12th Int. Particle Acc. Conf. IPAC2021, Campinas, SP, Brazil JACoW Publishing
ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-TUPAB059

MEASUREMENT OF THE ADVANCED PHOTON SOURCE LIFETIME AT DIFFERENT LEVEL OF BETA-BEATING*

Yipeng Sun†, ANL, Argonne, IL 60439, USA

Abstract

Linear optics correction of a particle accelerator may not be perfect due to the existence of different errors sources in response matrix measurements and optics correction process. Previous numerical simulation study has shown that the single particle beam dynamics performance may be highly correlated with the level of residual beta-beating. In this paper, the machine study results on beam lifetime of the APS storage ring is presented. The experiment is performed at different level of predefined beta-beating with negligible betatron tunes variations. As expected, the measured beam lifetime has an inverse correlation with the level of beta-beating.

INTRODUCTION

The Advanced Photon Source (APS) is a third generation storage ring based synchrotron light source with the emittance of 3 nm. It is composed of double bend achromat lattice. The APS upgrade (APS-U) [1] is replacing the APS storage ring by a hybrid seven bend achromat lattice [2], reducing the natural emittance to 42 pm. The APS-U nonlinear beam dynamics optimization is very challenging, even though the hybrid seven bend achromat lattice already provides an optimum phase advance between sextupole pairs, thus eliminating many geometric abberations. The linear optics correction has critical impact on achieving the APS upgrade design performance parameters.

Optics correction of a particle accelerator usually end up with residual optics beatings, due to existence of different sources of errors during the measurements and correction of optics. The sources of errors may include magnets power supplies, beam position monitors, steering correctors, and residual orbit in nonlinear magnetic fields.

Previous numerical simulation studies [3] have shown that the APS-U single particle beam dynamics performance may be highly correlated with the residual beta-beating around the storage ring.

In this paper, the lifetime measurement of the operating APS storage ring is presented, which is performed at different level of beta-beating. The beta-beating is introduced by tuning the strength of all 400 quadrupole magnets with predefined random error sets.

* Work supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC02-06CH11357.
† yisun@anl.gov

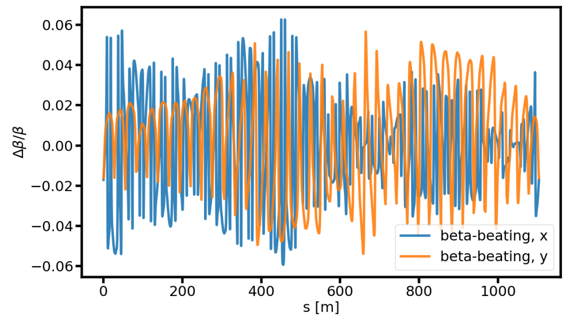

Figure 1: Distribution of beta-beating along the APS storage ring. Uniformly distributed strength errors are applied on all 400 quadrupole magnets with maximum $\Delta K_1/K_1$ of 0.001.

SIMULATION ON FILTERING OF QUADRUPOLE MAGNETS STRENGTH ERRORS

Random quadrupole magnets strength error introduces distortion on linear optics. Tracking simulations are performed to evaluate the impact numerically. There are a total of 400 quadrupole magnets in 40 sectors of the APS storage ring. To illustrate the beta-beating effects, uniformly distributed strength errors on all 400 quadrupole magnets are generated with maximum $\Delta K_1/K_1$ of 0.001. After applying these focusing errors on the lattice, the relative beta-beating of $\Delta\beta/\beta$ is shown in Fig. 1.

As shown in Fig. 2 (top), if arbitrary quadrupole magnets random errors $\Delta K_1/K_1$ are employed, the betatron tunes may be greatly changed from the design/operating ones. The design fractional tunes are (0.17, 0.24) for the APS storage ring. This tune variation may not be preferred for an experiment to measure the beam lifetime of the APS storage ring, as transverse emittance ratio and resonance properties may heavily depend on fractional tunes.

Also the experiment is expected to be carried out automatically and quickly, without the need to correct betatron tunes and other linear optics parameters. To meet these goals, the quadrupole random errors need to be filtered to only include the ones with small tunes distortions. A total of 600 random seeds are initially employed to generate the quadrupole errors. These are filtered for minimum changes in fractional betatron tunes. There are 10 random seeds which have tunes change within 0.005 in both transverse planes, as shown in Fig. 2 (bottom). These 10 random seeds are saved for the beam lifetime measurement experiment. Gaussian kernel density estimation is generated of the fractional betatron

