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CORRELATIONS BETWEEN BETA BEATING AND APS-U SINGLE PARTICLE DYNAMICS PERFORMANCE*

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Abstract

In the optimizations and evaluations process of the Advanced Photon Source upgrade (APS-U) lattice, it was observed that there are negative correlations between beta beating and APS-U single particle dynamics performance (such as dynamic acceptance and local momentum acceptance). These correlations are not always present due to different reasons. To understand these and possibly to assist in directing the future optimizations, in this paper a systematic simulation study is performed to understand the correlations between beta beating and APS-U single particle dynamics performance. Relatively high beta beatings are generated to reveal these possible correlations. In general a negative correlation is found between APS-U single particle dynamics performance and beta beating. Such correlations may vanish with relatively small beta beating, where the performance may be determined by physical apertures, resonances strength, and other factors.

INTRODUCTION

The Advanced Photon Source (APS) is undergoing an upgrade [1], where the double bend achromat lattice (DBA) is replaced by a hybrid multi bend achromat (HMBA) lattice [2], reducing the emittance from 3nm to 42pm. To achieve this, dispersion D_x is greatly reduced with more and weaker dipole magnets. Also quadrupole focusing is much stronger which in turn requires strong sextupole magnets for the chromaticity correction. Although the HMBA lattice provides optimum phase advance between sextupole pairs which eliminates many geometric abberations, the APS-U nonlinear optics optimization is still very challenging.

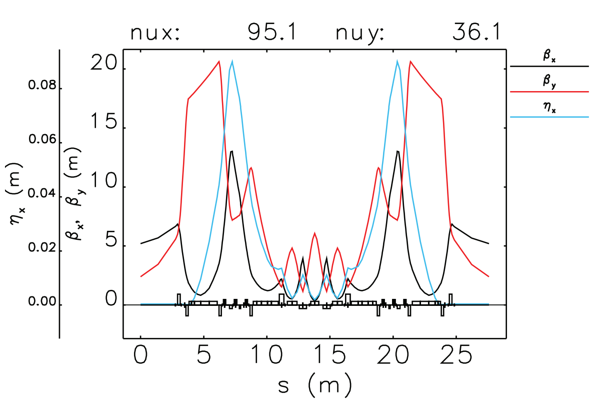

Figure 1: Linear optics of the final APS-U lattice.

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Often when the optimized lattice solution is evaluated with errors, one observes a correlation between beta beating and single particle dynamics performance (such as dynamic acceptance and local momentum acceptance). However, these correlations are not always present, due to the complication with closed orbit and physical apertures. With improved APS-U commissioning simulation procedures, the range of resulting beta beating after commissioning simulation is also smaller, which makes it harder to establish any correlations. Here, a systematic simulation study is performed to understand the correlations between beta beating and APS-U single particle dynamics performance, with relatively high beta beatings intentionally generated.

The optics functions in one of fourty sectors for APS-U final lattice [1] are shown in Figure 1. There are six sextupole magnets in the dispersive region of each sector, which are grouped into three pairs.

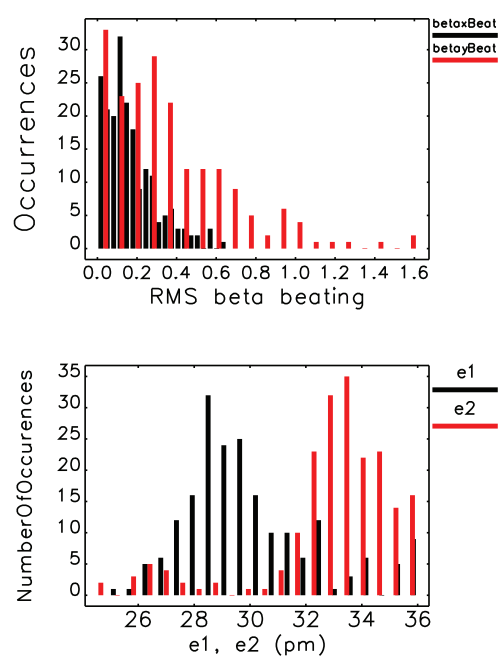

Figure 2: Histogram of beta beating (top) and beam moments of 200 filtered random seeds.

