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Transverse Field Profile of the NLC Damping Rings Electromagnet Wiggler

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Abstract: The primary effort for damping ring wiggler studies has been to develop a credible radiation hard electromagnet wiggler conceptual design that meets NLC main electron and positron damping ring physics requirements [1]. Based upon an early assessment of requirements, a hybrid magnet similar to existing designs satisfies basic requirements. However, radiation damage is potentially a serious problem for the Nd-Fe-B permanent magnet material, and cost remains an issue for samarium cobalt magnets. Superconducting magnet designs have not been pursued due to their increased complexity and our unfamiliarity with the technology. Having produced and developed an electromagnet design, we now find that the transverse field roll-off is severe, and recognizing similar experience with beamline 11 at SSRL we believe that the resulting beam quality will not meet the damping ring requirements. We therefore propose, in parallel with more detailed optics studies of the wiggler field requirements, to revisit the hybrid permanent magnet design.

Transverse field profile of the NLC damping rings electromagnet wiggler

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1.0 Summary

The primary effort for damping ring wiggler studies has been to develop a credible radiation hard electromagnet wiggler conceptual design that meets NLC main electron and positron damping ring physics requirements [1]. Based upon an early assessment of requirements, a hybrid magnet similar to existing designs satisfies basic requirements. However, radiation damage is potentially a serious problem for the Nd-Fe-B permanent magnet material, and cost remains an issue for samarium cobalt magnets. Superconducting magnet designs have not been pursued due to their increased complexity and our unfamiliarity with the technology.

Having produced and developed an electromagnet design, we now find that the transverse field roll-off is severe, and recognizing similar experience with beamline 11 at SSRL we believe that the resulting beam quality will not meet the damping ring requirements.

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1.1 Requirements

The design objective for the wigglers is to maximize the energy loss within the wigglers, which is proportional to the integrated magnetic induction squared,

$$I_B^2 = \int B^2 \, dz$$

while minimizing the quantum excitation, which is proportional to $B^{3/2}$. The current NLC lattice design requires a total value for I_B^2 of 106 T^2m. Wigglers are to be arranged in a single FODO lattice straight, occupying one of the two long straights in the main damping rings [2]. A total length of approximately 50 m is required to achieve I_B^2 of 106 T^2m.

The baseline electromagnet design characteristics are summarized below.

- B = 2.05 T (sinusoidal field)
- I_B^2 = 0.32 T-m^2/pole
- wiggler period λ_w = 0.27 m
- magnet gap, g = 2.0 cm

- number of wiggler sections, $N_s = 10$
- length of wiggler sections, $L_s = 4.51$ m
- distance between quadrupole centers, $L_q = 5.09$ m
- total length of straight, $L_{st} = 50.9$ m

2.0 Electromagnet design

Figure 1 shows a single period of the electromagnet design. The pole is square and long in the beam direction in order to maximize I_B^2. However, in order to minimize the effects of magnet saturation that would normally occur for a square pole, the pole is narrow at the base and is strongly tapered in the direction transverse to the beam direction. Saturation is further reduced by placement of Sm-Co permanent magnet blocks in the pocket left by the pole taper. (Note that while Sm-Co material is weaker magnetically than Nd-Fe-B, it is more radiation tough). The magnet orientation is chosen to reverse bias the pole flux. A coil is wrapped around the pole and block assembly. The coil is removed from the first pole of Figure 1 to show the pole and permanent magnet block configuration.

The width of the pole tip is chosen to give a peak field corresponding to 98% of that for an infinitely wide pole. This minimizes the flux entering the bottom pole surface without sacrificing the peak field and thus I_B^2 on the axis. Because of the high on-axis field and the consequent flux entering the pole tip, the pole tip will be saturated. Additional flux that enters the lateral pole surfaces would result in increasing flux density beyond the pole tip for an untapered pole. The pole taper, in conjunction with the reverse flux bias provided by the permanent magnets, results in a manageable flux density beyond the immediate pole tip.

The issue of pole saturation relates directly to the current required to achieve the desired field. The desired field together with the pole geometry fixes the required current. The fixed period length together with the limited capacity for coil cooling place constraints upon the maximum allowed current density. For a fixed current, the required power is proportional to current density. The objective of minimizing power and cooling requirements conflicts with the desire to concentrate current near the pole tip to reduce pole flux, and thus pole saturation.

