ON-AXIS SWAP-OUT R&D FOR ALS-U*

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Abstract

The ALS-U upgrade promises to deliver diffraction limited performance throughout the soft x-ray range by lowering the horizontal emittance by a factor of 40 compared to the current ALS. One of the consequences of producing a small emittance is a small dynamic aperture, although the momentum acceptance will remain large enough for acceptable beam lifetime. To overcome this challenge, ALS-U will use on-axis swap-out injection to exchange bunch trains between the storage ring and an accumulator ring. On-axis swapout injection requires special fast pulsers and state-of-the-art stripline kicker magnets. This paper reports on the results of the on-axis swap-out injection R&D program, including beam tests of a complete stripline kicker/pulser system on the current ALS and the development of methods to speed up beam based commissioning after the upgrade shutdown.

INTRODUCTION

The ALS-U design replaces the existing triple-bend achromat with a stronger-focusing multi-bend achromat [1, 2] aiming at producing round beams of approximately 50 pm-rad emittance, about 40 times smaller than the horizontal emittance of the existing ALS, and thus leading to a big increase in coherent flux. The current baseline design is a nine-bend achromat. ALS-U was evaluated in June 2016 by a Basic Energy Sciences Facility Upgrade Prioritization Subcommittee as 'Absolutely Central' to contribute to world leading science and as 'Ready to Initiate Construction' and received approval of Mission Need (CD-0) from DOE/BES in September 2016. Table 1 summarizes the main parameters and Figure 1 shows the nine bend achromat as well as the new accumulator ring.

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Table 1: Parameter List Comparing ALS with ALS-U

Parameter	Current ALS	ALS-U
Electron energy	1.9 GeV	2.0 GeV
Beam current	500 mA	500 mA
Hor. emittance	2000 pm-rad	~50 pm-rad
Vert. emittance	30 pm-rad	~50 pm-rad
rms beam size (IDs)	251 / 9 µm	≤10 / ≤10 µm
rms beam size (bends)	40 / 7 µm	≤5 / ≤8 µm
Energy spread	9.7×10^{-4}	$\leq 9 \times 10^{-4}$
bunch length (FWHM)	60–70 ps (harm. cavity)	120–200 ps (harm. cavity)
Circumference	196.8 m	~196.5 m
Bend angle	10°	3.33°

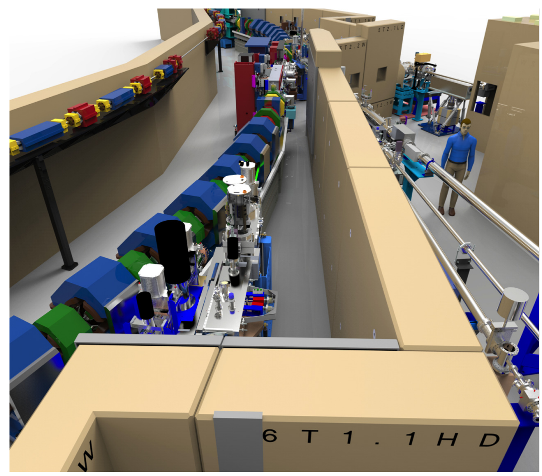

Figure 1: CAD model of ALS-U showing the existing accelerator tunnel with the new storage and accumulator rings.

ON-AXIS SWAP-OUT INJECTION

It is planned to use on-axis injection [3,4] with bunch train swap-out and an accumulator ring. The new accumulator will be housed in the storage ring tunnel and will act as a damping ring. Its lattice will allow for off-axis injection from the booster and the extracted low emittance beam is injected on-axis into the small dynamic aperture of ALS-U. This allows a performance leap over rings that use stacking in the main ring. On-axis swap-out injection requires special fast pulsers and state-of-the-art stripline kicker magnets (see Fig. 2).

Pulser: Inductive Voltage Adder

We have developed prototype pulser hardware in house and have demonstrated pulses with the necessary very short rise and fall times [5], as well as the required flat-top length and flatness for an inductive voltage adder (see Fig. 3). We

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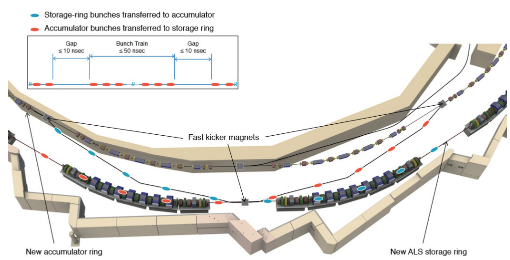

Figure 2: Illustration of the planned swap-out process between the full energy accumulator and the storage ring of ALS-U.

also explored commercially available options. At least two solutions (including the in house developed inductive adder) have demonstrated the capability to fulfill the minimum requirements to allow swap-out injection. Ongoing work concentrates on further minimizing the perturbation of neighboring bunches/bunch trains.

