THE THREE DIPOLE KICKER INJECTION SCHEME FOR THE ALS-U ACCUMULATOR RING

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Abstract

The ALS-U light source will implement on-axis swap-out injection of individual trains employing an accumulator between the booster and storage rings. The accumulator ring design is a twelve period triple-bend achromat that will be installed along the inner circumference of the storage-ring tunnel. A non-conventional injection scheme will be utilized for top-off off-axis injection from the booster into the accumulator ring meant to accommodate a relatively narrow vacuum-chamber aperture while maximizing injection efficiency. The scheme incorporates three dipole kickers distributed over three sectors, with two kickers perturbing the stored beam and the third affecting both the stored and the injected beam trajectories. This paper describes this "3DK" injection scheme, how it was chosen, designed and optimized, and how we evaluated its fitness as a solution for booster-to-accumulator ring injection against alternate injection schemes.

INTRODUCTION

As is common among 4th generation light source projects, the dynamic aperture of the ALS-U storage ring is small and requires particular attention [1]. To inject into the small dynamic aperture, ALS-U will build an intermediary accumulator ring (AR) between the booster and storage ring which allows for on-axis swap-out injection of individual trains. The AR has a 2 nm-rad natural emittance, which is much smaller than the 300 nm-rad emittance of the booster and can be injected with nearly 100% efficiency into the storage ring. It is designed and instrumented to store an entire full-current 26-bunch train. Storage ring current will be maintained by swapping out its lowest current train for a full current train from the AR (the storage ring will contain a total of 11 trains). Trains in the AR are restored to full current by off-axis top-off injection from the booster. The beam parameters for the AR and SR are summarized in Table 1.

The AR is similar in layout to the existing ALS, though it has tighter space constraints. It was shrunk to fit along the inner circumference of the storage ring tunnel by reducing the length of its straights, thereby reducing the space available for injection components. In order to meet egress it is mounted overhead, above the tunnel access doors. To simplify the support structures, the AR's vacuum chamber is shrunk to make the magnets less bulky, which has the consequence of shrinking the machine acceptance. In consideration of these constraints, while recognizing that the AR can tolerate a significant injection transient, we have developed a simple and nearly 100% efficient injection scheme,

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coined "3DK", that distributes 3 single-turn dipole kickers over three consecutive sectors in combination with a pair of thick and thin pulsed septa, depicted in Fig. 1.

Table 1: Parameter List of the ALS-U Accumulator Ring and Storage Ring. Quoted Emittances Ere Those Given by Radiation Integrals for the Uncoupled Lattice

	AR	**SR**
Beam energy, E	2.0 GeV	2.0 GeV
Circumference, C	182.122 m	196.5 m
# of sectors	12	12
Tune, ν_x/ν_y	16.221/8.328	41.358/20.354
Emittance, ϵ_{x0}	1.8 nm	91.8 pm
Energy spread, σ_δ	8.5×10^{-4}	9.4×10^{-4}
Energy loss/turn, U_0	285 keV	217 keV
Harmonic number, h	304	328

THREE DIPOLE KICKER INJECTION SCHEME

The first two of the three dipole kickers (located in sectors 11 and 12) kick only the stored beam and place it on a trajectory that partly compensates the main injection kick received in sector 1. The two kickers provide control over the offset and angle of the stored beam as it passes the injection septum. Both the stored and injected particles follow a non-zero trajectory through the following arc. The main injection kicker kicks both the stored and injected particles onto stable (but not closed) trajectories. Table 2 shows the parameters and results of the various injection modes.

The on-axis injection mode is expected to be useful for beam threading in early commissioning, but the large amplitude of the stored beam transient limits misalignment tolerance and generates unacceptably large short range wake fields. The closed stored bump mode only allows for 33.6% injection efficiency. It is included here as a reference.

The nominal "balanced" configuration (Mode A), shown in Fig. 2 fits nearly 100% of the injected particles within the acceptance with no appreciable losses in the stored beam. It is optimal with respect to injection efficiency while keeping the stored beam transient reasonable. However, when short range wake fields are included, the fields generated by the stored beam cause a loss of 16.4% of the injected particles.

