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INJECTION AND EXTRACTION KICKERS FOR THE ADVANCED LIGHT SOURCE UPGRADE PROJECT (ALS-U)*

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Abstract

The Advanced Light Source upgrade project (ALS-U) at Lawrence Berkeley National Laboratory includes the construction of a new accumulator ring and the replacement of the existing storage ring. Both ferrite-loaded kickers and stripline kickers are used in the ALS-U design for injection, extraction, and decohering the beam before storage ring extraction. In the accumulator ring, the rise and fall time requirements are based on the single bunch revolution time of 608 ns which allows the use of ferrite-loaded kickers. The 10 ns spacing between bunch trains in the storage ring requires stripline kickers to meet the rise and fall time requirements. Both types of kickers are driven by solid-state inductive voltage adders using MOSFETs. Modeling and prototyping efforts have characterized the kicker impedance and beam-induced heating, and explored the effects of beam strike on electrodes.

INTRODUCTION

The Advanced Light Source Upgrade Project (ALS-U) at Lawrence Berkeley National Laboratory will increase the brightness of soft x-rays for users by a factor of 100 compared to the existing ALS [1]. The triple-bend-achromat storage ring lattice will be replaced with a nine-bend-achromat lattice to achieve a focused beam with a natural emittance of approximately 100 pm. Injection into the small-aperture storage ring requires on-axis swap-out injection to exchange bunch trains between the 2.0 GeV storage ring and a full energy accumulator ring through the ATS/STA transfer lines [2].

FERRITE-LOADED KICKERS IN THE ACCUMULATOR RING

The Booster-to-Accumulator Ring (BTA) transfer line kickers and Accumulator-to-Storage Ring transfer line (ATS/STA) kickers are similar in design (Table 1). Each kicker assembly consists of a brazed ceramic chamber that sits inside CMD5005 ferrite blocks (Figs. 1, 2, and 3). The BTA kicker chamber is 0.7 m long and the ATS/STA kicker chamber is 1.1 m long. The inner diameter of each chamber is coated with titanium by Brookhaven National Laboratory to reduce the beam coupling impedance of the kicker. The copper bus bars at opposite polarity are fed from HN connectors from one end and are terminated into a matching resistor at the other end. There are redundant thermocouples to monitor the temperature of the ceramic and ferrite and a B-dot pickup loop to monitor the pulsed magnetic field. A thermal study showed that 100 W on the interior surface of the ceramic chamber and 200 W on the interior surface (worst case) of the ferrite block results in acceptable maximum temperatures of 78°C and 75°C, respectively. Simulations do not show appreciable power deposition in the ceramic chamber with the nominal 50 mA stored beam in the accumulator ring. A prototype BTA primary kicker will be installed on the current ALS storage ring to validate the beam-induced heating calculations (Fig. 4).

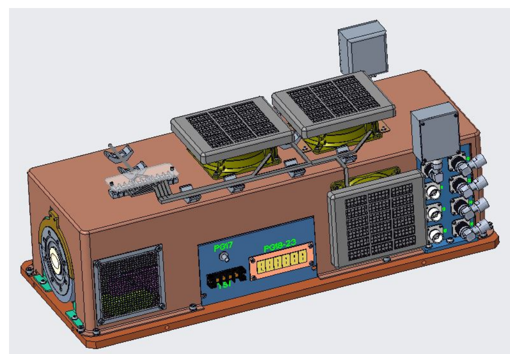

Figure 1: Complete BTA ferrite-loaded kicker assembly.

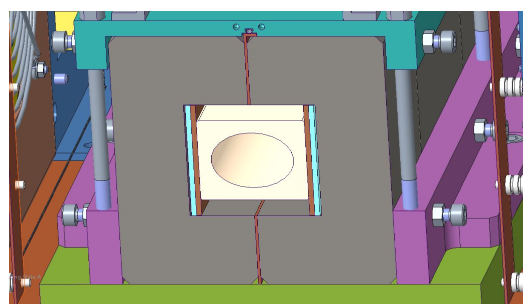

Figure 2: BTA ferrite-loaded kicker cross section.

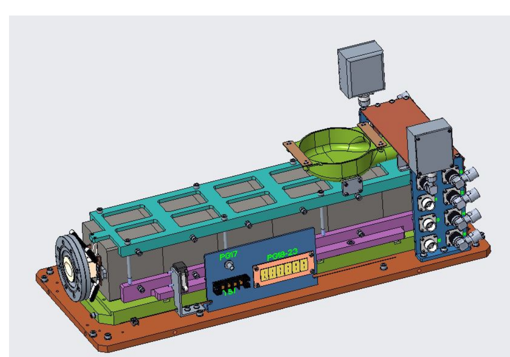

Figure 3: BTA ferrite-loaded kicker assembly without the cover.

