IMPACT OF NARROW GAP UNDULATORS ON THE ADVANCED LIGHT SOURCE*

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Abstract

In low emittance synchrotron light sources the main source of beam loss is intrabeam or Touschek scattering. In most cases the Touschek scattered particles get lost on the vacuum chamber with the narrowest vertical gap. The particles reach the vertical chamber from either diffusion or coupling of the particle motion from the horizontal to the vertical plane. The beam lifetime can be very sensitive to the size of the vertical chamber that can limit the dynamic momentum aperture. The reduction in lifetime limits the minimum size of the chamber that can be installed in the ring. In this paper we examine the effect of the size of the vertical apertures on the beam lifetime at the ALS under various different machine conditions. We show that there are conditions where one can make the beam lifetime much less sensitive to the size of the vertical aperture.

INTRODUCTION

Third generation light sources have been very successful. Nearly all have met and are exceeding their brightness performance expectations. In some cases the brightness delivered is several orders of magnitude higher than the design values. There are several reasons for this. The three main ones are that the facilities are operating with larger currents, smaller emittances (both horizontal and vertical) and beta-functions, as well as insertion devices with smaller vertical gaps. Still there is interest in increasing the brightness further. In particular for the ALS the interest is increasing the brightness for photon starved experiments such as photon-in photon-out and diffractive imaging experiments. There is also interest in extending the range of undulator radiation to higher energy. Presently undulator radiation is being used up to 2keV but with small period narrow vertical gap permanent and superconducting magnet devices it will be possible to extend the spectrum to much higher energies.

Of concern is that smaller gap vacuum chambers required for these insertion devices will increase the loss rate of the particles. Already with the existing chambers, it is known that most of the particle loss occurs on the narrowest gap chamber. The chamber is located in a region where the full gap is 8.9 mm with a beta-function of 5.1 m. Also experimental tests using vertical scrapers to further limit the physical aperture have shown that the lifetime can be strongly dependent upon the size of the vertical aperture [1]. It is desirable to operate in a region where the lifetime is less sensitive to the aperture. In this paper we investigate several different operational modes where the lifetime has markedly different dependence upon the size of the vertical aperture.

LIFETIME VERSUS GAP

Using a vertical scraper, one can measure the dependence of the lifetime on gap. Lets look at three different cases:

1. High-Coupling,
2. Low-Coupling, and
3. Eta-Wave.

In all three cases the ring was filled with 24 mA with 1.5 mA/bunch. In the High-Coupling case the vertical emittance is increased to 2% of the horizontal emittance by powering one family of skew quadrupoles to excite the linear coupling resonance. In the Low-Coupling case 18 skew quadrupoles are adjusted to correct the vertical emittance to 0.35% of the horizontal. In the Eta-Wave case the 18 skew quadrupoles are used to correct the coupling then 12 skews are used to introduce a vertical dispersion wave (i.e. Eta-Wave) without exciting the coupling resonance to increase the vertical emittances to 2% of the horizontal emittance [3] (i.e. emittances for blue and red cases are equal). The results are plotted in Fig. 1.

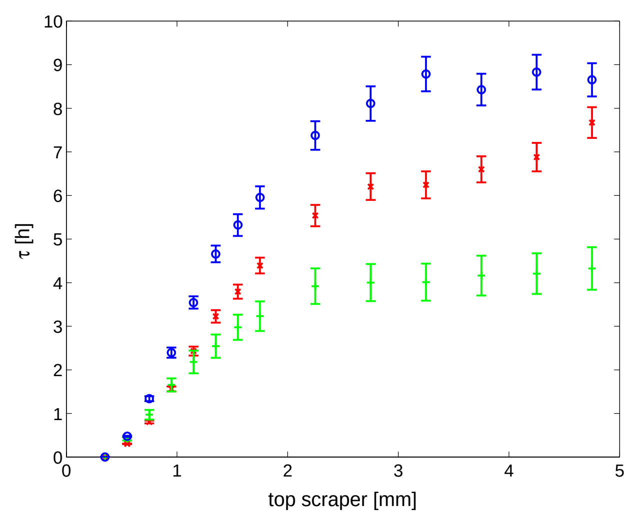

Figure 1: Lifetime versus vertical scraper for High-Coupling (red), Low-Coupling (green), and Eta-Wave (blue).

