ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-MOPAB118

THE IMPACT OF SHORT-RANGE WAKES ON INJECTION INTO THE ALS-U ACCUMULATOR RING*

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Abstract

As part of the ALS-U design, bunches with small charge will be added to the accumulator ring in a manner that initially leaves both the stored and injected bunches displaced from the nominal orbit. While the beam current is below instability thresholds, transient effects due to the combination of short-range wake fields and large initial displacements can have an impact on injection efficiency. In this paper, the impact of wake fields on the two bunches is detailed using the elegant simulation code, and different techniques to optimize the injection efficiency are explored.

INJECTION INTO ALS-U ACCUMULATOR RING

The ALS-U is an upgrade of the Advanced Light Source (ALS) to produce diffraction-limited radiation in the soft x-ray regime [1]. The storage ring will swap out single trains of 25 or 26 bunches at a rate of up to once every 30 seconds. The bunch trains will be prepared in a second ring, the accumulator ring (AR), which will itself be fed from the current Advanced Light Source booster in a top-off configuration. The high emittance of the bunches from the booster, combined with the smaller aperture of the AR vacuum chamber compared to the ALS, prevents returning the stored bunch to the reference orbit immediately after injection without significant injection losses.

The injection scheme, referred to as 3DK [2], utilizes two pre-injection kickers which only interact with the stored bunch, followed by injection of the bunch from the booster using a pair of septa, and then a third kicker (referred to simply as the "injection kicker") which simultaneously affects both the injected and stored bunches. This configuration allows for a large separation between the kickers, and offers a wide range of flexibility in terms of the final disposition of the two bunches.

A direct optimization of the injection efficiency leads to settings which give the stored bunch a significantly higher transverse excitation after the injection kicker than the injected bunch; this will be referred to as Mode A. These settings are driven by the larger emittance of the injected bunches and the narrow apertures in the AR (compared with the current ALS apertures). The maximum trajectory offset of the injected bunch is in fact slightly smaller than its rms width. The stored bunch, on the other hand, will have already equilibrated to a much smaller emittance and can be pushed closer to the walls of the vacuum chamber without incurring losses. Through single-particle tracking, Mode A is found to incur negligible losses for the stored bunch, and significantly less than 1% losses for the injected bunch.

SHORT-RANGE WAKES

This picture changes when short-range transverse wake fields are taken into account. The wake fields are well below the level of generating a transverse head-tail instability, with a threshold of 5.8 nC bunch charge compared to the nominal bunch charger of 1.15 nC. However, the injected bunch occupies most of the physical aperture of the vacuum chamber until the bunch becomes damped, and thus transient wakes can cause significant injection losses even in the absence of an instability. The injected bunch carries only 10% of the nominal charge, so the intensity of the wakes is determined by the trajectory offset of the stored bunch. The transverse short-range wake potentials have been calculated based on detailed models of each beamline element, and the combined total is shown in Fig. 1. These are obtained as a pseudo-Green's function [3] through simulating a comparatively short 1-mm bunch in the electromagnetic code CST Suite [4].

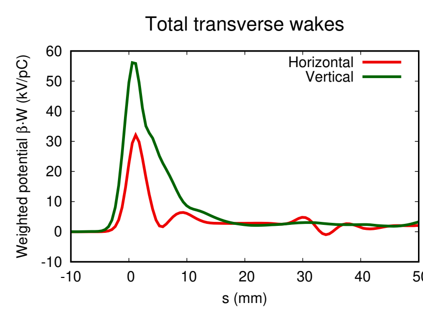

Figure 1: Transverse short-range wake field potentials for the ALS-U accumulator ring.

Simulations using the code elegant [5] show that wake fields prevent the stored bunch from completely decohering in phase, as seen in Fig. 2. The evolution of the bunches is shown in Fig. 3. Note that in the presence of wakes, the stored bunch does not grow as large as it does without wakes, and there is also a larger oscillation amplitude after around 2000 turns around the ring. Meanwhile, the injected bunch with wakes incurs a significant increase in both bunch width and displacement, peaking after 1500 turns (about 1 ms). Increased losses also occur about this time. There are modulations in the envelope of the centroid motion after this, but overall it takes many milliseconds for the transverse motion to damp out.

* This work was supported by the Director, Office of Science, Office of Basic Energy Sciences, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.
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For the nominal strength of the wakes, the injection efficiency for Mode A drops to 84%. The goal for AR injection is to have an injection efficiency of at least 95%. Thus, mitigation for the short-range wake fields is required.

