DESIGN OF A COLLIMATION SYSTEM FOR THE NEXT GENERATION LIGHT SOURCE*

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Abstract

The Next Generation Light Source at LBNL will deliver MHz repetition rate electron beams to an array of free electron lasers. Because of the high beam power approaching one MW in such a facility, effective beam collimation is extremely important to minimize radiation damage, prevent quenches of superconducting cavities, limit dose rates outside of the accelerator tunnel and prevent equipment damage. This paper describes the conceptual design of a collimation system, including detailed simulations to verify its effectiveness.

INTRODUCTION

A collimation system is necessary in the NGLS to deal with the beam halo which will be generated due to dark current in the injector and in the accelerating modules, scattering from residual gas particles, Touschek scattering within the main bunches, as well as off-energy beam tails caused by coherent synchrotron radiation in the bunch compressors and beam spreader, and several other smaller effects. If not collimated, this beam halo can damage undulators, cause Bremsstrahlung co-axial with the photon beams, cause quenches in superconducting cavities and can activate the components of the facility. Collimating the beam halo at the lowest possible beam energy, which means as near as possible to the various sources is preferred as this reduces the overall radiation levels in the machine. Figure 1 shows the conceptual collimator layout for the NGLS.

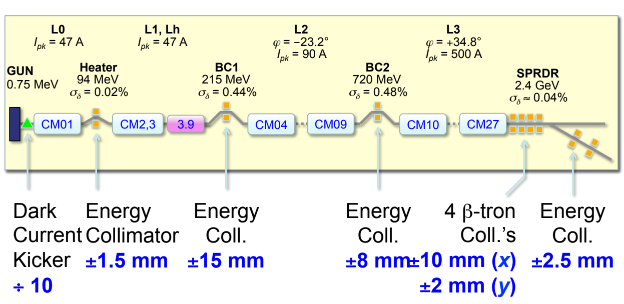

Figure 1: Schematic layout of NGLS injector, linac, bunch compressors, and undulators with collimator locations and settings.

At the moment, superconducting undulators are the preferred design choice, which relaxes the requirements for the collimation system. In addition to removing the beam halo continuously, the collimation system must also provide protection against mis-steered beam or element failure scenarios without being damaged itself.

Collimation Strategy and System Layout

NGLS will employ a distributed collimation system, similar to the approach used at FLASH [1], however with a larger number of collimators at lower energy. In the injector, in addition to general collimation of large transverse amplitude particles, a dark current kicker will clear out most of the dark current buckets without perturbing the main bunches. The next stage consists of multiple (energy) collimators in the middle of each of the bunch compressors as well as the laser heater chicane to reduce beam losses in the superconducting linac and achieve collimation at the lowest beam energy feasible. The post-linac collimation removes the beam halo particles in a transverse collimation section with approximately 90 degree phase advance between each set of horizontal and vertical collimators. Finally there is another energy collimation section that makes use of the dispersion at the beginning of each of the spreader arcs. The geometry of the spreader also allows to keep any particle showers after the collimators away from the undulator sections, which has proven effective with collimation systems at 3rd generation light sources [2].

DARK CURRENT TRANSPORT

Dark current from the gun usually is the major source of beam halo. This is expected to be true at NGLS, since gradients for the s/c cavities are relatively low (15 MV/m), where dark-current-free cavities have been demonstrated. Any collimation system at a minimum has to be effective in containing the dark current halo such, that losses in superconducting cavities and the undulator section can be minimized. To study the effectiveness of the conceptual NGLS collimation system, simulation techniques similar to FLASH, XFEL [1] and LCLS [3] have been employed. The dark current model has been calibrated with data from the APEX gun where relatively large dark currents of up to 8 μA have been measured. It is expected that this will be improved over time, however, it provides a conservative starting point for the collimation design and dark current tracking. The dark current emission is then simulated in ASTRA [4], generating a large ensemble of macroparticles at the exit of the injector. The distribution has a very large energy spread and part of the particles spreads over multiple linac buckets. We simulate about 250,000 macroparticles at the cathode, of which about 50,000 sur-

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vive to the end of the injector at about 90 MeV (compare Fig. 2). The predicted loss rates in the injector cryomodule for the most conservative dark current model appear to have little safety margin so it was decided to make use of a dark current kicker to reduce those losses.

