes. In Fig. 2 a stored beam current contour map

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is shown on ν_x - ν_y tune space. Three families of quadrupole magnets are employed as the tune knob [9]. It is observed that the stored beam is stable at most fractional tunes ranging from 0.1 to 0.4. When the fractional tunes cross certain resonances, the beam loss rate is larger.

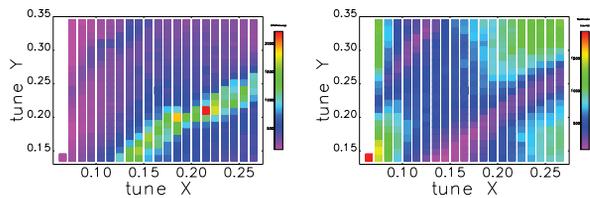


Figure 3: Stored beam lifetime (left) and beam loss rate at ID4 (right) on ν_x - ν_y space during fractional tunes scan on hybrid lattice.

HYBRID OPERATION LATTICE

One of the other operation modes is the hybrid fill mode. The total beam current of 102 mA is distributed in a single high-current bunch and eight groups of seven consecutive low-current bunches. The single bunch has a high current above 16 mA. It is isolated from the remaining 56 bunches by a symmetrical gap of 1.6 microseconds, which is designed for some timing mode users. The chromaticity is corrected to +10 to suppress single bunch instability. The linear optics has a periodicity of 40 around the storage ring. Similar to the nominal lattice, the sextupoles in two sectors around the new ID4 chamber are optimized to manipulate the stored beam transverse phase space for better injection efficiency.

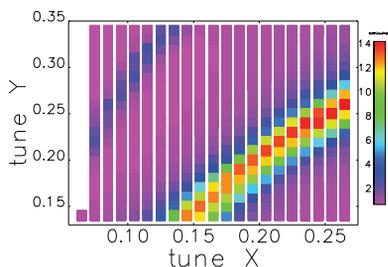


Figure 4: Emittance ratio on ν_x - ν_y space, during fractional tunes scan on hybrid lattice.

A fractional tune scan was performed on the hybrid operation lattice, where it was observed that the stored beam was lost quickly when ν_x is close to 3rd resonance ($3\nu_x=1$). Starting from the tunes of (36.17, 19.25), the beam lifetime and beam loss at ID4 (minimum physical aperture) are measured in a tune range of ± 0.1 (step size of 0.01), as shown in Fig. 3. The emittance ratio, measured using synchrotron light monitors at one bending magnet beamline, is shown in Fig. 4. Consistent results were achieved between these measured parameters as shown by Fig. 3 and Fig. 4. Along the linear difference resonance line, the lifetime and emittance ratio is high, while the beam loss is low. That is

due to lower beam scattering rate with larger beam volume. On the left top corner, there is a skew sextupole resonance line showing up.

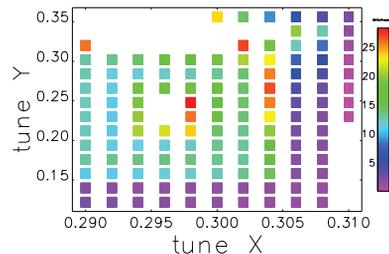


Figure 5: Stored beam lifetime on ν_x - ν_y space shows strong 3rd resonance in hybrid lattice.

Another scan was performed in a small range of ν_x near the 1/3 resonance. The vertical betatron tune was scanned in a large range of 0.1 to 0.35. As shown in Fig. 5, the beam lifetime was reduced to 1 minute when ν_x was moved to 0.31. This is true for ν_y between 0.15 and 0.35 which excludes possibility of x-y coupling. When ν_y was near an integer the lifetime was also low. Simulations are performed to evaluate the performance of the hybrid and nominal lattice at an official tune of (0.17, 0.23), a tweaked tune of (0.33, 0.23) and a tweaked tune of (0.35, 0.23). Calibrated lattice models are used. As shown in Fig. 6, the dynamic acceptance of the hybrid lattice is greatly reduced when ν_x is near the 1/3 resonance. At (0.35, 0.23), the DA is recovered. For nominal lattice such phenomenon is not observed.

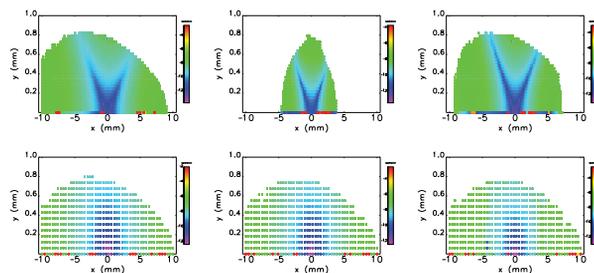


Figure 6: Simulated frequency map on x-y space for tunes (0.17, 0.23) (left), tweaked tunes of (0.33, 0.23) (middle) and (0.35, 0.23) (right). Top: hybrid lattice; bottom: nominal lattice.

