BEAM LOSS SIMULATION AND COLLIMATOR SYSTEM CONFIGURATIONS FOR THE ADVANCED PHOTON SOURCE UPGRADE*

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Abstract

The proposed multi-bend achromat (MBA) lattice for the Advanced Photon Source upgrade (APS-U) has a design emittance of less than 70 pm. The Touschek loss rate is high: compared with the current APS ring, which has an average beam lifetime ~ 10 h, the simulated beam lifetime for APS-U is only ~ 2 h when operated in timing mode ($I = 200$ mA in 48 bunches). An additional consequence of the short lifetime is that injection must be more frequent, which provides another potential source of particle loss. In order to provide information for the radiation shielding system evaluation and to avoid particle loss in sensitive locations around the ring (for example, insertion device straight sections), simulations of the detailed particle loss distribution have been performed. Several possible collimation configurations have been simulated and compared.

INTRODUCTION

A preliminary study indicates there are three major particle loss sources in the APS MBA lattice: (1) The Touschek effect, with an average Touschek lifetime ~ 2 h in 48-bunch mode [1], giving a particle loss rate of ~ 102 pA. (2) Gas scattering, with an average lifetime ~ 10h@100Ah to ~ 60h@1000Ah [2], giving a particle loss rate of ~ 20 pA to 3 pA. (3) Injected beam losses. Since we are doing the “swap-out” on-axis injection [3–5], the required injected bunch charge is ~16.6 nC/shot every ~15 s for timing mode. Assuming 97% injection efficiency, the particle loss rate is ~ 33 pA. The Touschek and injected beam losses are studied in this paper.

Collimators are planned in order to confine losses to a designated area. In this paper, we first describe the aperture limitations around the ring. We then present simulation results with different collimator locations and apertures. Simulation results show a good agreement between calculated beam lifetime and lifetime from a detailed scattered particles tracking study that used the methods described in [6]. Based on the simulations, a summary of loss distributions is given.

APERTURE LIMITATIONS

The physical aperture limitations around the ring in radial size (x/y) are

- Nominal arc vacuum chamber: 11/11 mm (round)
- Nominal photon absorber at each arc BPM location: 8/8 mm (round)
- Nominal ID vacuum chamber: 10/3 mm (elliptical)
- Narrow ID vacuum chamber:
  - Type I (Sector 3/7/10/14/21/24/28/31): 4/3 mm (n=6 super elliptical)
  - Type II (Sector 17/35): 4/4 mm (round)
- Stripline kicker: 6.7/4.2 mm (elliptical)
- Septum: 3.7/2.7 mm (n=6 super elliptical)

COLLIMATOR CONFIGURATIONS

There are two major concerns with any beam loss: radiation safety and protecting an insertion device (ID) from radiation damage. For radiation safety, we want stray particles to be lost in areas with a better existing shielding or where supplemental shielding can easily be added. For protecting ID, we would like particles to be lost at the downstream end of the ID straight section, so the shower propagates away from the nearest ID.

In general, to collimate Touschek scattered particles (with a large momentum error), collimators are best installed in an area with large dispersion and betatron functions. This suggests the dispersion bump generated by the longitudinal gradient dipole, as shown in Fig. 1. However, in sectors 1 through 35, this region is close to the ratchet door that gives access to the beamline front end, as shown in Fig. 2. This area has weaker radiation shielding compared to the utility region (rf/injection section) from sector 36 to 40, which has a thicker, continuous shielding wall. With all these facts in mind we explored the following collimator configurations. The collimator in this initial study has a 6x6 mm radius round aperture, and only multipole errors are included. Distances refer to Fig. 1.

- Case A: Collimators in the first dispersion bump area, from 6.32 m (entrance of AS1) to 7.04 m (exit of AQ4), in sector 20, and sector 36-40.
- Case B: Same collimator locations as Case A, but in all sectors (1-40).
- Case C: Collimators in both dispersion bump areas (6.32 m to 7.04 m and 20.56 m to 21.28 m), in all sectors.
- Case D: Extended collimator area to cover high beta-y area, 5.95 m (entrance of AQ3) to 7.24 m (entrance of AS2), all sectors.
- Case E: Add n=6 super-elliptical aperture limits at the downstream end of all ID straights (sector 1 to 35) and collimators as in Case D.