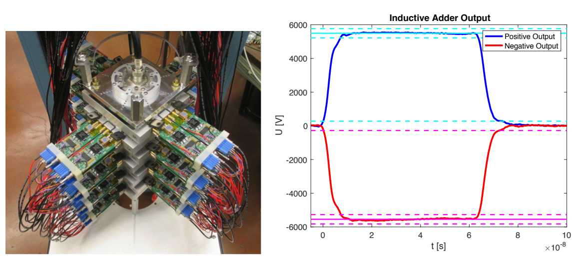

Figure 3: (Left) Full assembly (8 stages) of inductive adder. (Right) Voltage output of inductive adder at 105% of nominal setpoint.

Stripline Kicker

A small gap stripline kicker with 6 mm full gap between its electrodes, the same as needed for ALS-U, was designed and built [6]. This kicker has design features to minimize its beam impedance (see Fig. 4). This includes tapering of the electrodes, highly tailored electrode shapes, custom feedthroughs, RF gaskets for all flanges and optimized transitions and photon masks.

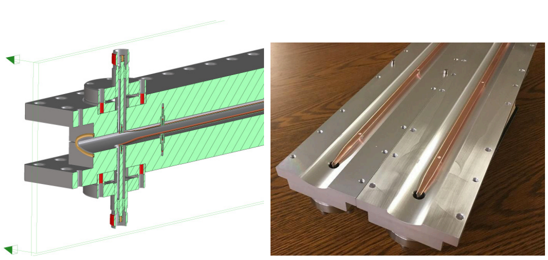

Figure 4: (Left) CAD model of stripline kicker with small gap and tapered electrodes. (Right) Prototype of stripline kicker.

To allow the electrodes to get rid of the power deposited by wakefields via radiative cooling, a plasma deposition process was used to deposit a one micron thick (black) CuO layer (see Fig. 5) increasing the emissivity of the electrodes above 0.5. A grade of copper with a high annealing temperature was used. The stainless steel body was chemically treated to also increase its emissivity (> 0.5). High bandwidth (8 GHz) attenuators/loads are used and all feedthroughs are actively cooled.

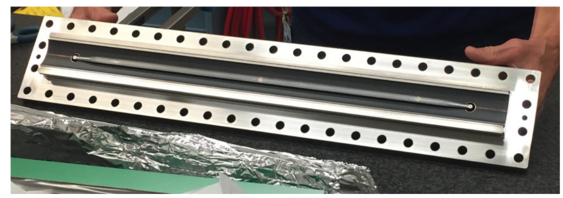

Figure 5: Picture of the top assembly of the stripline kicker, showing the copper stripline electrode and the stainless body which have been coated and treated to increase the emissivity.

We first characterized a cold model of the kicker and later the prototype to be installed in the ALS for its longitudinal as well as transverse impedance, used time domain reflectometry (TDR) measurements (see Fig. 6) to characterize its transmission properties and measured the magnitude and time dependence of the magnetic field on the bench. We also fiducialized the magnet and carried out extensive vacuum tests and cleaning. After all of these tests the stripline kicker was installed in the ALS during this winter's upgrade shutdown in February 2017 (see Fig. 7).

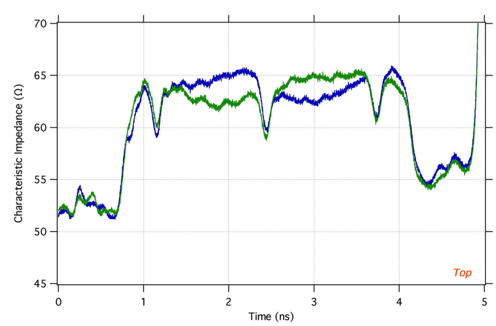

Figure 6: TDR measurements of the top and bottom striplines of the kicker. In the measurements, only one electrode is excited. The nominal impedance for that case is about 64 Ohms.

Beam Tests in the ALS

After installing the kicker, we first verified the electrical properties of the striplines, feedthroughs and attenuators by measuring single bunch beam signals at low current.