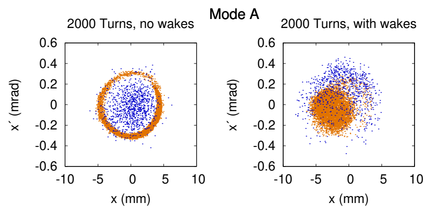

Figure 2: Distribution of the stored (orange) and injected (blue) electrons in the Mode A configuration after 2000 passes around the ring, both without (left) and with wakes (right).

MITIGATION STRATEGIES

The first mitigation option is to change the kicker settings and thus the disposition of the stored and injected bunches after the injection kicker. The wake fields change the optimum so that it is preferable to reduce the stored bunch excitation even at the expense of immediately scraping more of the injected bunch. Losing a few percent of the injected particles is acceptable if the overall injection efficiency could be maintained above 95%.

The re-optimized settings, Mode B, yields a transverse displacement for the stored bunch that is 0.76 times the value for Mode A, while the displacement for the injected bunch is a factor of 1.42 times the value for Mode A. Ignoring the wakes, this only increases injection losses by less than 1%. It is possible to avoid most of these additional losses with further adjustments, which are not considered in this paper. When wake fields are included, they are sufficiently smaller than those for Mode A that the final injection efficiency rises to 93%.

This result is still slightly below the target value of 95%, and furthermore it is desirable to have some safety margin in case the transverse wake potentials are larger than predicted. Two other mitigation strategies will be considered. The nominal chromaticity in the AR is 1.0 in both horizontal and vertical planes. The chromaticity increases the spread in tunes and makes it more difficult for the injected electrons to stay synchronized with the average transverse motion of the stored bunch. Raising the chromaticity even to 1.2 (in both planes) increases the injection efficiency for Mode B to 96.5%, while a chromaticity of 1.5 yields 98%. For Mode A, a chromaticity of 1.2 yields an efficiency of 93%. The change in chromaticity seems small, but injected electrons with high-amplitude trajectories will experience significant higher-order corrections to the chromaticity as well. It is interesting that changing only the vertical chromaticity can still significantly reduce the injection losses due to horizontal wake fields.

Finally, the injected bunch can be injected into the AR with an initial time delay relative to the stored bunch. The bunch length is much smaller than the width of the RF bucket, and the wake field potential has a characteristic width of about 5 mm (about 15 ps), comparable to the bunch length. Therefore, two bunches can be sufficiently separated so that the injected electrons will on average see wake fields that are significantly weaker than the peak fields near the stored bunch. Synchrotron motion is rapid compared to the time scale for losses to occur, so the periods when an electron catches up with the stored bunch will not last long enough to generate the same losses as for the case with no delay. A time delay of 100 ps, gives more than 98% injection efficiency in either Mode A or Mode B. Increasing the chromaticity to 1.2 as well gives an injection efficiency of almost 99%.

The dynamics of the bunches using Mode B and the other mitigations for the nominal wakes is shown in Fig. 4. The impact of the wake fields on the injected bunch is almost completely suppressed, except for a slight increase in the width of the injected bunch.

STRONGER WAKE FIELDS

Mitigations for the short-range transverse wakes have been found that achieve an injection efficiency above 95%. For all of the cases considered in this paper, the stored bunch incurs negligible losses. We also consider the possibility that the wake fields will be significantly higher than the expected values, to see if these mitigations are flexible enough to maintain the required performance.

Figure 5 shows the dependence of losses with number of passes around the ring, for the case of no wakes, the nominal wakes, and double the expected wakes. The combination of using Mode B with chromaticity equal to 1.2 and a time delay of 100 ps yields almost 99% injection efficiency for the nominal wakes and almost 98% for the doubled wakes.

The time delay is especially effective, and a delay of 100 ps is by itself sufficient to achieve the performance goals without any other mitigations. A delay of 200 ps is adequate even for four times the nominal wakes. However, it is observed that some kicker settings lead to enhanced losses for a large time delay, even when wake fields are ignored. This seems to be related to enhanced dispersion at high transverse amplitudes, in combination with synchrotron motion.