2.1 Lateral Field Distribution

The narrow pole design developed for the electromagnet wiggler is very efficient in minimizing the effects of pole saturation while meeting the I_B^2 requirement with a modest power. However, the narrow pole tip results in a horizontal field roll-off that may have an effect on the storage ring dynamic aperture. The lateral field distribution for this pole design is shown in Figure 2. A field distribution is also shown for a pole modified by the addition of pole face bumps used to flatten the field distribution. The nominal amplitude of beam centroid motion in the wiggler is 0.59 mm, and the horizontal beamsize in the wiggler straight is typically 60 μm. The field distributions shown in Figure 2 are the result of two dimensional field analysis. Figure 3 shows one half of the pole tip profile; the pole tip with bump is shown as a solid line, while the pole tip without bump is shown as a dashed line. While the pole tip bumps significantly reduce the transverse field roll-off, there remains considerable field variation over the width of the bunch.

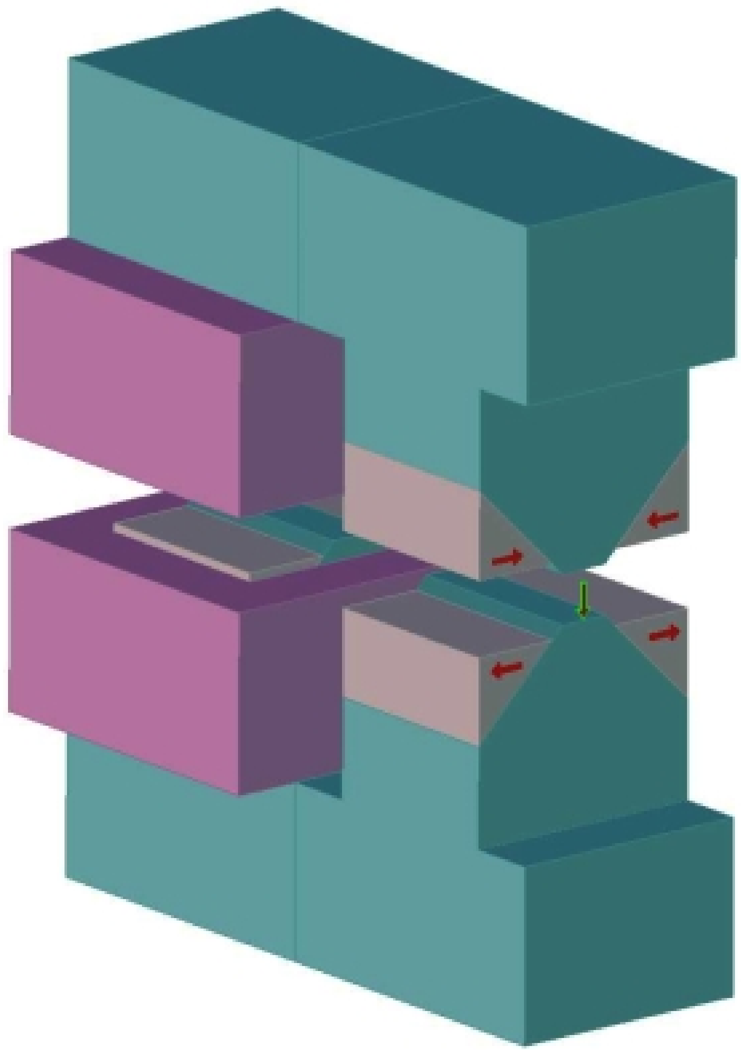

Figure 1. Electromagnet wiggler, one period.

