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# DEVELOPMENT OF NONLINEAR INJECTION KICKER MAGNET FOR ALS ACCELERATOR*

Chris Pappas, David Robin, Christoph Steier, Changchun Sun, Charles Allen Swenson, Jin-Young Jung, Dennis Baum, LBNL, Berkeley, CA 94720 USA

*Abstract*

The ALS in now engaged in the construction of a new hard x-ray beam line and insertion device for protein crystallography. The scope of work entails the reconfiguration of ALS Sectors 1-3 to make room for the new insertion device. The project will require the melioration of the ALS injection system as well as the development of a longitudinal RF kicker. A key aspect of the injector work is the development and integration of a nonlinear injection kicker (NLK) magnet system to facilitate top off injection without noticeable motion of the beam. The technology will, in principal, ultimately allow the removal of the conventional bump injection magnets presently located in ALS Sector 1. The nonlinear injection concept has been explored at several other light sources [1]. We examine the beam dynamics and magnet design requirements to adapt this technology to the ALS lattice with its 1.9 GeV beam. The work will review the injection beam matching, tracking simulations, the electromagnetic design and tolerance analysis, and power supply design. The paper will also review the project plan for the integration of this technology into the ALS.

## INTRODUCTION & NLK TECHNOLOGY

NLK technology offers the promise of a compact space efficient injection technology without the inclusion of injection bump magnets common to 3rd generation storage rings like the ALS. The technology is attractive for this reason. Other laboratories have build and tested prototypes of NLK designs with varying success [2,3], however none are presently now in use for a user facility. Soleil and MAXIV are working together on a modified BESSY design they plan to use at both facilities [4]. The reason NLKs have thus far not used for operations has been lower injection efficiency compared to conventional kicker approaches. The successful accelerator integration of the NLK requires the co-development of several key-supporting technologies such as: the optimization of the magnetic field shape to match the requirements for the injected and stored beams, a magnetic design and measurement technology that allows shim correction of field errors resultant from construction tolerances, and a reliable method for spatial fiducialization of the magnetic fields. The NLK technology under development at ALS employs a novel winding configuration resultant from a genetic algorithm to optimize injection efficiency. The windings symmetry is neither quadrupolar or sextupolar.

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## REQUIREMENTS FOR ALS, DESIGN METHODOLOGY & OPTIMIZATION

The ALS requirements have evolved from the concept developed at BESSY and is presently in development at Soleil. These concepts position eight magnet buses at 45° from the axis. The inner buses are driven with current in one direction and the outer buses with current of the opposite polarity. A BESSY type magnet geometry, flux lines, and the normalized y component of the **B** field are shown in Figure 1. The ideal magnet has the advantage of zero field, and dB/dx on axis, however is not an optimal field shape for injection into the ALS due to the 275 nm beam emittance of the ALS injection booster.

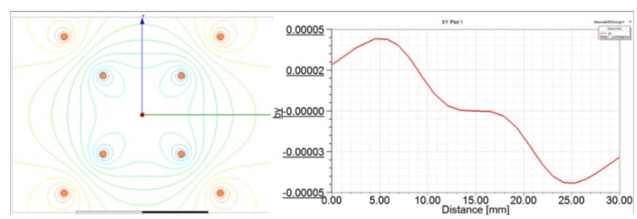


Figure 1: Modified BESSY magnet flux and **B**y.

From tracking simulations it became clear that the shape of the field in a BESSY type magnet is not optimal for injection into the ALS. In particular, a profile that has a wider zero field region near the axis, rises more steeply to the peak, and then decays more slowly would improve the injection efficiency. An exploration of the wire symmetries using analytic solutions for the magnetic fields indicated that the field could be flattened in the region of the injected beam while maintaining the field requirements for the stored beam. The resultant wire geometry could be called a double diamond configuration as illustrated in Figure 2. Another aspect of the design study entailed a tolerance analysis of both winding configurations. The resultant magnetic field errors in the stored beam region were comparable for either winding configuration indicating the validity of the approach.