There is a marked difference in the dependence of lifetime on scraper position for the three cases. When the scraper is out at 5 mm, the lifetime of the High-Coupling

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case is 8 hours and the Eta-Wave case is 9 hours. The difference is due to the larger dynamic momentum aperture of the Eta-Wave lattice. The lifetime of the Low-Coupling lattice is about 4 hours. The reduction in lifetime is expected due to the higher density of the Low-Coupling case. One sees that the High-Coupling case is much more sensitive to the position of the scraper and the Low-Coupling case is the least sensitive. In fact in the Low-Coupling case the lifetime is only impacted by the scraper at scraper values less than 2 mm. Also the Eta-Wave case is much less sensitive to the position of the scrapers. Earlier theoretical studies of the Swiss Light Source [4] showed similar dependencies.

Analysis

In the ALS the lifetime is strongly limited by Touschek scattering. After a particle is scattered, the energy of the particle changes. If this happens in a region of nonzero dispersion the energy change results in a horizontal oscillation. This can then result in an increase in the vertical motion through resonance excitation and particle diffusion. If the vertical motion is large enough, the particle will collide with the chamber. An illustration of this process is seen in Fig. 2 where a particle is launched with an initial offset of 12 mm horizontally, 1 mm vertically, and an energy offset of δ = 2% and tracked turn-by-turn with synchrotron oscillations and damping. In the figure one sees periods of rapid growth to large vertical amplitudes. At one point the particle reaches an amplitude larger than 4 mm which is the size of the vacuum chamber. To calculate the momentum aperture it is necessary to know how much energy can that particle gain or lose and still remain in the ring after a particle undergoes a Touschek scattering.

Another way [1, 5] to illustrate the effect of Touschek scattering is to plot the Amplitude versus energy at one point in the ring (e.g. the injection point) for a particle scattered at some point s in the ring. This is shown in Fig. 2 If the particle changes energy it will increase its amplitude. At the injection point the induced amplitude would be $\sqrt{\frac{H(s)}{\gamma(inj)}}\delta$ where $H = \gamma\eta^2 + 2\alpha\eta\eta' + \beta\eta'^2$. Next the particle will undergo synchrotron oscillations and slowly damp back to zero. During this time the particle may encounter a region of large diffusion causing the particle to become lost. To predict the size of the momentum aperture, it is necessary to map out all the regions that the particle may encounter after a given energy and amplitude change and to determine the largest energy change where no dangerous regions are encountered.

In order to understand the difference in the three cases, simulations were made on models fitted with measured response matrices [6, 7]. Using the fitted models the particles were tracked using a symplectic integrator [8, 9]. In addition we used a post processor [10] to compute the frequency maps. Because we were interested in the Touschek lifetime particles were launched at the injection point with various different initial amplitudes in x and δ, and a small fixed vertical amplitude in y of 0.05 mm and tracked without synchrotron oscillations or damping for 1024 turns or until lost. A $\pm$ 4mm aperture was included in the simulation.