CONCLUSION

Short-range wake fields in the accumulator ring do have a serious impact on injection efficiency, even though the bunch charge is far below the head-tail instability threshold. There are several straightforward adjustments which can suppress these losses and achieve the desired injection efficiency even for significantly larger wake field potentials than expected. Here we have explored adjusting the kicker strengths and the chromaticities of the ring, as well as introducing a moderate time delay between the injection of bunches from the booster and the passage of the stored bunch. The goal of 95% injection efficiency can be achieved through a combination of these mitigations. The time delay is observed to be especially effective at reducing losses due to wake fields.

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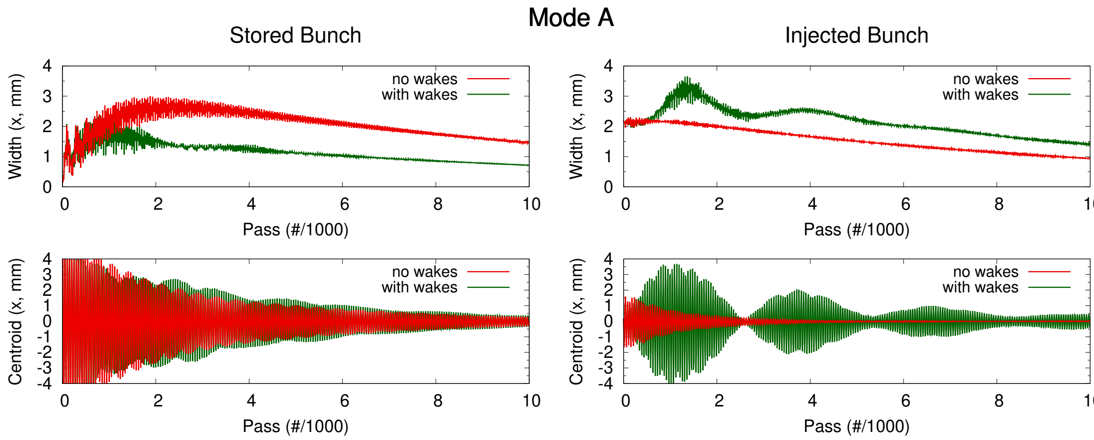

Figure 3: Dynamics of the stored and injected bunches without wakes (red) and for the nominal wakes (green), in the Mode A configuration.

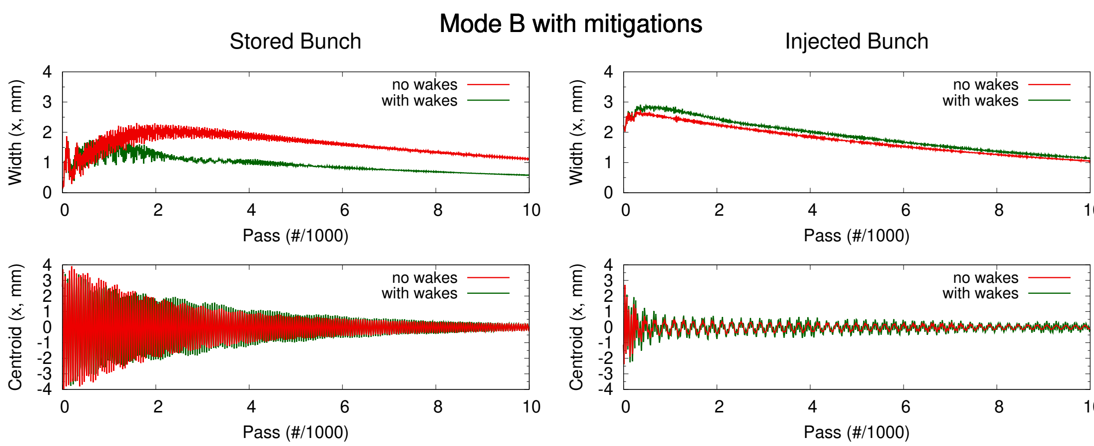

Figure 4: Dynamics of the stored and injected bunches without wakes (red) and for the nominal wakes (green), in the Mode B configuration with chromaticity increased to 1.2 and a time delay of 100 ps.

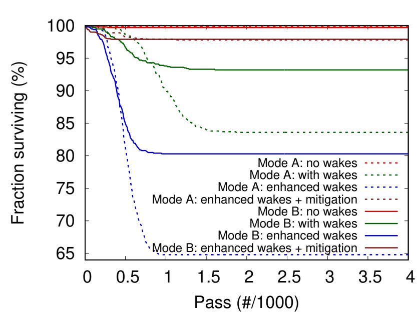

Figure 5: Dependence of losses with number of passes around the ring, for various configurations and for different scalings of the wake field.

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