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DEVELOPMENT OF A DECOHERENCE KICKER FOR THE ALS UPGRADE PROJECT (ALS-U)*

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Abstract

The Advanced Light Source (ALS) at Lawrence Berkeley National Laboratory is upgrading the existing storage-ring lattice to a nine-bend-achromat lattice with on-axis swap-out injection. The upgraded storage ring will provide a highly focused beam of about 15 µm transverse rms sizes at IDs, with a single bunch-train energy of about 60 J at 2.0 GeV. Such a small and intense beam could damage the transfer-line vacuum chambers in case of an extraction-element failure or the storage-ring vacuum chamber in case of an RF failure. To mitigate the potential damage, a fast kicker magnet (decoherence kicker) will be installed in the storage ring and activated to dilute the beam charge density either on the train to be swapped out a few 100's turns before extraction or on the whole beam after an RF failure. In this paper, we present both the physics and engineering designs of this decoherence kicker.

INTRODUCTION

The ALS-U is the Lawrence Berkeley National Laboratory project upgrade of the Advanced Light Source to a diffraction-limited light-source, delivering soft x-ray beams at least 100 times brighter than those of the existing ALS [1]. The upgraded ALS storage ring will occupy the same facility as the current ALS, replacing the triple-bend-achromat lattice with a nine-bend-achromat strong-focusing lattice with about 100 pm natural emittance. The price to pay for such a low emittance is a small dynamic aperture, which makes a conventional off-axis injection of the 300 nm booster beam unworkable. Therefore ALS-U will apply on-axis swap-out injection to exchange bunch trains between the 2.0 GeV storage ring and a full-energy 2 nm accumulator ring through the Accumulator-to-Storage-Ring and Storage-Ring-to-Accumulator (ATS/STA) transfer lines [2].

The storage ring will be operated at full coupling to maximize the Touschek lifetime, resulting in a round beam of about 15×15 µm transverse rms sizes at the insertion devices. The storage ring will be filled with 11 bunch trains, each consisting of 25 or 26 bunches, with total beam current of 500 mA. At 2.0 GeV, each train will carry about 60 J energy. In case of hardware failure during the swap-out process, such a small and intense beam from the storage ring could cause damage to the vacuum chambers of the downstream STA transfer line and accumulator ring. In case of an RF failure, the storage ring vacuum components could be damaged.

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To mitigate risk, a fast kicker magnet (decoherence kicker) will be installed in the storage ring to dilute the beam charge density either on the train to be swapped out ahead of extraction or on the whole beam after an RF failure is detected. The kicker is intended to deflect the electron beam onto a trajectory with a sufficiently large betatron-oscillation amplitude so that the nonlinear-detuning induced tune spread decoheres particle motion in the subsequent turns, effectively increasing the beams transverse size and reducing its density.

A factor 10 reduction in the beam peak transverse-density would make the ALS-U storage-ring beam density comparable to that of the existing ALS and represents a sensible design goal. In the following, we discuss the decoherence kicker particle-tracking studies, define its specifications and present the engineering design.

BEAM TRACKING STUDY WITH DECOHERENCE KICKER

The accelerator-simulation parallel-code Tracy [3] is used to study the effect of the decoherence kicker on the beam dynamics. The decoherence kicker is modelled as a dipole magnet, kicking the beam only during a single beam passage. Both horizontal and vertical kicks have been studied and similar results have been obtained from the tracking. However, the vertical kick is chosen as the baseline design since it offers advantage of avoiding direct incidence of synchrotron radiation on the stripline (see the following kicker design section). Tracking through the storage ring is done in a lattice with realistic systematic and random errors (magnet multipole errors, misalignments) including account of closed-orbit and linear-optics correction. The beam is represented as a 1 M particle 6D-gaussian matched distribution initially positioned at the kicker location on the closed orbit. The harmonic cavities are accounted for in the simulations and modelled as active devices. Collective and wake-field effects are not included in tracking.

Calculated from the tracking data, the peak density normalized to the initial-beam peak density is shown in Fig. 1 as a function of the number of turns following a 100 µrad angle kick. We observe oscillations that subside within the first 100 turns while on average the beam peak density steadily decreases. After about 150 turns, the density is below 6% of the original peak density. This defines the timing for a safe extraction of the beam from the storage ring into the STA transfer line. Figure 2 shows the density plots for the the initial beam and the beam at the 150th turn following a 100 µrad vertical kick. The beam size is increased by about

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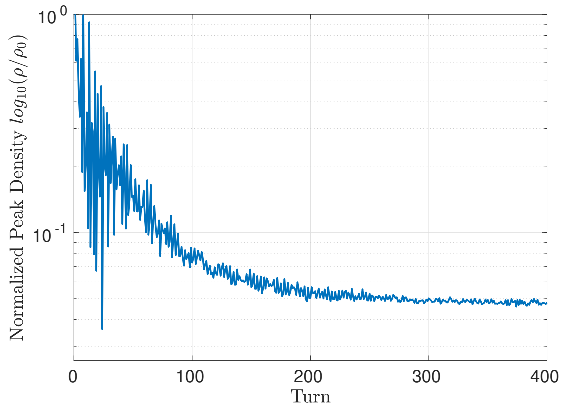

Figure 1: Peak density as a function of the number of turns starting from an initial 100 µrad vertical kick.