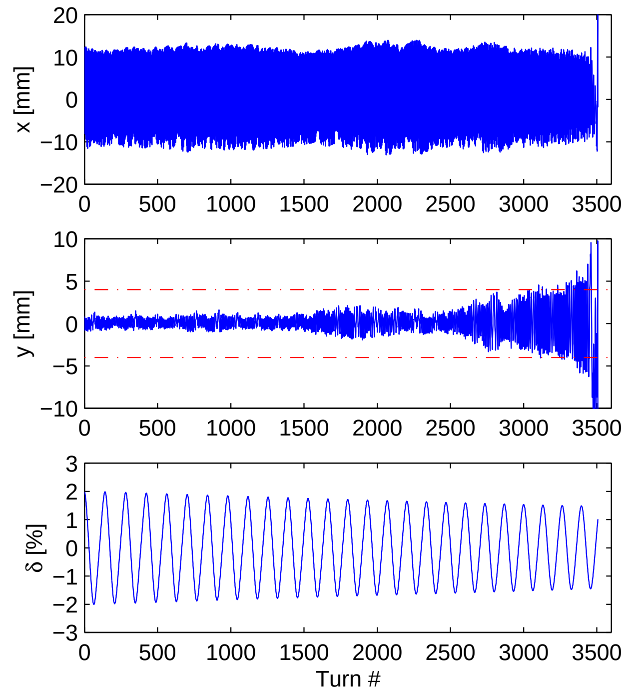

Figure 2: Simulation of the horizontal (top), vertical (middle), and longitudinal (bottom), position versus turn number of a particle which was launched with initial coordinate of x = 12mm, y = 1mm, and δ = 2%.

In Fig. 4 the initial coordinates of the particles that survived are plotted for all three cases. All initial conditions that survived are plotted in color and those that did not are not plotted. The color indicates the maximum vertical amplitude that a particle reached in the 1024 turns. Red corresponds to 4 mm, yellow to 2.5 mm and blue is less than one mm. Also on the plot the induced amplitudes are plotted as red lines. In each plot there are two sets of red lines. The steeper ones correspond to the induced amplitude for particles that get scattered in the arcs and the flatter lines correspond to particles that get scattered in the straight [1].

What determines the momentum aperture in the arcs and the straights is the maximum area inside the lines in where the motion can stably damp back to the closed orbit. One sees that the High-Coupling case in Fig. 4, is very different from the other two. In particular there is a loss region near $\delta = 0.02$ which in the High-Coupling case is wider and collapses rapidly if we limit the aperture. If one decreases the aperture from 4 mm to 3 mm for instance, the maximum δ reduces to about 0.018 due to this region. However this region does not strongly effect the other two cases until one reduces the gap further to about 2 mm. Also on the negative δ the aperture is reduced with respect to the other two cases from about 0.024 to 0.022 at 4mm for particles scattered in

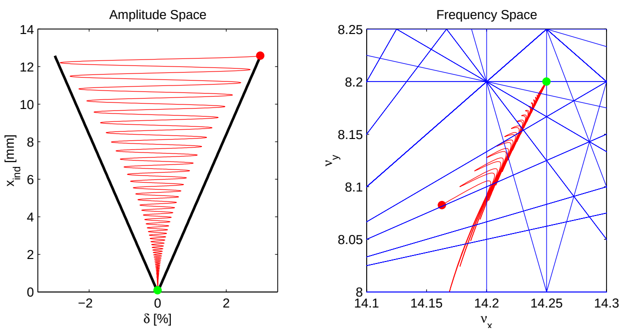

Figure 3: Particle motion in Amplitude (left) and Frequency space (right) after undergoing Touschek scattering

the arcs and that boundary is more sensitive to reducing the vertical aperture than the other two cases. In the High-Coupling case, the aperture starts to further reduce for a vertical aperture of about 2 mm whereas it reduces at 1 mm for the other two cases.

Using a frequency analysis post processor, we then can determine what is the cause. In all cases the region at $\delta = 0.02$ is determined by the linear coupling resonance which is more dangerous for the High-Coupling case. On the negative δ side the restriction are a number of resonances intersecting near $\nu_x = 14.15$ and $\nu_y = 8.075$ with the third order coupling resonance $\nu_x - 2\nu_y = -2$. Again the effect of these resonances as a function of gap is stronger for the High-Coupling case.

SUMMARY

These studies show that one can minimize the reduction of lifetime with vertical gap by controlling the beamsize with vertical dispersion rather than exciting the linear coupling resonance. With the Low-Coupling and Eta-Wave cases it is possible to reduce the half gap to 2.5 mm without impacting the lifetime. There is good agreement of the measured lifetime versus vertical gap and tracking studies. Frequency analysis of the tracking data suggests that the reduction of lifetime with gap in the High-Coupling case is due to strong excitation of linear and nonlinear coupling resonances.

