

# A RECIRCULATING LINAC AS A CANDIDATE FOR THE UK NEW LIGHT SOURCE PROJECT

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## Abstract

A design for a free electron laser driver which utilises 1.3 GHz superconducting CW accelerating structures is studied. The machine will deliver longitudinally compressed electron bunches with repetition rates of 1 kHz with a possibility to increase up to 1 MHz. Tracking is performed from an NC RF photocathode gun, accelerating and compressing in three stages to obtain peak current greater than 1 kA at 2.2 GeV. This is achieved through injection at 200 MeV, then recirculating twice in a 1 GeV main linac. The optics design, optimisation procedures and start to end modelling of this system are presented.

## INTRODUCTION

The UK New Light Source (NLS) [1] will be a next generation photon facility based on conventional laser and free electron laser (FEL) technologies. In this paper a candidate accelerator design is described, this being a recirculating superconducting CW linac reaching 2.2 GeV.

The NLS accelerator design specifications are to produce electron bunches with  $< 1$  mm mrad transverse slice emittance, peak current above 1 kA and slice energy spread less than  $5 \times 10^{-4}$ . Initially, the facility will utilise a normal conducting L-Band photoinjector [2] to deliver bunch repetition rates of up to 1 kHz to three seeded FELs covering photon energies from 50 eV to 1 keV. An upgrade will see a high repetition rate gun (of which a number of options are being considered [3]) delivering bunch rates up to 1 MHz to six FELs.

Two designs are currently being evaluated for the NLS accelerator; a single pass machine consisting of fourteen TESLA type cryomodels [4]; and a two pass recirculating machine consisting of nine TESLA type cryomodels. The latter is described in this paper.

Motivations for considering a recirculating machine in comparison to a single pass machine include: reduced capital and running costs; shorter footprint; ease of extraction of multiple energy beams; and a natural upgrade path to higher energy. Issues in comparison to a single pass machine include: additional injection and extraction sections; restrictions to the bunch compression scheme; synchrotron radiation effects in the arcs; and more stringent jitter tolerances.

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## COMPONENTS & OPTICS

Figure 1 shows the optics functions for the machine. The design philosophy is to minimise any bunch compression from components not dedicated for that purpose, in other words separating as much as possible transverse and longitudinal manipulations. In this way, one retains the ability to tailor the final bunch profile in a flexible way.

We assume in all cases that the achievable field gradient of the 1.3 GHz cavities is 20 MV/m. The gun is followed by two cryomodels, the first of whose cavities are fed from individual power supplies to enable independent phase and voltage control for emittance compensation in the gun [2]. This is modelled using the space charge code, ASTRA [5].

Tracking using the code Elegant [6] commences at this location. The beam is decelerated and linearised using a third harmonic system capable of achieving 15 MV/m in CW operating mode. Possible microbunching is then smeared by increasing the incoherent energy spread of the bunch using a laser heater [7]. This is followed by the first four-dipole compressor chicane, which reduces the bunch length from 20 ps to 5 ps FW.

Now at an energy of approximately 200 MeV, the beam enters an injection dogleg section, this uses two dipoles in addition to the last dipole of a standard four dipole chicane, which is that traversed by the high energy beam. It also uses three quadrupoles and a sextupole and is second order isochronous and achromatic. The dogleg is preceded by four matching quadrupoles to keep the optics functions small.

On first pass through the seven cryomodels of the main linac, the beam energy is raised to 1.2 GeV. To extract and separate the 1.2 GeV and 2.2 GeV beams, an achromatic system with no net bend is employed to match the 1.2 GeV beam to the arc. The  $R_{56}$  from this system is 7 mm and has not yet been included in the simulation.

A number of candidate arc lattices were studied before alighting on one based on the BESSY-FEL design [8]. Each  $180^\circ$  arc consists of four triple-bend achromats ( $\pi/12$  dipole bend angle) and was chosen due to the small incoherent synchrotron radiation (ISR) induced emittance dilution of the beam (4% total for both arcs). Coherent synchrotron radiation (CSR) does not degrade the beam significantly if the bunch length is kept above 2 ps FW through the arcs. The ISR induced incoherent energy spread of  $\sim 5 \times 10^{-5}$  is actually fortuitous as it enables the laser power within the laser heater to be reduced whilst still suppress-