GENERATING BETA BEATING IN A LARGE RANGE

As discussed above, beta beating are intentionally generated in a large range to reveal the correlations between beta beating and APS-U single particle dynamics performance. Nominal quadrupole focusing errors (K1) and skew

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quadrupole errors (J1) in all the 240 sextupole magnets (using ELEGANT code [3]) are employed to generate the required level of beta beating and transverse coupling (to generate same horizontal and vertical beam moments when the tunes are equal).

The starting point of the RMS (root mean square) quadrupole focusing errors (K1) is 1×10^{-5}, which is increased in 100 steps with a step size of 4×10^{-5}. At each step, the RMS value of skew quadrupole errors (J1) is fixed at 1×10^{-3} , and 2 random error seeds are filtered for similar X and Y moments when betatron tunes are equal. The resulting beta beating is then determined by the filtered skew quadrupole errors (J1) and the random quadrupole focusing errors (K1). A total of 200 error seeds are generated, where all have 'same' X and Y moments when tunes are equal, plus that the beta beating are distributed in a relatively large range (up to 60% in horizontal plane). The filter selection ratio is roughly 6 to 1.

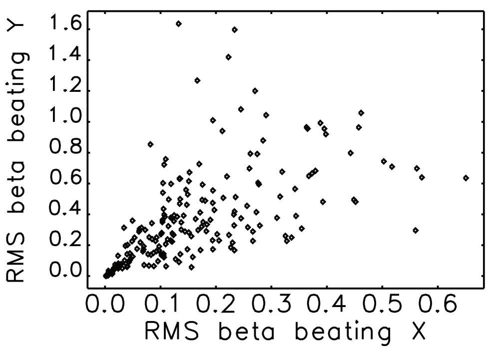

Figure 3: Correlations between horizontal and vertical beta beatings of 200 filtered random seeds.

The histograms of these 200 error seeds are shown in Figure 2. It is observed that there are more error seeds with smaller beta beatings than larger beta beatings. As shown in Figure 3, there are positive correlations between horizontal and vertical beta beatings, with large deviations from a linearly fitted curve. The beta beating is larger in vertical plan due to the sextupoles scheme where there are two defocusing sextupoles magnet (at large β_y location) and one focusing sextupole magnet (at large β_x location) in each half cell.

TRACKING SIMULATION WITH 200 RANDOM ERROR SEEDS

ELEGANT [3] simulations were performed with these 200 error seeds, to calculate the on-momentum dynamic aperture with and without physical apertures, also to calculate the local momentum acceptance with and without physical apertures. It is noted that the minimum physical apertures in the horizontal and vertical planes are 3-4 mm, which greatly impacts on the performance.

As shown in Figure 4, the correlations between on-momentum dynamic acceptance of APS-U lattice with physical apertures and average x/y beta beating is observed. The correlations are somehow masked by physical apertures which limits the dynamic acceptance boundaries to 1.5-2.2 mm. As a comparison, there is much more obvious correlations between on-momentum dynamic aperture of APS-U lattice without physical apertures and average x/y beta beating, as shown in Figure 5. Here it is also observed that the dynamic acceptance of APS-U lattice is largely impacted by small physical apertures.

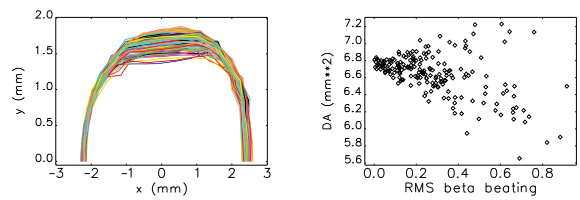

Figure 4: On-momentum dynamic acceptance of APS-U lattice with physical apertures (left) and the correlations with average x/y beta beating (right).

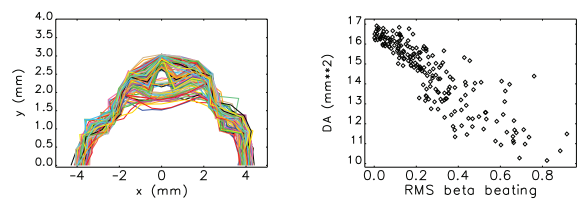

Figure 5: On-momentum dynamic aperture of APS-U lattice without physical apertures (left) and the correlations with average x/y beta beating (right).