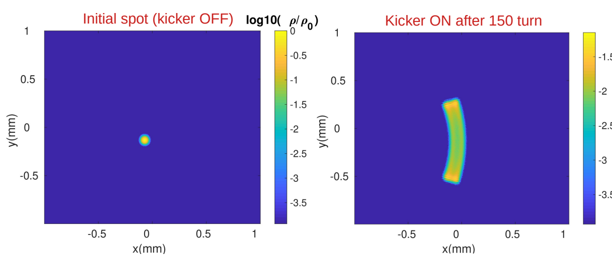

Figure 2: Initial beam density plot (left) and the one at 150 turn after the initial 100 µrad vertical kick (right).

a factor of 2 (H) x 5 (V) in horizontal and vertical directions respectively and the peak density is diluted by more than a factor of 10.

To meet the ≥ 10 dilution factor target, the kick angle should be large enough but not exceed the threshold where particle losses start to occur. To study the maximum allowable kick, we carry out a kick-angle scan. The result of the beam charge density and lost rate as the function of kicker angle is shown in Fig. 3. As we can see, the kick angle needs to be larger than 80 µrad to achieve a factor of 10 dilution, and less than 200 µrad to avoid any beam loss.

In case of beam dump due to RF failure, the decoherence kicker needs to be activated to dilute the whole 500 mA beam. Tracking, in this case, is carried out with the cavities turned off. Neglecting beam loading may, however, introduce a large error; we plan to revisit this issue in future studies. The results are summarized in Fig. 4. As shown in the figure, particle losses start at around the 260$^{\text{th}}$ turn when the beam density has already been diluted by a factor of ~30. Figure 5 shows beam density plot at different turns until the beam get loss. As we can see the beam size grows vertically, and the beam get lost in the vertical plane.

Table 1 summarizes the specification of the decoherence kicker. As mentioned before, the kicker has two operational modes: the extraction mode for swap-out injection and the beam dump mode due to RF failures. For the extraction mode, the kicker only needs to act on one swap-out train which consists of 25-26 bunches (2 ns spacing between each bunch) and has 10 ns gap between each train. Therefore, the flat-top pulse width needs to be 50-52 ns with less than 10 ns rise and fall time. For the beam dump mode, the kicker needs to act on the whole beam with a pulse width about of 655 ns.

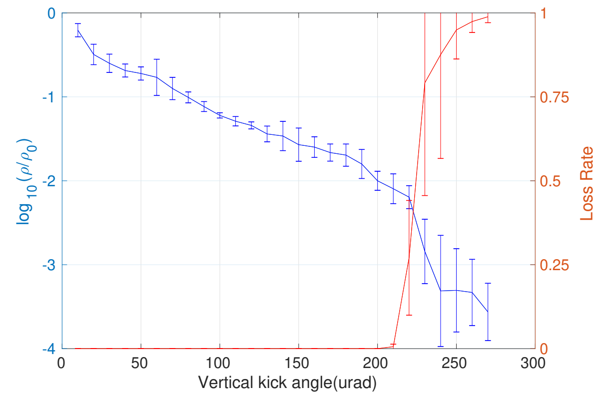

Figure 3: The beam charge density (blue) and loss rate (red) as a function of the vertical kick angle. The beam density is calculated at the 150th turn after the initial kick.

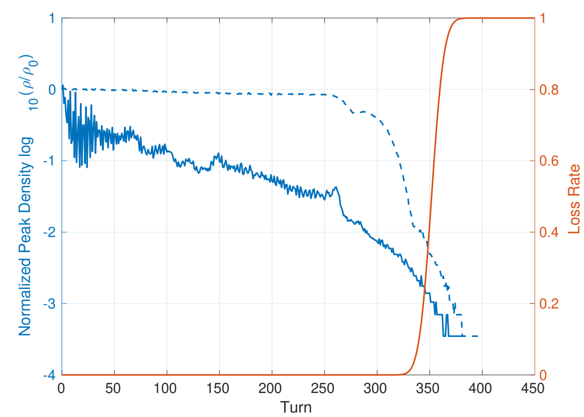

Figure 4: The beam charge density as a function of turn with cavity off and kicker on (blue solid) and off (blue dash). The lost rate (red solid) is plotted against the right y-axis as the function of turn.