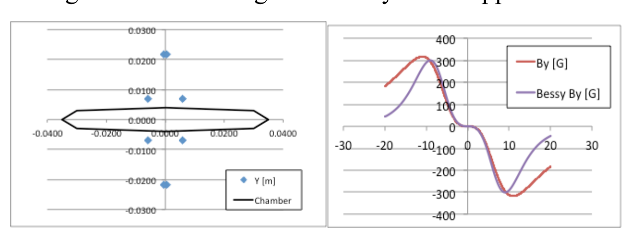


Figure 2: ALS NLK winding configuration and comparative plot of **B**y for the ALS and X wire configurations.

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### *Tracking & Optimization*

The electron beam delivered from the ALS booster has a large emittance of about 274 micro-rad. The horizontal beam size is about 3 mm at the injection point. To effectively capture this large beam with a nonlinear kicker magnet installed at sector 2 as shown in the Figure 2, it becomes important to match the injected beam Twiss parameter to the storage ring, as well as to optimize the NLK magnetic field at the injection point.

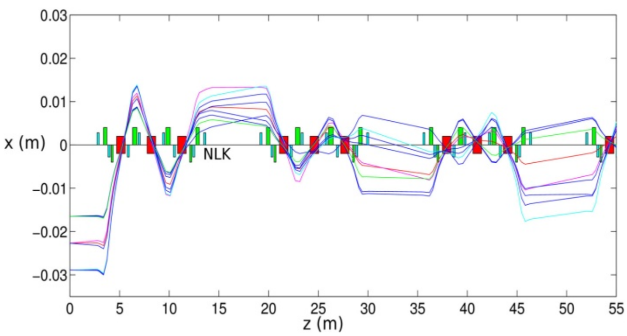


Figure 3: Particles tracking through the first 4 sectors of the ALS storage ring with the nonlinear kicker (NLK) turned on. 9 particles with different angles and offsets are tracked.

For injection matching, the parameters needed to be optimized are the horizontal beta and alpha functions of the injected beam and the beam offset and angle. So, there are a total of 4 parameters for the matching. As shown in the Figure 3, the injected beam has a wide spread at the NLK location, therefore a flat field profile at the peak (as shown in the Figure 2) is preferred in order to have a better injection efficiency. This field profile can be shaped by adjusting the positions of the 8 conductors symmetrically around the NLK center as shown in the figure. To optimize the NLK kicker field, there are 4 parameters for conductor coordinates (2 for inner conductors and 2 for outer conductors) and 1 parameter for the conductor current. Therefore, there are total of 9 parameters for the NLK injection optimization. The optimization objectives are to minimize the beam loss rate, i.e., to maximize the injection efficiency, and to minimize the conductor's current.

Multi-Objective Genetic Algorithm (MOGA) was used to optimize this injection problem. The field tolerance for the stored beam at the center of the NLK was specified as a constraint in the optimization. The magnetic field generated by the 8 conductors was evaluated using Biot-Savart law. 5000 particles were tracked through the septum channel, the nonlinear kicker and storage ring lattice for 1000 turns. At the end of 1000 turns, the beam lost rate was calculated. The Pareto optimal front at the $100^{th}$ generation is shown in Figure 4.

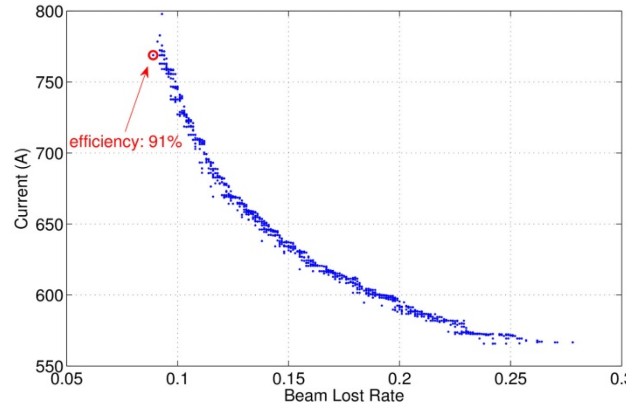


Figure 4: The Pareto optimal front for NLK injection optimization with MOGA.

As can be seen from the optimal front, the maximum injection efficiency achieved with optimized NLK and twiss parameters is about 91%. The conductor positions for the optimized solution indicated in the plot are given in Table 1.