The beam loss distributions were simulated based on these collimator configurations using `Pelegant` [7, 8]. From Table 1, we see that having two collimators in one sector doesn’t

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

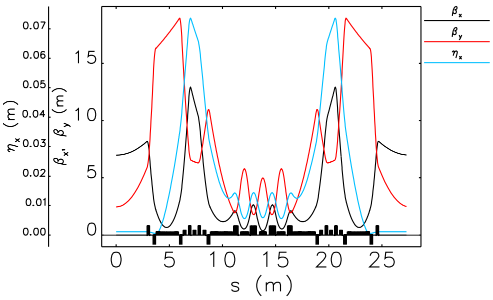

Figure 1: Optical function for the MBA storage ring (single sector).

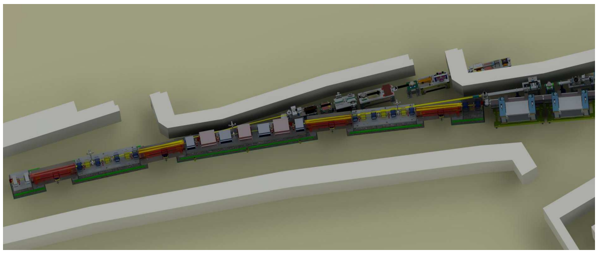

Figure 2: MBA storage ring layout and shielding wall (single sector). Red - longitudinal gradient dipole.

help to reduce particle losses at ID straights (Case B and Case C), though it reduces the loss rate at each collimator location if this is a concern. Having an extended collimator to cover a high beta-y location reduces beam losses at ID straight (Case B and Case D). A collimator at the downstream end of the IDs does reduce the losses at the upstream end, but it also increases the total loss over the ID straight (Case D and Case E).

COLLIMATOR SIZES

From the above, we found that it is difficult to completely prevent losses in the ID straights. This is due to several factors: the small size of the ID apertures; operation of the lattice on the linear difference resonance (giving $\epsilon_y = \epsilon_x$); and strong non-linear effects. To make more efficient collimation, the collimator apertures need to be reduced. Collimators located at the ID downstream end or close to a ratchet door are also not preferred, so we start a study of collimator configuration with that the collimator location in the sector is same as Case D, but collimators were only placed in sectors 20 and 36-40. Four values of the collimator radius where simulated: 5.7 mm, 5.4 mm, 5.0 mm, and 4.7 mm. Further reducing the collimator aperture will pose other problems, such as impedance and alignment issues.

Two particular optical error sets are used in these simulations: Case I — the calculated Touschek lifetime is 2.09 h, which represents the average beam lifetime. Case II — the calculated Touschek lifetime is 1.26 h, which has the shortest beam lifetime. A summary of the simulation results is listed in Table 2. The simulation results shows up to ~ 30% difference between the calculated and simulated beam lifetime. This is because the calculated beam lifetime assumes that the local momentum aperture, which is determined from single-particle tracking using a search method [9, 10], has a hard boundary. In contrast, the simulated lifetime is the sum total of lost scattered particles from a Monte Carlo simulation [6], which in general has a fuzzy momentum aperture boundary. The fuzziness of the boundary results from the factor that Touschek scattering affects particle momentum in all three planes, not only in the longitudinal plane. This feature is shown in Figure 3 with the loss ratio (the simulated lost rate divided by the simulated scattering rate) vs momentum error.

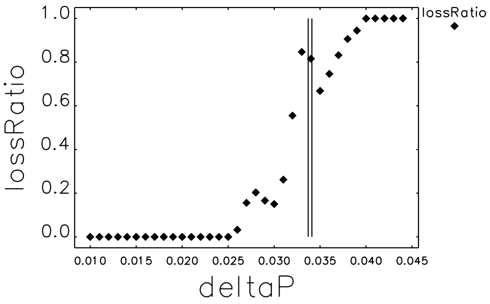

Figure 3: Simulated scattered particles loss ratio (dot) vs momentum error. The loss region is fuzzy. Black line shows local momentum aperture from a single particle tracking.