By accepting slightly larger losses of the injected beam to the dynamic aperture, the stored beam transient amplitude can be reduced from 2.44 mm to 1.86 mm. This is the Mode B parameterization, and is the optimum when wake
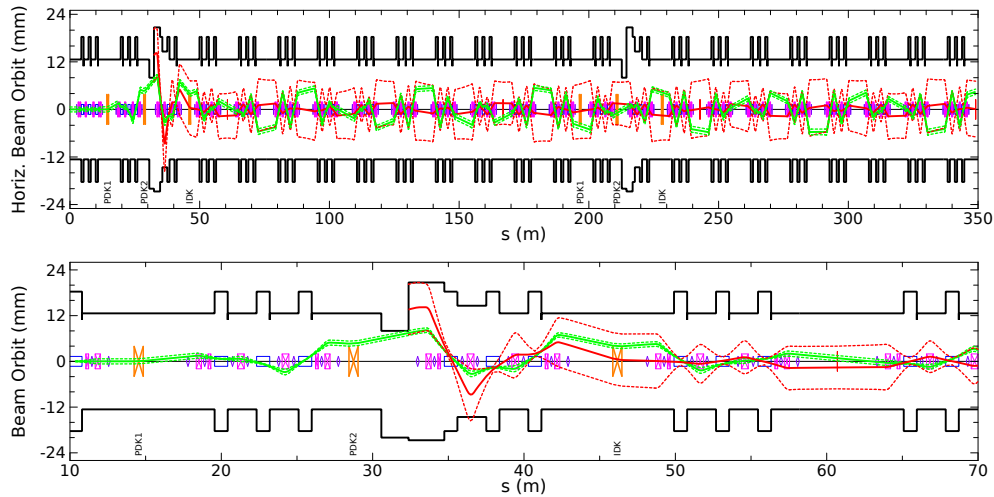
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Figure 1: Trajectories of the stored (green) and injected (red) beams during an injection cycle for "Mode A". Dashed lines delineate 3σ of the beam size. Locations of pre-kickers PDK1, PDK2, and IDK as labeled.
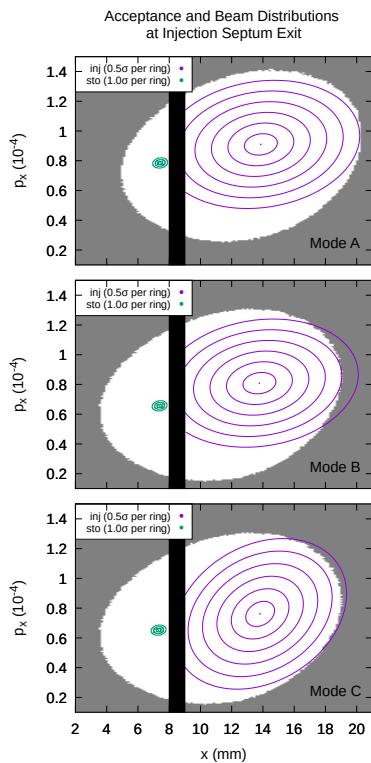

Figure 2: Injected and stored beam profiles out to 3σ at septum exit during an injection cycle. The white region is the acceptance in x-x' space at the septum exit. The x-x'-space septum image is drawn in black and is 1 mm thick with its inward edge 8 mm from the stored beam reference trajectory.

fields are taken into consideration. It reduces short range wake losses to 6.8%.

Mode C applies injection mismatching similar to that in [2]. Reducing the stored beam transient for Mode B

required reducing the strength of the main injection kicker. This in turn required bringing the incoming injected beam closer to the septum sheet, which increases injected beam losses on the septum sheet. To recover these losses, we mismatch the optics of the injected beam so as to fit it better within the available machine acceptance after taking the thin septum sheet into account. By reducing β_x of the incoming beam from 14.82 m to 11.33 m, transfer line losses on the septum sheet are reduced to 0.48%.

Short range wake predictions are subject to large uncertainty and so we have evaluated additional methods for mitigating their effects. These are discussed in detail in [3] and bring the predicted losses due to short range wakefields to the 1% level. One method is to delay the injected particles about 100 ps such that they sample the peak of the short range wakes only briefly during their synchrotron oscillations. Another method is to increase the chromaticity from the design value of 1 to 1.2.

