# DESIGN OF POST LINAC BEAM TRANSPORT FOR THE UK NEW LIGHT SOURCE PROJECT

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*Abstract*

The design of free electron laser (FEL) driver needs careful beam transport design to pass very short bunches through the switchyard/spreader to switch the beam to different FEL lines. The spreader design which allows flexibility in operation has been adapted following the LBNL design [1]. In order to measure the slice properties of the bunches two beam diagnostics lines are proposed, a straight one for beam commissioning purposes and a branch of the spreader similar to the FEL lines to measure the adverse effects that may arise due to passing the short bunches through the kicker and septum magnets. As a part of machine protection, post linac collimation system collimates the halo particles in transverse and energy planes. The design of the collimation, beam spreader and beam diagnostics lines is discussed.

## INTRODUCTION

The proposed New Light Source facility in the UK has been designed to drive seeded FELs. The NLS design is described in [2] and the beam dynamics optimisation for single pass linac (Fig. 1) is described in [3]. An alternative accelerator design based on a recirculating linac is described in [4]. The high energy linac in both these designs is followed by a dedicated post-linac collimation system for machine protection reasons and a spreader to send bunches to the FELs. The facility includes two dedicated high energy diagnostics sections for tuning/commissioning and ensuring the properties of bunches as required for the seeded FELs. At the end of each of these sections the beam is dumped into individual beam dumps at baseline repetition rate of 1 kHz (beam power of 450 W) and beam transport strategy has been suggested to combine the beam dumps for higher repetition rate of 1 MHz (beam power of 450 kW) at later stage. The design of the beam dumps and collimators at the 1 MHz repetition rate is described in [5].

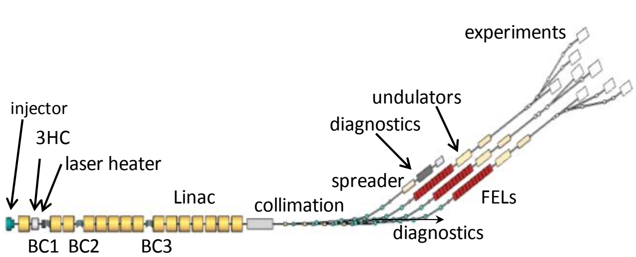


Figure 1: Layout of the NLS facility

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## POST-LINAC COLLIMATION

A collimation system is necessary in NLS to deal with the beam halo which will be generated due to dark current, scattering from residual gas particles, off-energy beam tails caused by coherent synchrotron radiation (CSR) etc. If not collimated, this beam halo can demagnetise the undulator magnet [6], cause Bremsstrahlung co-axial with the photon beam lines and can activate the components of the facility. Collimating the beam halo as near as possible to the various sources is preferred as this reduces the overall radiation levels in the machine. The post linac collimation scheme for NLS is dictated by the requirement of protecting the undulators.

The collimation design strategy removes the beam halo particles in a dedicated transverse and energy collimation sections. The collimation scheme devised for the BESSY FEL [7] has been adopted for NLS as it is simple and adequate. Fig. 2 shows the optics functions of the collimation section. Transverse collimation is achieved using two betatron collimators separated by $\pi/2$ phase advance in each transverse plane. A dogleg located after the betatron collimation section contains two energy collimators at the high dispersion points. The betatron collimator aperture is determined by the undulator vacuum vessel gap and beam optics and is expected to be 2.1 mm (half-gap), assuming linear beam transport. The energy collimators must shadow the energy acceptance of the undulators which is approximately $\pm$ 4.5% for the worst case of FEL-3 (determined by tracking nominal halo of 10 K particles, with energy spread $\pm$ 10% from the collimators through the undulator), translating to a collimator gap of 2.4 mm (half-gap). If the spreader sextupoles are switched off (the requirement of sextupoles in the spreader is explained in the spreader section), these collimator gaps should ensure passive protection of the undulator modules, see Fig.3 and Fig. 4 for illustration.

However, the halo tracking with sextupoles on indicates that the collimator apertures may need to be reduced considerably due to non-linear beam transport as the energy bandwidth of the system is reduced. This needs tighter energy collimation and the non-linearities in the transverse phase space transport also demand smaller betatron collimator apertures. It was found from tracking simulations that betatron collimator apertures of 1.6 mm (half-gap) combined with an energy collimator gap of 1.0 mm (half-gap) gave nearly no losses in the undulator when a halo of transverse dimensions three times larger than the undulator aperture and energy spread of $\pm$10 % was tracked from the entrance of the collimation section.