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Table 1: Ferrite-Loaded Kicker Specifications

Kicker	BTA	ATS/STA
bend angle	1.1 mrad	4 mrad
kick direction	horizon-tal	vertical
length	0.7 m	1.1 m
min aperture height	14.5	8 mm
min aperture width	32.5	30 mm
rise/fall time	250 ns	250 ns
flat-top length	50-52 ns	50-52 ns
flat-top ripple (+/-)	2%	2%
inter-pulse ripple (+/-)	2%	2%
repetition period	1 s	30 s

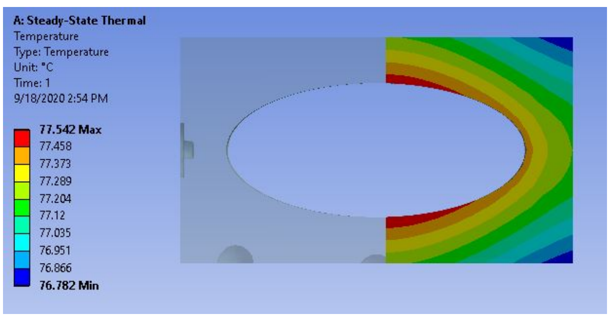

Figure 4: Thermal modeling of the ceramic chamber with 100 W of power dissipation. Ducting routes air from fans on the cover to cool the ceramic chamber and the ferrites.

STRIPLINE KICKERS IN THE STORAGE RING

Swap-out Kicker

The swap-out process [3] to inject and maintain 500 mA in the storage ring relies on a fast kicker capable of providing a nominal 3.5 mrad horizontal extraction kick to a designated bunch train after its charge has depleted below 90% (Table 2). The same kick will simultaneously inject a full current bunch train on axis from the accumulator ring. Given the 10 ns separation between bunch trains, a fast pulser was designed based on an inductive voltage adder, which drives the narrow-gap stripline kicker. In order to satisfy the field rise and fall time requirements, the kicker structure cannot add more than 3.5 ns to the pulser waveform rise and fall times. This reduces the maximum length of the striplines to approximately 500 mm. Approximately 2 meters of available length in the injection straight are used to install four stripline pairs (Fig. 5). This approach limits the necessary pulser voltage to less than ±6 kV and allows using commercial HN feedthroughs. The striplines feature 35 mm long tapers on each end to reduce their beam coupling impedance (Fig. 6) and to improve the characteristic impedance matching to the 50 Ω feedthroughs. Three Macor supports along the length of each stripline help in achieving and maintaining alignment in the presence of beam-induced heating, which is limited by impedance-control measures (tapers and ground planes between the striplines). Since the deflected bunch train diverges from the circulating beam in excess of 3 mm which is more than the half-gap between striplines, the outer stripline pairs have been slightly angled to maintain the maximum possible distance from the circulating beam, while avoiding scraping from the deflected bunch trains.

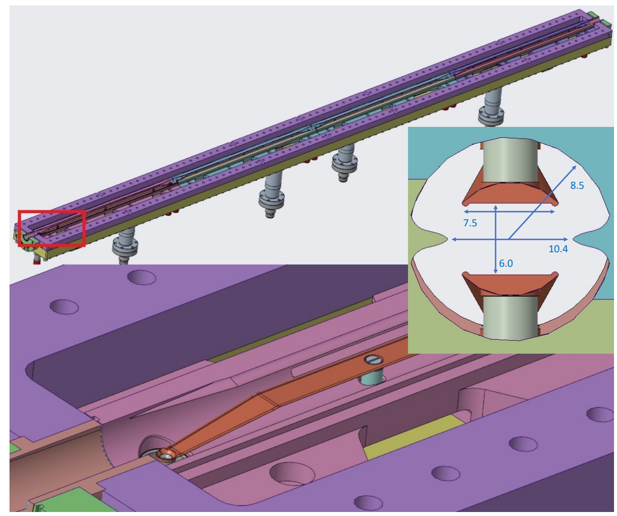

Figure 5: Swap-out kicker 4-module assembly (top), stripline dielectric support and taper (bottom), and transverse section with dimensions in mm (insert).

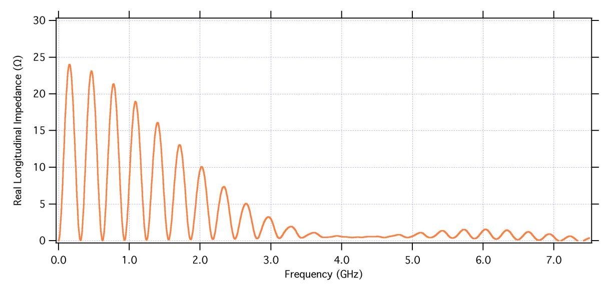

Figure 6: Real longitudinal impedance of the tapered stripline kicker.