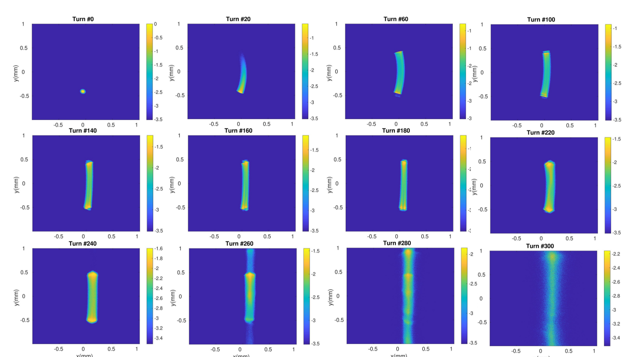

Figure 5: The beam density plots at different turns with cavity off and kicker on at the first turn.

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Table 1: Decoherence Kicker Specifications

bend angle	100 µrad
bend direction	vertical
striplines length	0.22 m
min aperture height	6 mm
min aperture width	8 mm
rise/fall time (5-95%)	10 ns
flat-top pulse width	50-52 ns (swap-out) 655 ns (beam dump)
flat-top ripple (+/-)	2%
inter-pulse ripple (+/-)	2%
pulse repetition period	30 s (swap-out) on request (beam dump)

KICKER AND PULSER DESIGN

The decoherence kicker design is derived from the ALS-U storage ring swap-out injection kicker [4]. It consists of a pair of 220 mm long, 50 Ω matched molybdenum striplines with an aperture of 6 mm (Fig. 6). Other relevant dimensions are shown in Fig. 7. The striplines are positioned above and below the beam, thus providing a vertical kick. However, since the Storage Ring operates near the betatron coupling resonance, the kicker is capable of exciting the beam on both transverse planes. The vertical arrangement of the striplines offers the advantage of avoiding direct incidence of synchrotron radiation on the striplines. The striplines are tapered to reduce beam coupling impedance and improve the characteristic impedance matching with the feedthroughs. Horizontal fenders in the vacuum chamber reduce the aperture to a still acceptable 10.4 mm and reduce the characteristic impedance mismatch between the kicker even mode, which is excited by the circulating beam, thus further reducing the beam impedance. Power absorbed from the beam is dissipated largely through thermal radiation towards the chamber and minimally conductively, through the three Macor supports and the two copper feedthrough posts. Baking the electrodes in atmosphere and an alkaline oxidizing process on the stainless steel chamber yield two coatings with emissivities >0.5 to aid the heat transfer. A 2 mm reduction in aperture in the upstream end of the vacuum chamber with a brazed water channel absorbs the synchrotron radiation fan. The electrodes can be accurately positioned by adjustable support posts that use a threaded mounting hole and locking nut, and once in position the chamber uses 1 mm diameter aluminum wire compressed by the stainless steel chamber body parts.

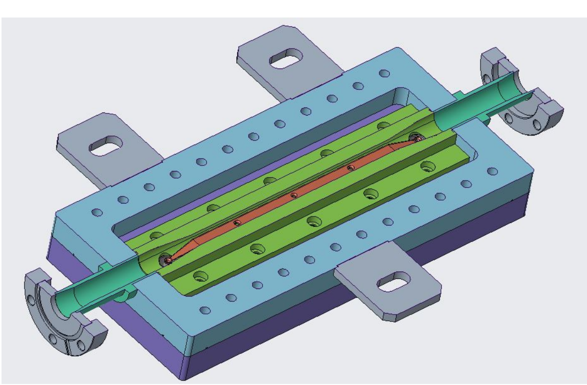

Figure 6: Bottom half of the Decoherence Kicker.

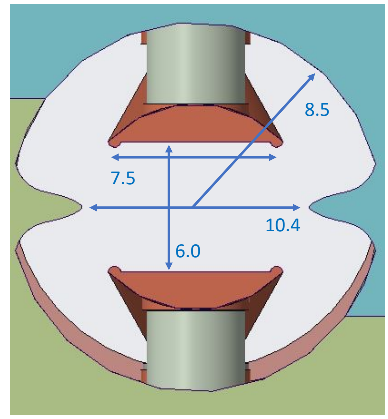

Figure 7: Transverse cross section of the Decoherence Kicker with principal dimensions in millimeters.

The pulser is a MOSFET-switched inductive voltage adder which provides both polarity pulses to drive the stripline electrodes at approximately +/- 2 kV. The output pulsewidth is determined by the incoming trigger pulsewidth. The ferrite cores in the inductive voltage adder can support operating with a 50-52 ns pulsewidth for bunch train swap-out or with a 655 ns pulsewidth for a full beam dump.

CONCLUSION

At ALS-U, a fast kicker magnet installed in the storage ring will be activated to dilute the beam charge density before beam extractions to the STA line or before beam dumps due to RF failures. The kicker magnet is based on a stripline design derived from the ALS-U swap-out injection kicker. To mitigate radiation damages from the intense SR beam, the beam charge density needs to be diluted at least by a factor of 10, which can be delivered by this kicker with a 100 µrad vertical kick.

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