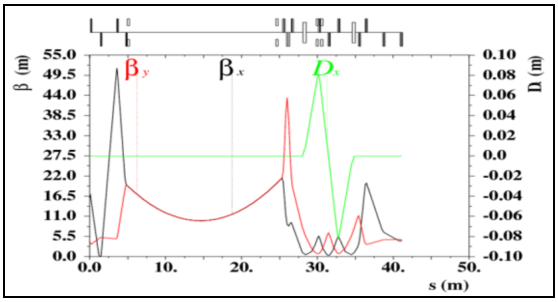


Figure 2 : Optics of the post-linac collimation section

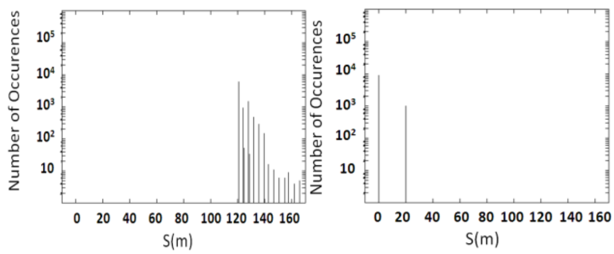


Figure 3: Particle loss distribution from halo tracking simulation without (left) and with (right) betatron collimation. Betatron collimators located at s=0, 19.5 m.

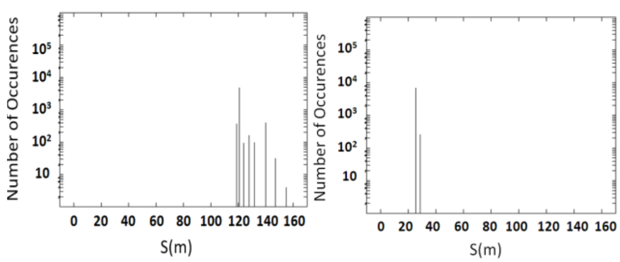


Figure 4: Particle loss distribution from halo tracking simulation without (left) and with (right) energy collimation. Energy collimators located at s=26, 28 m.

The wakefields of the collimators need to be included in the bunch tracking simulations to make sure that the bunch properties do not deteriorate significantly. Reliable theoretical estimates and simulations of collimator wakefields have not yet been established for the NLS beam parameters [8]. However, practical experience with TTF2/FLASH [9] shows that it is possible to operate a FEL with a similar collimation system and similar beam parameters without prohibitive wake field effects.

## SPREADER DESIGN

The post linac collimated beam passes through the beam spreader which in the baseline design needs to switch the electron beam to three FEL beam lines at 1 kHz repetition frequency, with a possibility of diverting all the bunches to any one FEL at a time. The design also needs to be compatible with future increases in repetition rate up to 1 MHz and the possible addition of extra FEL lines.

The scheme based on fast kickers similar to the LBNL design [1] has been chosen for the NLS due to its flexibility to increase the number of FEL beam lines without major changes in the facility layout and also to allow full flexibility in setting the repetition rate for individual FEL beam lines.

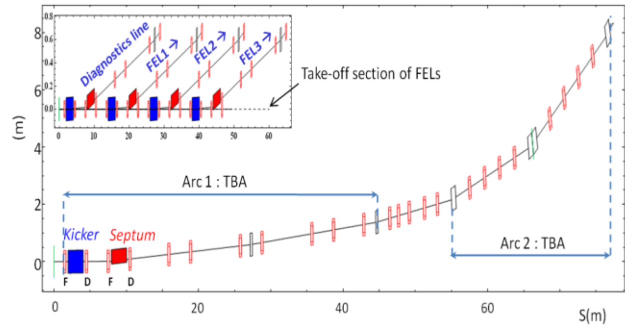


Figure 5: Layout of spreader design. The inset shows the start of the different FEL beam lines and the main figure shows details of the complete lattice for one spreader line.

As shown in Fig. 5 the spreader consists of a long FODO take-off section with a series of extraction points for various FEL lines. Bunches which are not diverted to the particular FEL line continue to pass on-axis through the FODO. Each extraction section consists of two Triple Bend Achromat (TBA) arcs, where the kicker and the septum replace the first dipole of the first TBA arc. A 2 meter long kicker placed between the first F and D quadrupole provides a kick of 3 mrad. The beam passes off-axis by ~4 mm in the centre of the D quadrupole immediately after the kicker and by ~16 mm in the centre of the F quadrupole before the septum. The beam is nearly parallel to the take-off axis at the entry of the septum. The septum kicks the beam by 27 mrad. The beam passes off-axis by ~53 mm through the D quadrupole after the septum giving an additional dipole kick of 17.5 mrad, thereby reducing the required strength of the septum magnet. The beam is finally separated from the incoming beam after the D magnet adjacent to the septum. The first TBA arc is then completed with two additional dipoles and seven quadrupoles. This section is followed by matching quadrupoles to match the beam into the second TBA arc. The NLS beam spreader optics is shown in Fig. 6. The optics has been optimized to be achromatic and isochronous within each arc.

The second order terms in the spreader; namely the horizontal and vertical chromaticities and the second order dispersion ($T_{566}$) do not affect the standard operation but can adversely affect the performance of the single spike operation due to the large energy chirp acquired during compression. It was found to be effective to correct these higher order terms in order to remove the curvature in the longitudinal phase space and maintain a high current in some single spike optimisations. Studies indicate that it would be advantageous to leave the sextupoles in the spreader as knobs for correcting these higher order terms as well as to correct the possible error in $R_{56}$ feeding through $T_{566}$.