The accumulator ring is stable against multibunch HOM modes with radiation damping alone. However, some of the higher order resistive wall modes exceed the radiation damping time and the AR will depend on transverse multibunch feedback (TFB) for stability. During an injection cycle, the TFB will detect the transient of the stored beam and apply kicks to damp it. Unfortunately, these kicks will anti-damp the injected particles since the stored beam and injected particle transients are 180° out of phase. To prevent the loss of injected particles as the TFB responds to the injection transient, it will be masked for those 4 buckets into which charge is injected. Masking the buckets reduces the ability of the TFB to damp multibunch instabilities and so we have investigated the situation using a multi-bunch tracking simulation that incorporates feedback and resistive wall wakes. The study, documented in a dedicated paper at this conference [4], shows that while the effectiveness of the TFB is significantly impacted by the masking, the beam remains multi-bunch stable.

Table 2: Injection Modes Achieved by Various Pulsed Injection Element Strengths Transfer Line Optics

		On-axis Injection	Closed Stored Bump	Mode A	Mode B	Mode C
Injection element strengths	Septum (mrad)	35.82	35.85	35.85	35.72	35.67
	Pre-kicker 1 (mrad)	0.37	.49	0.383	0.417	0.417
	Pre-kicker 2 (mrad)	1.1	0.76	1.04	0.933	0.933
	Inj. kicker (mrad)	1.2	.61	1.11	0.987	0.987
Post-injection cycle residuals	Stored beam rms (mm)	3.54	0.0	3.00	2.27	2.31
	Stored beam max (mm)	6.32	0.0	5.39	4.18	4.18
	Injected beam rms (mm)	0.0	4.58	0.898	1.24	1.22
	Injected beam max (mm)	0.0	8.16	1.59	2.21	2.17
Transfer line	β_x at BTA exit	14.82	14.82	14.82	14.82	11.33
	Septum losses (%)	0.89	0.89	0.89	1.05	0.48
AR Capture losses	no wakes (%)	–	66.3	0.36	0.91	0.46
	with wakes (%)	–	–	16.4	6.8	6.9
	with wake mitigations (%)	–	–	0.7	1.1	1.0

COMMISSIONING SIMULATION

To evaluate the robustness of the injection scheme to machine imperfections, the injection efficiency is evaluated using AR and Booster-to-Accumulator transfer line (BTA) lattices obtained after undergoing a process of simulated commissioning [5]. Simulated commissioning applies an ensemble of misalignment and powering imperfections to the lattice and corrects it following a procedure of beam threading and LOCO [6].

Optimizing the injection efficiency in the presence of errors requires small adjustments to the nominal dipole kicker angles, with the exact value depending on the error realization. For each misaligned and corrected lattice, the injection element strengths are scanned about their nominal values to restore injection efficiency and stored beam survival. Temporal and spatial imperfections, such as the time and spatially varying septum leakage fields and the shot-to-shot stability of the pulsed elements as well as their flat-top uniformity, are applied to the injection components during this scan.

Figure 3 shows the cumulative density functions (CDF) of the injection efficiency for 50 error realizations, versus 0%, 4%, and 10% variation of the main injection kicker pulse along the bunch train.
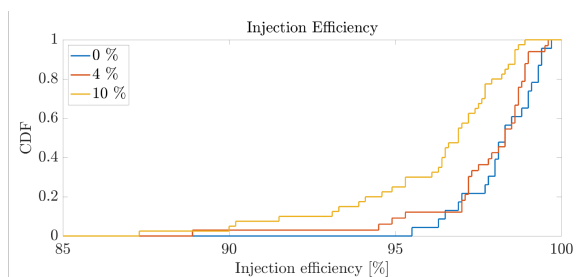

Figure 3: Injection efficiency following the full misalignment and correction for 3 different amounts of main injection kicker pulse non-uniformity along the bunch train.

CONCLUSION

The three-dipole injection scheme is well-fit to the particular requirements of the ALS-U accumulator ring. It delivers nearly 100% efficiency to enable quick top-off of ALS-U bunch trains for swap-out injection. By distributing the injection kickers across multiple straights, it meets the AR's tight space constraints. It accomplishes this by exploiting the fact that the AR can tolerate an injection transient. The scheme is robust in the presence of machine imperfections, and versatile in that it is compatible with various methods for mitigating the effects of short range and long range wake fields. Finally, the injection scheme relies only on conventional kicker technology and so frees up R&D resources.

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