Accurate positioning of the striplines within the vacuum chamber is critical, given the very small separation from the deflected beam and the necessity of keeping the circulating beam as far away from the striplines as possible to reduce heating. Considering the 6 mm aperture and the estimated transverse beam jitter, our target is to install the striplines within 200 µm of their nominal position. To achieve this target, we can take advantage of the strong dependence of the stripline characteristic impedance, which can be measured with a benchtop TDR setup, on its distance from the chamber surface. Fig. 7 shows incremental alignment steps on a stripline for a prototype kicker. The measurement is performed simultaneously with the alignment procedure with the kicker opened in half, so that the stripline is accessible. The characteristic impedance of the half kicker was evaluated to be 64 Ω using an electrostatic analysis code.

Copper striplines were successfully tested on the ALS with the same beam power. Further analysis of thermal ex-

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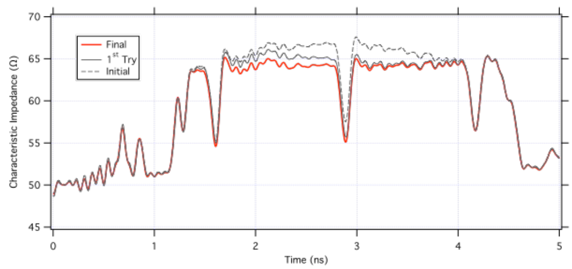

Figure 7: TDR measurements used for prototype stripline alignment, clearly identifying the location of the three Macor supports.

pansion under wakefield-induced heating and in the presence of synchrotron radiation, and concerns regarding the potential for cumulative damage due to occasional impact with incoming/outgoing bunch trains, steered the material choice for the production electrodes to molybdenum (Fig. 8). The roughly three times higher electrical resistivity is more than offset by the three times lower thermal expansion coefficient and more than four times higher melting point, since beam heating only increases from 0.7 to 2 W per stripline, while heating from synchrotron radiation is substantially larger and independent of the material. The higher melting point of molybdenum improves the resilience to beam impact which can cause localized melting in a copper electrode under the ALS-U operational beam conditions.

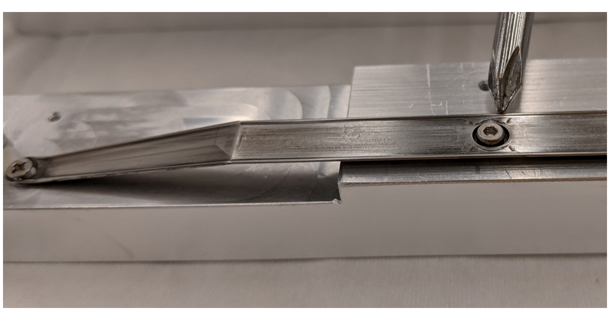

Figure 8: Tapered end of a prototype molybdenum stripline electrode which was fabricated at LBNL.

Decoherence Kicker

The decoherence kicker is a shortened version of the swap-out kicker designed to provide a kick of 0.1 mrad to bunch trains in advance of their extraction to increase their emittance in the space of 100 turns (Table 2). This is necessary to avoid potential damage to the accelerator in the case where a bunch train with nominal emittance impacts the vacuum chamber or other elements due to a kicker or septum magnet failure [4]. For the same reason, the kicker must be capable of increasing the emittance of the entire stored beam before a dump [5]. The single stripline pair is oriented to produce a vertical kick and avoid the direct impact of synchrotron radiation on the electrodes from upstream dipole magnets.

Table 2: Stripline Kicker Specifications

Kicker	Swap-out	Decoherence
bend angle	3.5 mrad	0.1 mrad
kick direction	horizontal	vertical
stripline length	0.497 m	0.22 m
min aperture	6 mm	6 mm
rise/fall time (5-95%)	10 ns	10 ns
flat-top length	50-52 ns	50-52 ns
flat-top length (beam dump)	N/A	655 ns
flat-top ripple (+/-)	2%	2%
inter-pulse ripple (+/-)	2%	2%
repetition period	30 s	30 s
repetition period (beam dump)	N/A	on request

CONCLUSION

There are both ferrite-loaded kickers and stripline kickers in the ALS-U design for beam injection and extraction. In the accumulator ring, where the timing requirements are more relaxed, ferrite-loaded kickers are used and the technical design challenges are associated with the titanium-coated ceramic chamber. In the storage ring, where the timing requirements are challenging, stripline kickers are used where the technical design challenges are associated with the field rise and fall times and the stripline electrode heating.

ACKNOWLEDGEMENTS

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