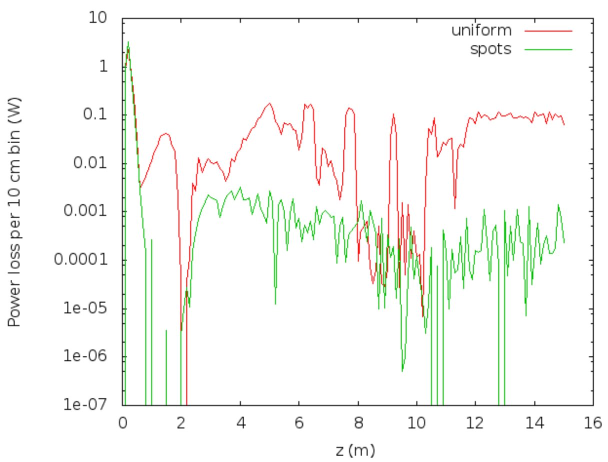

Figure 2: Predicted dark current losses in the injector up to 90 MeV beam energy for two different spatial emission distributions.

Dark Current Deflector

The dark current produced at the gun is quasi continuous with the rf-frequency of the gun as repetition rate (187 MHz). The beam used to drive the FEL has a nominal repetition rate of up to 1 MHz. Therefore it is possible to reduce the dark current significantly by kicking any dark current in between nominal bunches into a dump or collimator. Such a system has been employed at FLASH and reduces the dark current intensity downstream by a significant factor. A similar system is planned at NGLS as well and will be tested at APEX (see Fig. 3). It is based on a scaled design of a fast kicker that is installed for a different purpose in the ALS [5]. Since the NGLS system would be used just after the gun, i.e. at a beam energy of less than one MeV, a scaled version of the ALS design provides enough deflection that in simulations it is predicted to reduce the transported dark current by a factor of > 10.

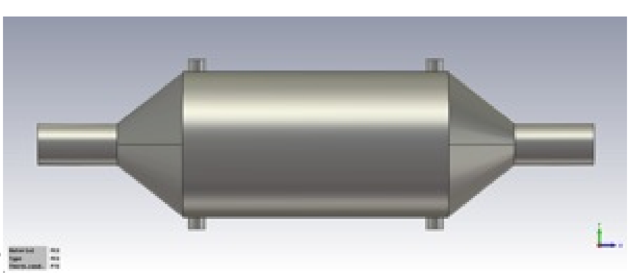

Figure 3: Model of stripline kicker scaled up from the ALS design.

Linac, Spreader, Undulator Section

Afterwards, standard tracking codes have been used to track the trajectories of the remaining dark current particles throughout the machine lattice. We used both AT [6] (upgraded to treat linacs) and elegant [7]. This allows to determine loss locations (at or away from the collimators) as well as a comparison of the final distribution at the entry point to the undulator sections with the acceptance of the undulator chambers. The draft collimator layout described above is effective in localizing losses of dark current particles from the gun away from the undulator sections as well as most other parts of the accelerator (see Fig. 4). To reduce the losses in the first injector cryomodule as well as on the first collimators, a dark current kicker is planned. The loss power on the first collimators could reach 100 W, without taking credit for the dark current kicker. With the expected reduction of a factor of more than ten with the kicker, the loss levels are acceptable when compared to FLASH and are used as basis for the tunnel shielding design.

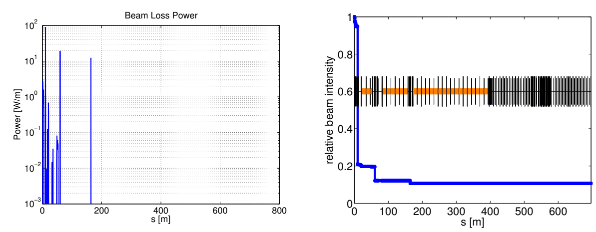

Figure 4: Left: Loss location histogram for NGLS normalized in W/m for conservative gun dark current assumptions. Right: Remaining fraction of dark current along the NGLS with dark current intensity at the laser heater entrance normalized to one.

Error sensitivity studies were performed by putting gradient and dipole errors on magnets as well as phase errors on acceleration sections and positioning errors on collimators (see Fig. 5). The collimator layout performed robustly for dark current collimation and reasonable error seeds with the first collimator in the laser heater being the most critical one.