RHB OPERATION MODE

The reduced horizontal beam size (RHB) operation mode has a higher effective emittance of 3.4 nm, plus reduced horizontal beam size of 120 μm at one insertion device. For this lattice, the chromaticity is corrected to +2 in both horizontal and vertical planes. The 40-fold symmetry in linear optics is broken by the modified optics in these two sectors for reduced horizontal beam size. However, unlike the nominal APS operation lattice and the hybrid operation lattice, the sextupoles arrangement has 40-fold symmetry.

A linear 1D tune scan was performed on RHB lattice, where ν_x was scanned with a step size of 0.01 while ν_y was

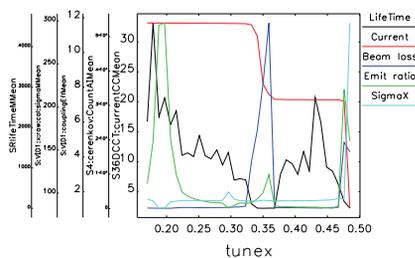


Figure 7: Linear fractional tune scan on ν_x .

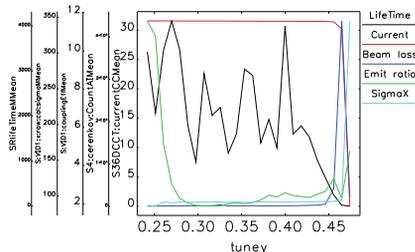


Figure 8: Linear fractional tune scan on ν_y .

fixed, or vice versa. The measurement of beam lifetime, current, beam loss at ID4, emittance ratio and horizontal beam size are shown in Fig. 7 and Fig. 8. One observes that there is beam loss when ν_x is crossing the 1/3 resonance, where the beam current drops from 33 mA to 20 mA. It is concluded that breaking symmetry of the linear optics seems to have an impact on achieving quasi-achromat condition. On the other hand, ν_x can cross the 1/3 resonance, which was not observed for hybrid lattice. In the vertical plane, the 1/3 resonance was not observed which indicates that the skew sextupole fields are not strong. When ν_x or ν_y was near half integer resonance, the lifetime was reduced to several minutes and there was beam size blow up.

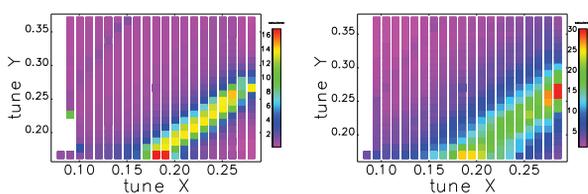


Figure 9: Emittance ratio on ν_x - ν_y space, during fractional tunes scan. Left: initial emittance ratio of 1.2 %; right: initial emittance ratio of 4.5 %.

A two dimensional betatron tune scan was also performed on RHB lattice for two different configurations of the skew quadrupoles. The measured emittance ratio is shown in Fig. 9 on ν_x - ν_y space. The initial emittance ratio before the scan is 1.2 % and 4.5 % respectively. The emittance ratio is recovered at the last step of the scan when the betatron tunes are recovered. One needs to note that the effect of vertical dispersion is not excluded from the results. It is observed that the measured width of linear difference

coupling resonance (0.025 and 0.06) is proportional to the emittance ratio (1.2 % and 4.5 %), which is from x-y coupling plus some impact from vertical dispersion. The skew sextupole resonance seems to be weaker than it appears in hybrid lattice.

Amplified betatron oscillations are excited by a reference oscillator, whose driver frequency is scanned near the expected fractional tunes. The betatron tunes are measured before and after the two dimensional betatron tune scan, as shown in Figure 10. It is observed that the measured tunes are the same before and after the scan, which means that the unwanted quadrupole field change due to hysteresis is acceptable.

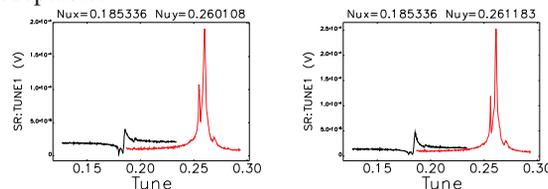


Figure 10: Measured tunes spectrum for RHB lattice, before and after the tune scan.

CONCLUSION

Tune scan studies are performed on several APS operation lattices to identify the impact of resonances. It is observed that breaking symmetry in linear optics, or strong nonlinear optics aberrations seem to have an impact on achieving quasi-achromat condition. In these cases stronger lower order resonances are present. Future work should have the APS operation lattices modified to achieve the quasi-achromat requirements on linear and nonlinear optics. Similar measurements will be performed on these new lattices. Future work should also include measurement of dynamic acceptance and momentum acceptance.

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