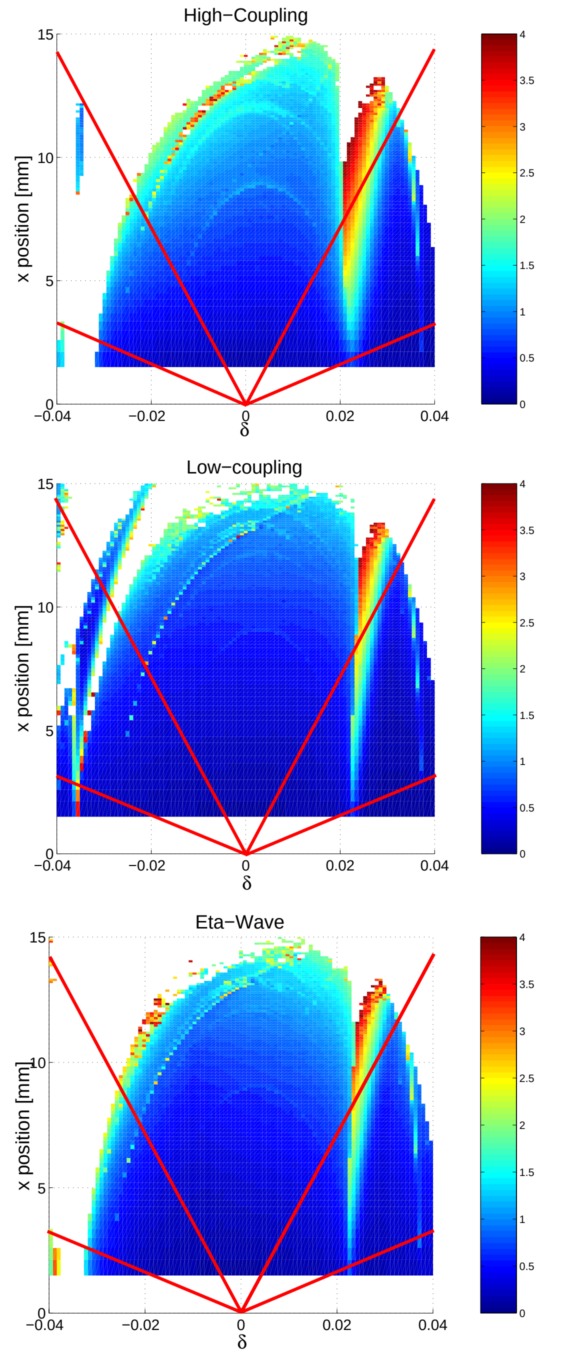

Figure 4: Off energy dynamic aperture for the High-Coupling, Low-Coupling, and Eta-wave versus gap.

REFERENCES

[1] C. Steier et al., Phys. Rev. E 65, 056506 (2002)

[2] D. Robin et al., Phys. Rev. Lett., 85, pp. 558, (2000)

[3] C. Steier et. al., “Coupling Correction and Beam Dynamics at Ultralow Vertical Emittance in the ALS”, Proceedings of this meeting.

[4] M. Boege, and A. Streun, in *Proceedings of the 18th Particle Accelerator Conference*, New York, 1999 (IEEE, Piscataway, NJ, 1999), 2430.

[5] A. Nadji, et al. in *Proceedings of the 17th Particle Accelerator Conference*, Vancouver, 1997 (IEEE, Piscataway, NJ, 1997), 1517.

[6] D. Robin, J. Safranek, and W. Decking, Phys. rev. ST Accel. Beams 2, 044001 (1999).

[7] J. Safranek, Nucl. Instr & Methods, **A388**, 27 (1997)

[8] R. Ruth, IEEE Trans. Nucl. Sci., **30**, 2669 (1983).

[9] A. Terebilo, in *Proceedings of the 19th Particle Accelerator Conference*, Chicago (IEEE, Piscataway, NJ, 2001), 1692.

[10] J. Laskar, in *Proceedings of 3DHAM95 NATO Advanced Study Institutes*, S’Agaro, 1995 (Kluwer Academic Publishers, Dordrecht, The Netherlands, 1999), 134.