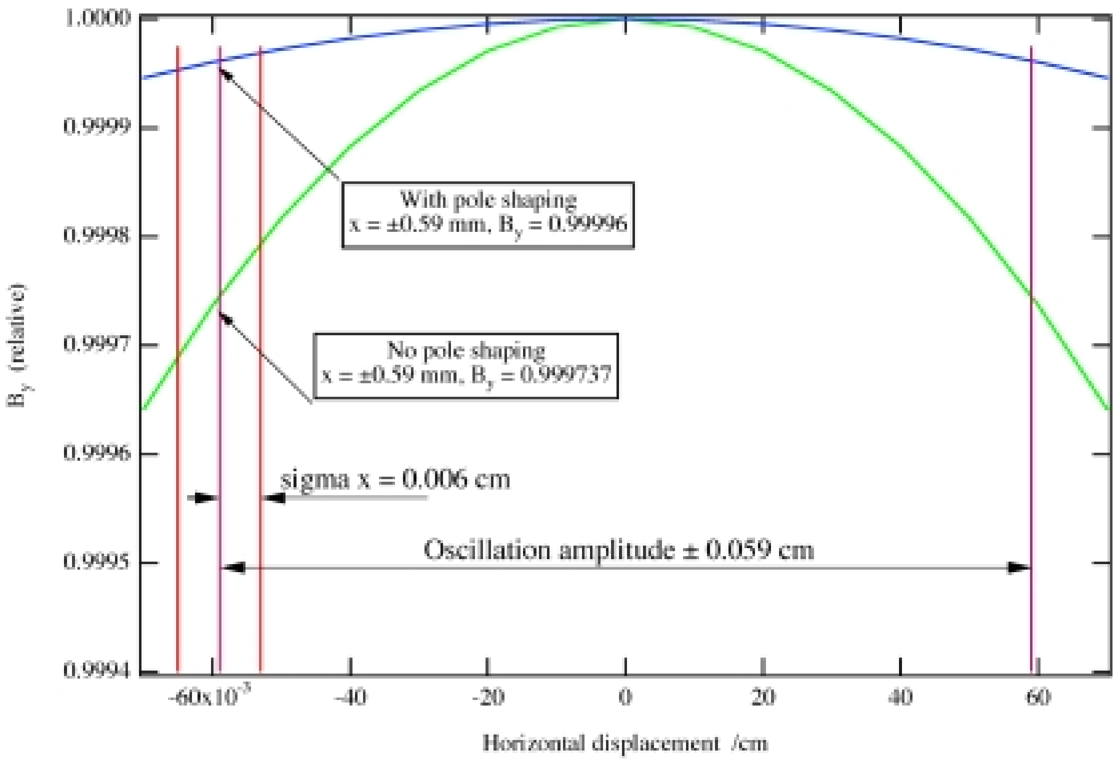

Figure 2. Lateral field distribution (normalized B) for baseline electromagnet design with and without pole tip bumps.

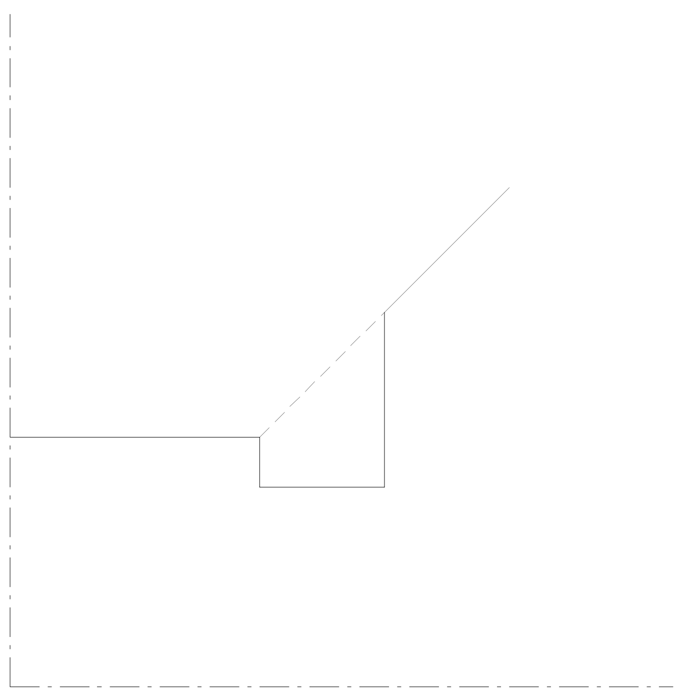

Figure 3. Pole tip bump.

3.0 Optics impact

The transverse field roll-off is thought to seriously degrade the dynamic aperture of the machine. Tracking studies have begun, initially using a simple hard-edged dipole model for the wiggler magnets. The full field profile will then be incorporated, and the effects of the transverse field roll-off on the dynamic aperture will be determined. Requirements for field quality will be determined and applied to future wiggler designs.

3.1 SSRL experience

The wiggler installed on beamline 11 at SSRL has a similar transverse field roll-off to the LBNL designed electromagnet wiggler, as shown in figure 4.