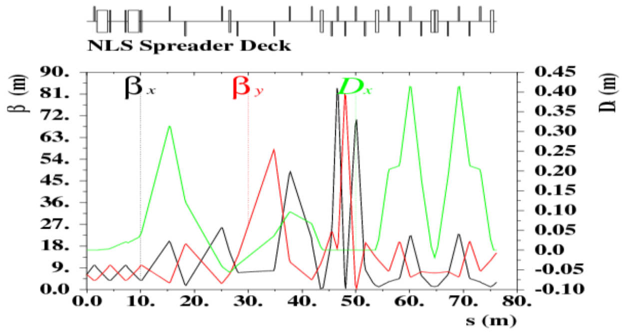

Figure 6: Optics of one branch of NLS spreader

To decide the tolerances on the kicker power supply, the kicker strength was changed by $10^{-4}$ and the position and angle offsets at the end of the spreader were estimated to be 1 μm and 0.23 μrad respectively. These numbers were then compared to the beam alignment tolerances defined by the FEL sensitivity studies. To maintain the angle tolerance within 0.35 μrad for keeping output power variations less than 1% the required kicker stability needs to be better than 1.5 $10^{-4}$.

## HIGH ENERGY DIAGNOSTICS

Two dedicated diagnostics sections, one located straight after the post linac collimation section and a second one located in the first branch of the spreader have been included to fully characterise the bunches during commissioning and normal operation. A dedicated straight on beam diagnostics section as shown in Fig. 7 has been included after the post linac collimation section to enable initial commissioning and tuning of the machine without the spreader. A few bunches can be diverted to this diagnostics section for monitoring purposes during the normal operation to ensure tuning of the linac decoupled from the spreader. The dedicated diagnostics branch in the first branch of the spreader as shown in Fig. 8 will characterise bunches including the effect of the spreader and thus measure equivalent bunches to those entering the FELs. This will allow the tuning and commissioning of the spreader magnets without having to send the beam through the undulators. Additionally, a few bunches can be diverted to this branch during normal operation for monitoring purposes.

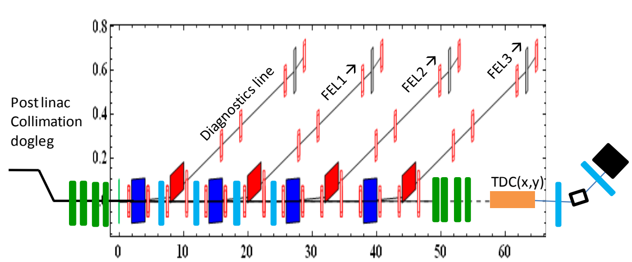

Figure 7: Possible layout of the straight ahead tomography beam diagnostics line in the first take-off branch of the spreader. Light blue-Screens, Green-matching quadrupoles.

The proposed tomography beam diagnostics section in both these sections will fully characterise the beam in 6D phase space, which will provide knowledge of projected transverse emittances (& additionally tomography on slices for transverse emittances in the spreader branch), longitudinal bunch profile and bunch length and together with a spectrometer dipole, projected as well as slice energy spread. The tomography section consists of a FODO lattice with four screens providing 45° phase advance per screen [10]. This is done by changing the quadrupole strength of the spreader take-off FODO for straight-on diagnostics line.

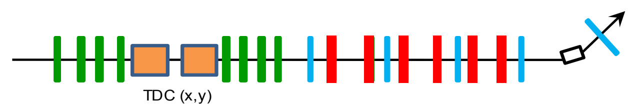

Figure 8: Possible layout of tomography diagnostics in beam spreader branch. Light blue-Screens, Green-matching quadrupoles, Red-FODO quadrupoles.

The design of the Transverse Deflecting Cavities (TDC) needs consideration of the required time resolution. As an initial design goal, a temporal structure with RMS width of $\sigma_z$ = 7 μm ($\sigma_t$ = 25 fs) is required to be resolved. To resolve this structure, it is assumed that the transverse streak must exceed the RMS transverse diameter of the unstreaked beam by at least a factor of three. From these considerations, for conservative NLS parameters the effective deflecting voltage $V_0$ must be greater than 64 MV (21 MV) for a 1.3 GHz (3.9 GHz) cavity, respectively. It is proposed that the NLS deflecting cavity will be a travelling wave structure operating at the third harmonic, for which the required effective deflecting voltages are most easily achieved.

## CONCLUSIONS

The post linac collimation apertures ensure that there are no beam losses in the undulators. The isochronous and achromatic arcs of the beam spreader do not deteriorate the bunch properties. Two high energy diagnostics sections are proposed to ensure delivery of suitable bunches to the FELs.

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