For the local momentum acceptance (LMA) with and without physical apertures, plus the Touschek lifetimes calculated [4] using LMA and other (same) beam parameters, negative correlations are also observed as shown in Figure 6 and Figure 7. It is also noted that without physical apertures, the local momentum acceptance and calculated Touschek lifetimes are much larger. The lifetime correlations to average x/y beta beating are complicated with the facts that local momentum acceptance are determined by chromatic detuning, off-momentum dynamic acceptance and other effects.

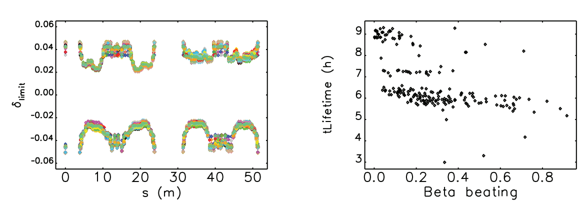

Figure 6: Local momentum acceptance of APS-U lattice with physical apertures (left), and the correlations between Touschek lifetimes and average x/y beta beating (right).

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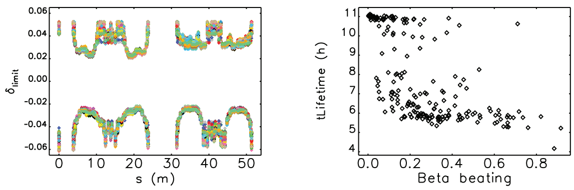

Figure 7: Local momentum acceptance of APS-U lattice without physical apertures (left), and the correlations between Touschek lifetimes and average x/y beta beating (right).

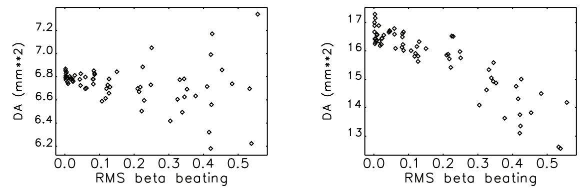

Figure 9: On-momentum dynamic acceptance (left) and dynamic aperture (right) of APS-U lattice, correlated with average x/y beta beating, with 66 uniformly distributed error seeds.

TRACKING SIMULATIONS WITH UNIFORMLY DISTRIBUTED BETA BEATING

As discussed above, random quadrupole focusing errors (K1) may result in quite different beta beating in the horizontal and vertical planes for a specific error seed. This may introduce the observed variances in the dynamic acceptance and lifetime correlations, when average x/y beta beating is employed. To rule out this possibility by generating similar level of beta beating in the horizontal and vertical planes, an additional filter is adopted to choose horizontal and vertical beta beatings in the same window (for example between 2% and 5%). To achieve this, the RMS quadrupole focusing errors (K1) at the focusing sextupole needs to be a factor of two larger than that at the defocusing sextupole, as there are four defocusing sextupoles (at large β_y location) and two focusing sextupole (at large β_x location) in one cell, and the optics are symmetric at these sextupoles.

Following these procedures 66 uniformly distributed error seeds are generated as shown in Figure 8. For this case the filter selection ratio is roughly 50 to 1. However, as shown in Figure 9, the dynamic acceptance and dynamic aperture correlations with average x/y beta beating remain similar, compared with the previous random quadrupole focusing errors case.

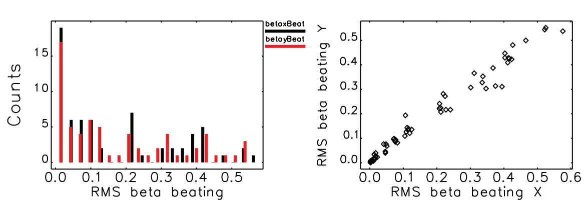

Figure 8: Histogram of beta beating (left) and correlations between horizontal and vertical beta beatings (right), for 66 uniformly distributed error seeds.

CONCLUSION

Beta beating are generated in a large range to reveal the possible correlations between beta beating and APS-U single particle dynamics performance. In general, there are negative correlations between single particle dynamics performance of APS-U lattice and average x/y beta beating. There is a strong correlation between dynamic aperture of APS-U lattice without physical apertures, and average x/y beta beating. The correlations are somehow masked when physical apertures are present which limits the dynamic acceptance boundaries to 1.5-2.2 mm. The lifetime correlations to average x/y beta beating are complicated with the facts that local momentum acceptance are determined by chromatic detuning, off-momentum dynamic aperture and other effects. These simulation results seem to indicate that it is prefered to reduced beta beating for better performance. However, at some points the performance may be determined by physical apertures, resonances strength, and other factors.

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