Table 1: Position of the Conductors of the NLK

| | R (mm) | Theta (deg) | x (mm) | y(mm) |
|---|---|---|---|---|
| Inner | 8.9321 | 52.1202 | 5.479 | 7.043 |
| Outer | 17.7037 | 83.8925 | 1.883 | 17.603 |

The required conductor current is 768.89 A. For this solution, the required beta and alpha function are 38.27 m and -0.0865, respectively; and the inject beam offset and angle are -20.849 mm and 80.088 micro-rad, respectively.

## ALS NLK SYSTEM DESIGN

A simplified schematic of the overall system is shown in Figure 5. The magnet resulting from the optimization process has a magnetic length of 28 cm, the aperture is 32×11 mm (w×h), and an inductance of 1.76 µH. The magnet that will be prototyped is shown in Figure 6. With the addition of a 10 m cable between the power supply and the wiring interconnects at the magnet, the voltage required from the power supply is 5 kV.

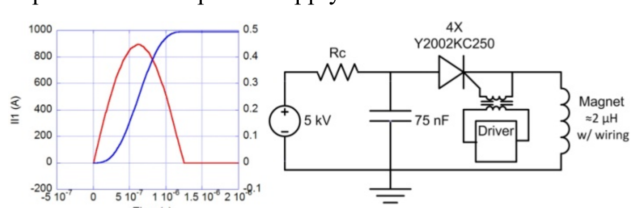


Figure 5: Simplified schematic of kicker system with the output pulse and $I^2t$.

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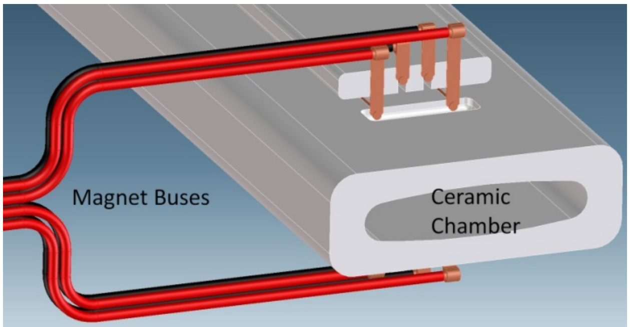


Figure 6: Model for optimized NLK magnet.

A coated ceramic chamber is required, which will also serve as the structural support and positioning of the buses. A titanium coating of 305 mΩ/□ is planned, which will result in the field being attenuated by approximately 1.1 % at the peaks, see Figure 7. This coating will dissipate approximately 10 W due to the beam image current. From thermal analysis, it has been determined that this dissipation will result in a maximum temperature of approximately 71 °C with a gradient of 1 °C as shown in Figure 8 with 2 m/s air flow. Eddy currents in the electrical cover for the magnet, and the stainless vacuum flange are also being investigated.

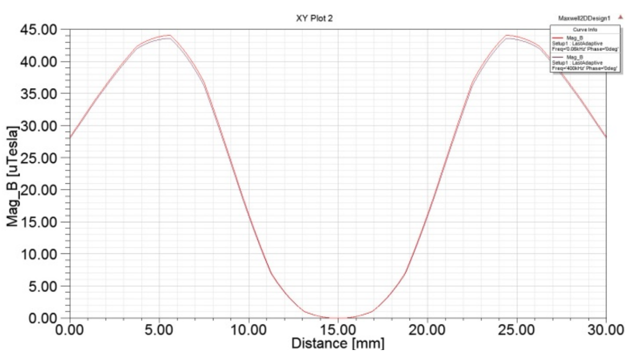


Figure 7: Attenuation of |B| field at 60 Hz and 400 kHz.

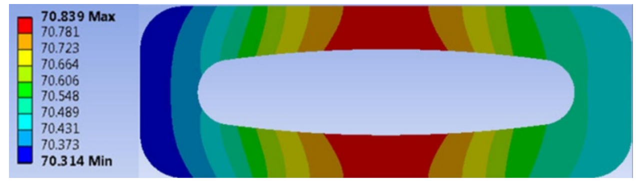


Figure 8: Results of thermal analysis of beam current heating of the ceramic chamber.

## CONCLUSIONS

Non-linear kickers built in the past were attractive for injection, however, they suffered from poor injection efficiency. The modelling and optimization done for the ALS shows an injection efficiency of greater than 90 % is achievable with NLKs. The geometry of the buses is sensitive to mechanical tolerances, so we are planning to first build an adjustable bench top prototype for testing and field mapping.

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