Other Sources of Beam Halo

Measurements at FLASH and LCLS indicate that background radiation in the undulator sections cannot be fully explained with just dark current production. This will likely be true for NGLS as well. Tracking studies were carried out to evaluate the effectiveness of the collimator layout for Touschek and gas scattering. In addition, analytical calculations were carried out to calculate the loss rates on each collimator for typical gas pressures. The loss rates were found to be small. Finally, losses due to Touschek scattering were estimated using analytical formulas based on the Piwinski treatment [8]. To calculate the Touschek loss rates (see Fig. 6) one first has to calculate the momentum acceptance along the NGLS for particles that undergo Touschek scattering at different locations. Then

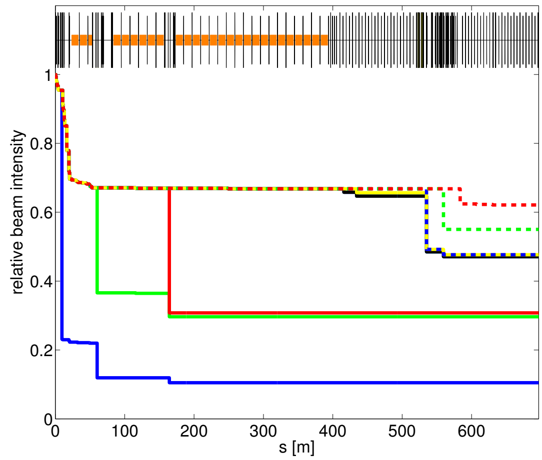

Figure 5: Ratio of remaining gun dark current along the NGLS when opening upstream collimators. The undulator section is well protected, unless almost all collimators are misaligned/opened. The linac structures are well protected for most reasonable collimator errors.

one can calculate estimated loss rates analytically. For standard NGLS beam parameters and very aggressive collimator settings, the beam loss on the worst collimator is less than 10 W, which is much smaller than the dark current losses and acceptable.

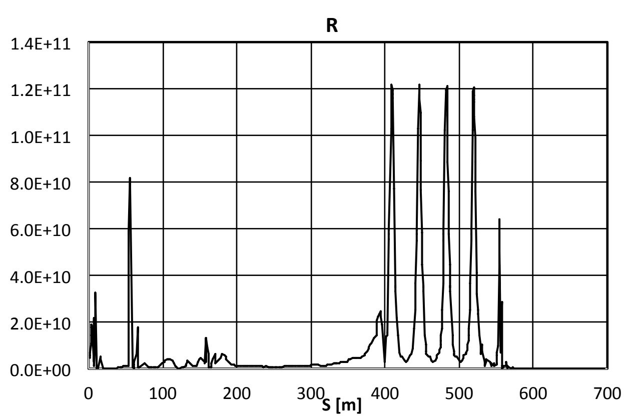

Figure 6: Touschek scattering rate R for typical NGLS beam parameters and the calculated momentum aperture of the NGLS lattice with collimators. This corresponds to less than 10 W losses on the worst collimator.

Tails produced by collective effects in the main bunch could also be relevant and will be included later.

COLLIMATOR DESIGN

The machine protection issues at NGLS include the collimation system itself, which of course is designed to prevent damage to other parts of the facility. Potential damage sources for the collimators could be synchrotron radiation, wakefields, as well as beam losses. The largest concern are beam losses of the full 1 MW beam in case of equipment failure. The collimator design has to withstand those until the machine protection system can shut down the beam. Because NGLS uses (almost) equal spacing between bunches, at any moment, only a few bunches are present. So the latency/integration time of the machine protection system is the determining factor. The system is planned to react in well under 1 ms, which limits the worst case deposited power to acceptable levels for properly designed collimators, similar in magnitude to beam dumps in 3rd generation light sources [2].

Another important consideration is the impedance of the collimators. In LCLS the short range wakes were minimized by using a thin Titanium-Nitrite coating of the collimator jaws. Similar coating techniques are envisioned for NGLS, but in addition efforts will be undertaken to minimize geometric impedance and long range wakes. Whenever possible the adjustable collimators will be double sided to allow to center the beam and minimize impedance induced dipole kicks.

SUMMARY

A conceptual design for a collimation system for the NGLS has been completed. Using a conservative dark current model for the gun, start to end tracking simulations of dark current particles have been completed. Results conclude that a standard set of energy collimators can effectively protect most of the linac and the undulator region with lost beam power at the collimators well within the limits of simple water-cooled designs. A fast dark current kicker right after the gun is planned to reduce losses in the very first superconducting linac module. The design has also been evaluated with regards to gas and Touschek scattered particles, and it was found to be effective and expected power deposition due to those effects are comparatively small. Error sensitivity studies have started, and showed the design to be robust. Work that remains for the future includes the detailed collimator design including impedance considerations, as well as a detailed treatment of secondary particles after the collimators.

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