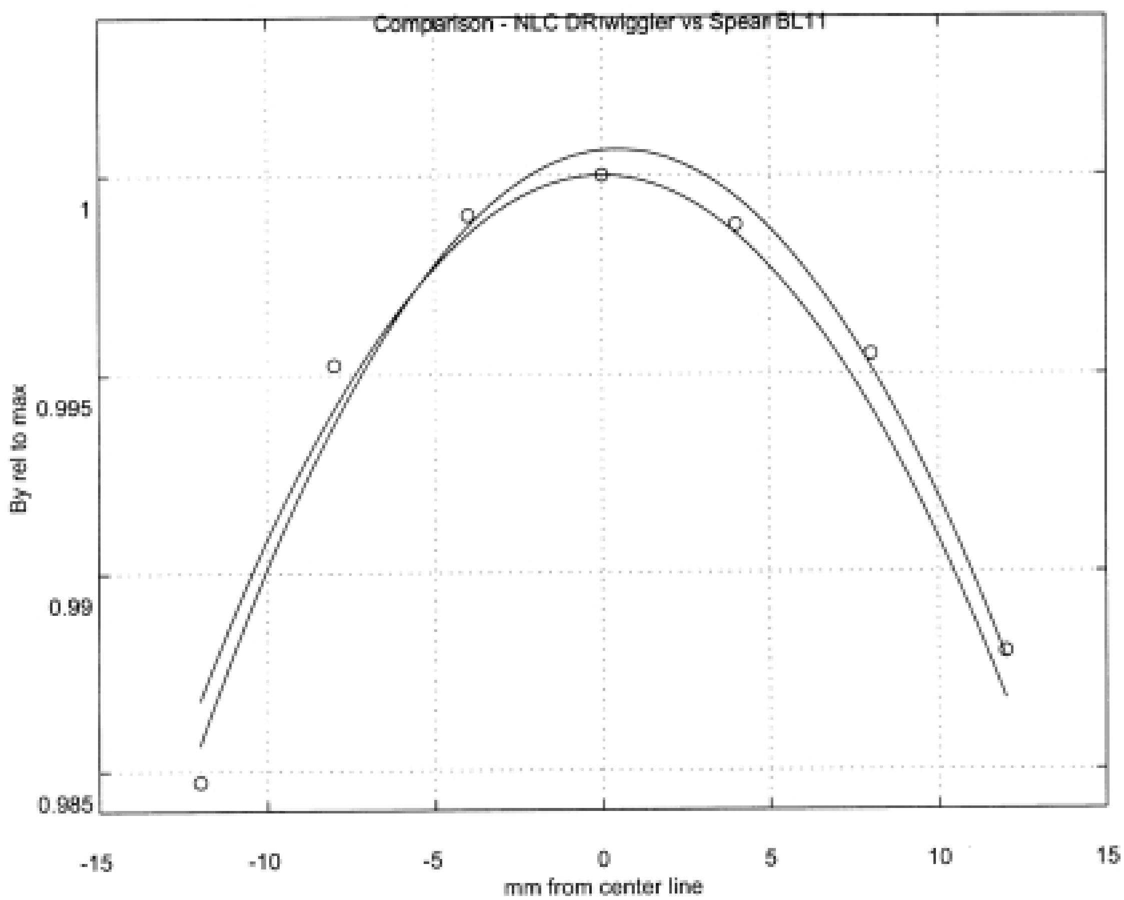

Figure 4. Comparison of SSRL BL11 wiggler transverse field with NLC damping ring electromagnet design. BL11 data is shown in circles, fitted with the off-center line. The damping ring design is the solid line symmetrical about the center line.

Experience at SSRL has shown that the machine nonlinear dynamics are seriously degraded when the BL11 wiggler is closed, resulting in reduced lifetime (30%), lifetime dependence on transverse position, reduced dynamic aperture, and increased tune shift with amplitude [3].

4.0 Magnet technology options

Three wiggler magnet technology options may be considered: electromagnet, hybrid permanent magnet, and superconducting. The advantages and disadvantages are summarized in the table below. The dominant points for each technology are underlined.

	Advantages	**Disadvantages**
Electromagnet	• Standard technology • Easy to turn off, tune field • <u>Radiation tough</u> • <u>Relatively low initial cost</u>	• Consumes power • Complicated connections • Narrow lateral field distribution
Hybrid	• Does not require power • Well tested in light sources	• Must move to turn off • <u>Subject to radiation damage</u> • Field varies with temperature • <u>Relatively high initial cost</u>
Superconducting	• Shorter straight • Larger gap	• Cryogenic infrastructure • Non-standard technology • <u>Costly</u> • <u>Uncertain reliability</u>

The NLC damping ring will be a high radiation environment, with 120 Hz injection/extraction cycles and a kW-level beam power injector. The vacuum chamber through the wiggler section is likely to be the limiting aperture. Therefore, the issue of potential radiation induced demagnetization of permanent magnet blocks is serious. A hybrid wiggler using Nd-B-Fe permanent magnets would require upstream beam collimation to limit the radiation within the straight. This adds complexity and cost to the ring design, as does the additional cost of permanent magnet over electromagnet design.

5.0 Future work

We will continue and conclude our analysis of the effects of the transverse field roll-off on the machine performance. We aim to provide specifications for the transverse field roll-off. We will revisit the hybrid permanent magnet design, based on experience with insertion device design at the ALS and at SSRL. We will make an assessment of the reduction of beam loss in the wiggler region through collimation elsewhere in the machine, and the resulting radiation levels in the wiggler.

References

[1] "NLC Damping rings wiggler studies 1999", J. Corlett, N. Hartman, K. Kennedy, G. Koehler, S. Marks, J. Rasson, T. Saleh., LCC-0031, CBP Tech Note - 199, November 1999.

[2] "Preliminary main damping ring design for the NLC", P. Emma, T. Raubenheimer, SLAC Memorandum, April 23, 1999.

[3] "Nonlinear Dynamics in SPEAR Wigglers", J. Safranek, SLAC seminar, February 2000.