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-TUPAB059

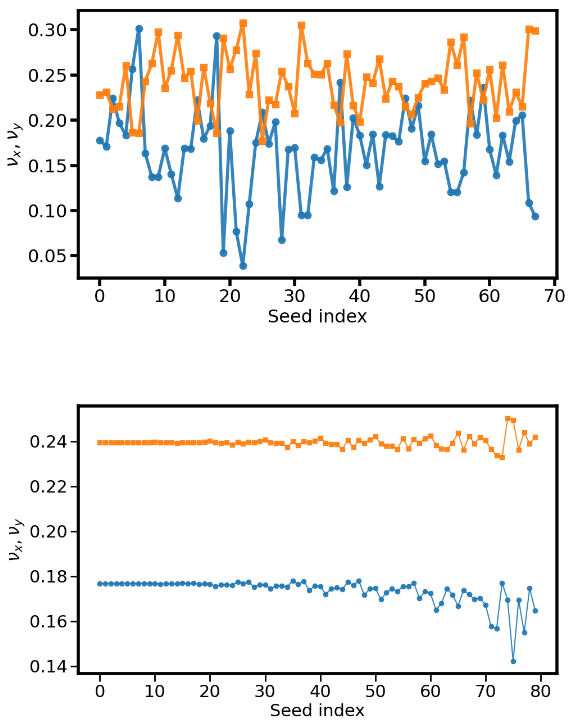

Figure 2: Top: the fractional betatron tunes with raw quadrupole magnets errors $\Delta K_1/K_1$, showing 70 samples out of 600. Bottom: the fractional betatron tunes on different error level, after filtering for minimum changes in fractional betatron tunes. There are 10 seeds which have tunes change within 0.005 in both transverse planes, which are populated on eight different levels.

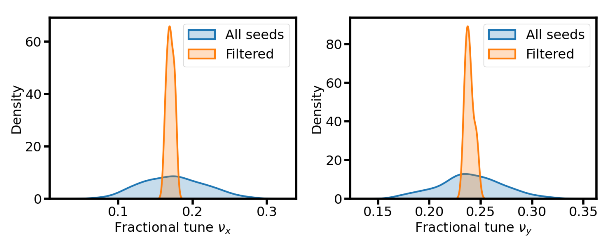

Figure 3: Gaussian kernel density estimation of the fractional betatron tunes with quadrupole magnets errors, with and without filtering. After filtering the tunes variations are expected to be negligible.

tunes with quadrupole magnets errors, with and without filtering, as shown in Fig. 3.

RMS beta-beating of these 10 filtered errors seeds are calculated at different error levels, as shown in Fig. 4. The resulting beta-beating is linearly related with the quadrupole strength error level, which is as expected.

Similar to the betatron tunes variations, the changes in the linear chromaticity are also minimized by the error filtering process. Chromaticity ratio (with respect to the design linear chromaticity) of these 10 filtered errors seeds are shown

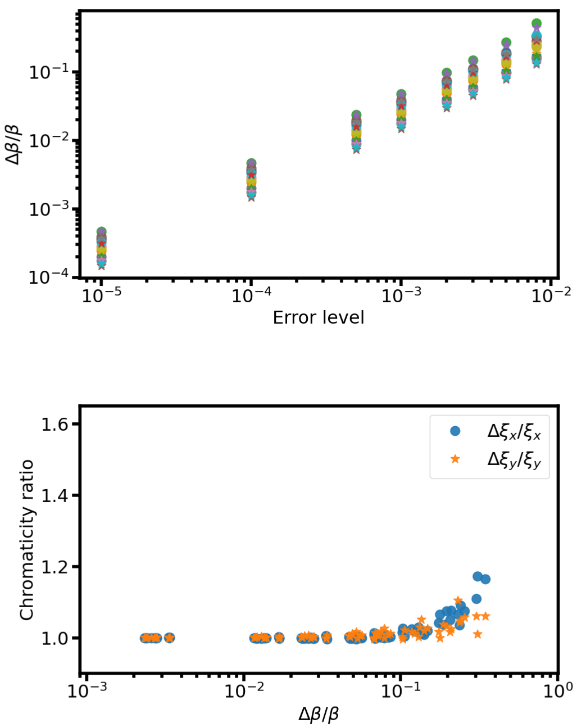

Figure 4: Top: RMS beta-beating of these 10 filtered errors seeds, at different error levels. Bottom: chromaticity ratio of these 10 filtered errors seeds, versus RMS beta-beating. Relative chromaticity change is within 10% for y, and 20% for x, at RMS beta-beating of 40%.

versus RMS beta-beating in Fig. 4. It is observed that the relative chromaticity change is within 10% for y, and 20% for x, at a relatively high beta-beating of 40% averaged for horizontal and vertical planes.

MACHINE STUDY ON BEAM LIFETIME

Machine studies are performed on the operating APS storage ring to measure the beam lifetime at different levels of beta-beating. A higher chromaticity lattice is employed in the machine study, where the stronger nonlinearity is employed to mimic the APS-U conditions. There are 24 stored bunches which are uniformed filled around the APS storage ring. The total beam current is around 60 mA. Transverse orbit feedback system is always running to ensure a relatively constant beam orbit around the ring. Limited by the available machine studies time, there are 5 error seeds (out of the total 10 filtered seeds) being applied at different error levels. A Python script with two layer nested loop is developed to automatically perform this machine study. One loop is over the error levels and the other is over the error seeds.