INJECTED BEAM LOSS

Using the same optical error sets and collimator configuration as for the Touschek scattering simulation summarized in Table 2, we simulated the injected beam losses using `Pelegant`. We included the gaussian distribution of the injected beam from the booster, inflated to account for the effects of jitter in the injected beam centroid positions and momenta. To improve the simulation accuracy without tracking too many particles, we generate particles that have a 6D uniform distribution with a weight assigned to each particle based on its location in the Gaussian distribution. The loss rate and loss distribution is then calculated based on these weights. In this way, the all-important particle population close to the tail is sampled more accurately.

The results, summarized in Table 3, show that the injected beam loss has a very different signature than the Touschek losses. This is because the injected particle losses result from large betatron oscillations rather than a large momentum error. As a result, the proposed collimator configuration doesn't provide a good shielding for the ID straights. The collimation effect becomes even worse when the simulated injection efficiency is low (Case II). This is not a desired feature and further investigation is needed.

Table 1: Summary of Touschek Beam Loss Distribution at Various Collimator Configurations

	Case A	Case B	Case C	Case D	Case E
Total Loss (p/s)	3.46×10^8	3.33×10^8	3.54×10^8	3.45×10^8	3.44×10^8
Beam Lifetime (h)	3.7	3.8	3.61	3.7	3.7
Loss @ ID straight (%)	34.7	19.9	20.1	15.8	22.1
Loss @ US ID straight (%)				8.52	4.7
Loss @ Injection (%)	5.7	5.7	5.6	5.5	2.4
Loss @ Collimators (%)	36.9	62.1	74.5	77.0	67.0
Loss @ Others (%)	16.7	1.7	2.1	1.5	1.3

Table 2: Summary of Simulated Touschek Lifetime and Loss Distribution

Optical Error Sets	Collimator Aperture (mm)	Calculated Lifetime (h)	Simulated Lifetime (h)	Losses @ID (%)	Losses @Collimator (%)	Losses @Other (%)
Case I	5.7	2.09	2.65	43.2	41.9	14.9
	5.4		2.65	27.1	63.1	9.8
	5.0		2.63	11.2	85.6	3.2
	4.7		2.61	4.0	93.4	2.6
Case II	5.7	1.26	1.16	48.7	35.2	16.1
	5.4		1.17	32.9	54.1	13.0
	5.0		1.17	14.2	79.1	6.7
	4.7		1.17	5.8	92.0	2.2

Table 3: Summary of Simulated Injected Beam Loss Distribution

Optical Error Sets	Collimator Aperture (mm)	Simulated Inj. Loss (%)	Ave. Loss Rate (e/shot)	Loss @ID (%)	Loss@Coll. (%)
Case I	11.0	0.1	1.10×10^8	100	
	5.0	0.1	1.13×10^8	45.9	54.1
	4.7	0.12	1.36×10^8	26.6	73.4
Case II	11.0	2.34	2.63×10^9	100	
	5.0	2.35	2.63×10^9	96.5	3.5
	4.7	2.35	2.64×10^9	89.8	10.2

CONCLUSIONS

We have modeled Touschek and injected beam losses for the APS MBA lattice for various collimator configurations together with different collimator aperture sizes. Simulation results show that the Touscheck scattered particle losses can be well collimated when using a 4.7 mm radius collimator without a noticeable impact to the simulated beam lifetime and injection efficiency. Due to the different loss procedure, the same collimator configuration is less effective to an injected beam loss. Therefore, protecting IDs from Touschek losses seems feasible, protecting them from injected beam losses remains challenging.

One potential mitigating factor is that the interest in very small horizontal ID apertures is much less than originally thought. Another possiblity is using a reduced-aperture transition at the downstream end of small horizontal aperture ID to localize injected beam losses. Further investigation is planned.

ACKNOWLEDGMENTS

Computations made use of Blues, a high-performance computing cluster operated by the Laboratory Computing Resource Center at Argonne National Laboratory.

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