Next, we checked the clear aperture of the kicker as well as its alignment, verifying the design and mechanical fiducialization. Afterwards we carefully raised the current and measured heating, while monitoring the beam signals from the kicker. We operated the ALS with the kicker installed at the nominal current of 500 mA and have seen no reduction

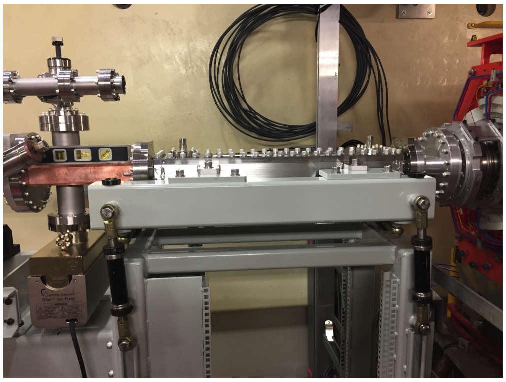

Figure 7: Stripline kicker with 6 mm full aperture between the striplines installed in the ALS.

in the TMCI threshold due to the kicker. This verifies the impedance design of the stripline kicker.

We also kicked the ALS beam with this stripline kicker and used turn-by-turn BPMs to measure the pulse amplitude, duration, and shape, as well as its reproducibility (see Fig. 8). The results confirm that the system fulfills the minimum requirements for bunch train swap-out in ALS-U.

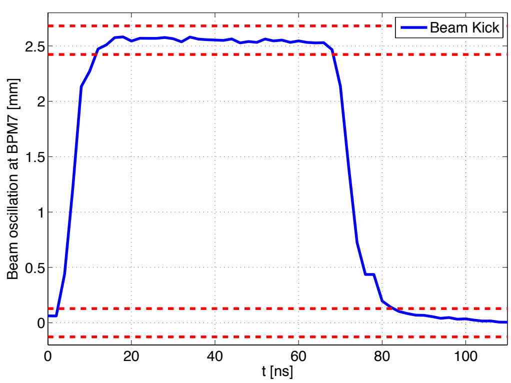

Figure 8: Full beam test mapping the beam integrated kick with turn-by-turn BPMs for the stripline kicker and pulser installed in the ALS.

BEAM-BASED COMMISSIONING

We are also improving beam-based commissioning techniques, especially for just injected beam using single or multiturn mode of BPMs for fast and accurate identification of lattice errors (misalignments, strength errors, coupling, etc.).

First, we implemented algorithms that deal directly with orbit/trajectory errors. One important aspect is beam-based alignment, which is necessary to reduce absolute BPM errors from several hundred microns to typically tens of microns. It usually is done with stored beam. However, initial BPM errors before beam based alignment might be a critical limitation to being able to quickly achieve stored beam in MBAs. We have demonstrated on the ALS that it is possible to achieve beam based alignment resolution with just the first turn data of freshly injected beam to accuracies much better than the many hundreds of microns of BPM construction errors. We achieve a resolution of about 50 microns (see example in Figure 9).

We have also demonstrated quick convergence of first/few turn trajectory correction. This correction iteratively adds more corrector magnets and more turns of trajectory data, as the correction progresses. It starts with just the first turn, followed by few turn trajectories, followed by closed orbit correction based on just tens of turns. We also incorporated a tune correction that goes hand in hand with the orbit correction. The algorithm has been tested after introducing random magnet errors in the ALS. It also received its first full test during the 2017 ALS startup, where many new small apertures were added to the storage ring. The beam-based correction algorithms allowed to re-establish stored beam much more quickly than in similar situations after similar shutdowns. In fact, stored beam with small orbit errors was stored just minutes after the last set of software was tested.

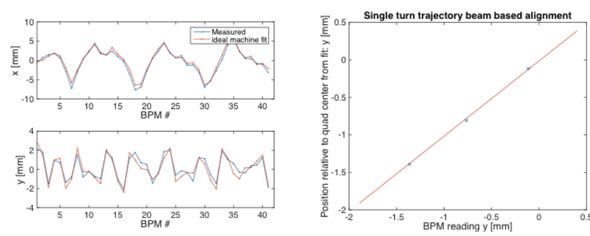

Figure 9: (Left) First turn trajectory of injected beam in the ALS - intentionally launched off-axis in the vertical plane – as well as trajectory fits using the ideal machine model. (Right) beam based alignment measurement for one quadrupole with the result agreeing within 50 microns with stored beam beam-based-alignment measurement.

SUMMARY

We have retired the main technical risks of on-axis swap-out injection by constructing a very small gap stripline kicker as well as an inductive voltage adder capable of producing the pulses necessary for ALS-U, installing the system into the ALS and demonstrating its high current performance as well as kick performance with beam in conditions representative for DLSRs. In parallel beam-based commissioning algorithms were devised, coded and beam tested to make use of the resolution of state-of-the-art turn-by-turn BPM systems to reduce the needed commissioning time for rings.

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