Shown in Fig. 5 (top) is the measured lifetime at different RMS quadrupole magnet error level, which is ranging from $\Delta K_1/K_1 = 0.001$ to $\Delta K_1/K_1 = 0.006$. On the other hand, the normalized beam lifetime is also calculated from lifetime,

12th Int. Particle Acc. Conf. IPAC2021, Campinas, SP, Brazil JACoW Publishing
ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-TUPAB059

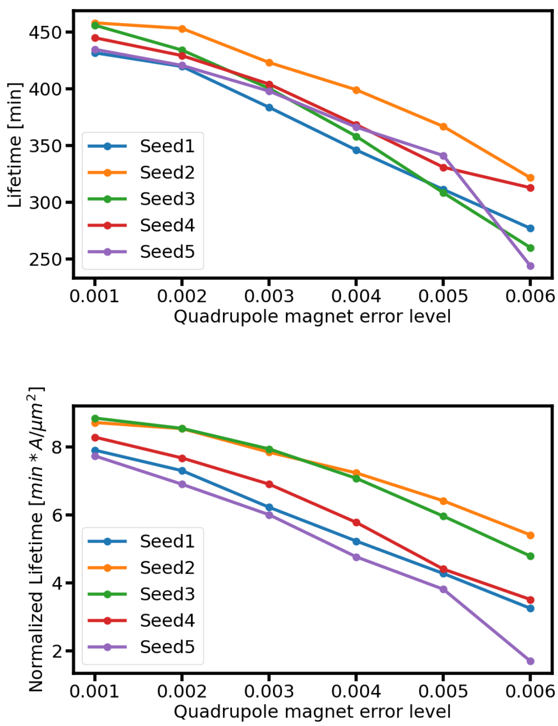

Figure 5: Top: Measured lifetime at different RMS quadrupole magnet error level from $\Delta K_1/K_1$=0.001 to $\Delta K_1/K_1$=0.006. Bottom: Normalized Lifetime (from lifetime, beam current and beam sizes) at different RMS quadrupole magnet error level from $\Delta K_1/K_1$=0.001 to $\Delta K_1/K_1$=0.006. There are 5 seeds from the filtering discussed previously.

beam current, and transverse beam sizes (measured at one dipole location), as shown in Fig. 5 (bottom). It is observed that these five random seeds follow a similar trend.

The mean and the standard deviation of the estimated horizontal and vertical RMS beta beating are calculated from a total of 20 seeds with somehow increased tolerance on betatron tunes distortion. The beta beating is an average of horizontal and vertical planes. Shown in Fig. 6 is the statistics of the measured lifetime from 5 pre-defined error seeds, versus the estimated RMS beta beating. It is observed that the measured beam lifetime is inversely correlated with beta-beating. The beam lifetime may drop up to 50% at 20% of beta-beating.

CONCLUSION

Numerical simulation is performed on filtering quadrupole magnet random error seeds for required level of beta-beating, plus minimum variations in fractional betatron tunes. Configurations are being setup to automatically perform the machine study of APS beam lifetime measurement, at different level of beta-beating. The measured beam lifetime correlation is as expected, which is inversely correlated with beta-beating. These observations agree with the previous APS-U numerical simulation results.

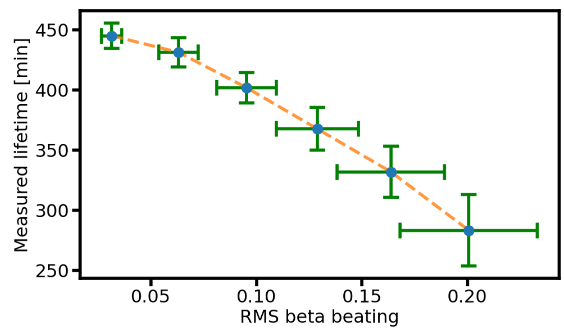

Figure 6: Measured lifetime from 5 seeds, versus estimated RMS beta beating (average of horizontal and vertical planes, total of 20 seeds with increased tolerance on betatron tunes distortion).

ACKNOWLEDGMENTS

The authors thank Michael Borland, Louis Emery, Vadim Sajaev, Aimin Xiao, C.Y. Yao and Sasha Zholents and AOP group for discussions. Several *Python* libraries are employed for data processing and scripts development in machine studies. The figures are generated using the *matplotlib* libraries in the *Python* code. The work is supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC02-06CH11357.

REFERENCES

[1] M. Borland *et al.*, "The Upgrade of the Advanced Photon Source", in *Proc. 9th Int. Particle Accelerator Conf. (IPAC'18)*, Vancouver, Canada, Apr.-May 2018, pp. 2872–2877. doi:10.18429/JACoW-IPAC2018-THXGBD1

[2] L. Farvacque *et al.*, "A Low-Emittance Lattice for the ESRF", in *Proc. 4th Int. Particle Accelerator Conf. (IPAC'13)*, Shanghai, China, May 2013, paper MOPEA008, pp. 79–81.

[3] Y. P. Sun, "Correlations Between Beta Beating and APS-U Single Particle Dynamics Performance", in *Proc. North American Particle Accelerator Conf. (NAPAC'19)*, Lansing, MI, USA, Sep. 2019, paper MOPLM03, pp. 95–97.