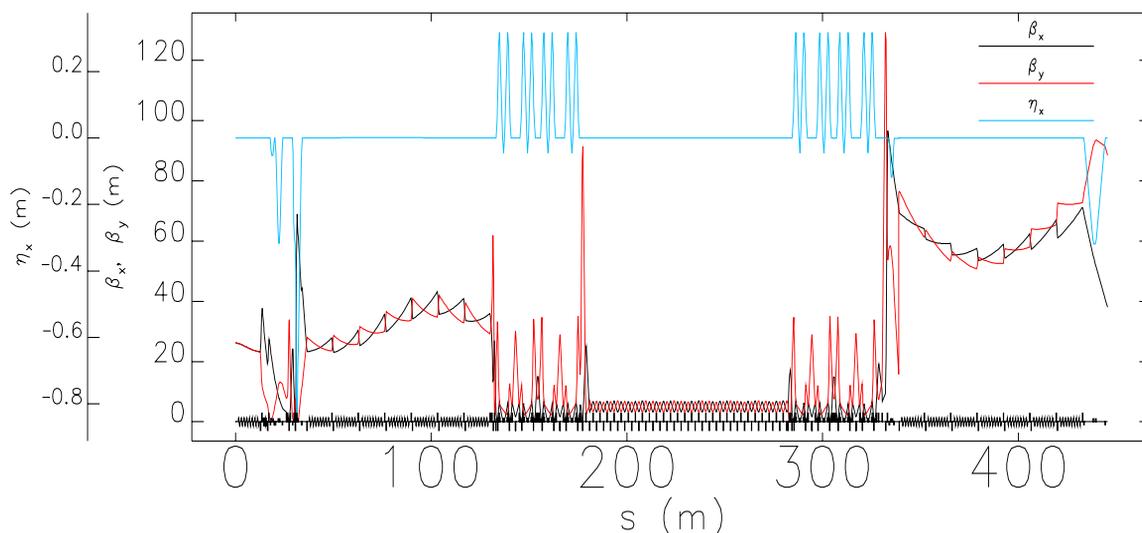


Figure 1: Optics functions from second injector cryomodule to final compressor at the end of the second linac pass.

ing microbunching. On traversal of the non-isochronous arcs the bunch length is reduced from 5 ps to 3 ps FW. Tuning the second order longitudinal dispersion within the arc ( $T_{566}$  term in the transport matrix) allows the reduction of the linearising voltage in the third harmonic system.

The return transport connecting the two arcs contains a system to independently adjust the path length between the two arcs over one RF wavelength. This consists of a focused movable girder dogleg pair [9] and allows the RF phase seen on the second linac pass to be varied independently to that of the first pass.

Exiting the second arc, the beam enters a second four-dipole compressor chicane and then traverses the high-energy branch of the injection system. On arrival at the linac for the second pass, the bunch length is thus reduced from 3 ps to 1.4 ps.

Exiting the linac at 2.2 GeV, the beam passes through the high-energy branch of the extraction system (which has an  $R_{56}$  of 0.1 mm) and through a final four-dipole compression chicane where it achieves a final bunch length of 200 fs FW.

Subsequent parts common to both the single pass and recirculation candidates include a collimation section, FEL switchyard and diagnostic tomography section as described in [4]. Further work will include these additional elements.

## START TO END SIMULATIONS

Collective effects included in the simulations are longitudinal space charge, ISR and CSR as implemented in the one dimensional approximation. In further work these results will be benchmarked against codes that model these effects more accurately.

To optimise the beam parameters, the saturation length was analysed as per the Xie method [10] with a slice length of 5 fs. The optimisation algorithm used is based on a Nelder-Mead simplex optimiser written in Mathematica and interfaced to Elegant. The ‘fitness’ of the optimisation was characterised as a minimal saturation length over

Table 1: Machine settings for optimised 200 pC working point. Phases are with respect to crest. The convention for positive  $R_{56}$  is chicane-like compression.

Position	Variable	Value
$3\omega$ lineariser	$V_{Peak}$	49.7 MV
$3\omega$ lineariser	$\phi$	+162.1°
Injector	$\phi$	-25.1°
Linac first pass	$\phi$	-16.9°
Linac second pass	$\phi$	-24.9°
First compressor	$R_{56}$	122 mm
Arcs (full 360°)	$R_{56}$	37.3 mm
Second compressor	$R_{56}$	29.4 mm
Third compressor	$R_{56}$	42.2 mm

any 100 fs slice of the bunch, and with a minimal standard deviation of the saturation length within that 100 fs slice. In future, the optimisation will be performed using a parallel non-dominated sorting evolutionary algorithm, which should allow a wider scope of possible solutions to be investigated.

Figure 2 shows the longitudinal phase space for the bunch after the final bunch compressor at the optimised parameters of Table 1. In this case  $1 \times 10^6$  particles are tracked and the number of bins used for the CSR computation is  $1 \times 10^4$ . The effects of CSR-induced microbunching are apparent. Figure 3 shows the current profile, Fig. 4 shows the normalised slice emittance, and Fig. 5 the fractional slice energy spread. Figures 6 and 7 show the Xie saturation length and power for 5 fs slices along the bunch.

A relatively long bunch length is chosen to allow for anticipated jitter with respect to the laser seed pulses of  $\sim 50$  fs. It is seen from these figures that the part of the bunch with the required properties is  $> 100$  fs long. It is proposed to increase the bunch charge to 500 pC if this ‘good’ region is required to be longer.

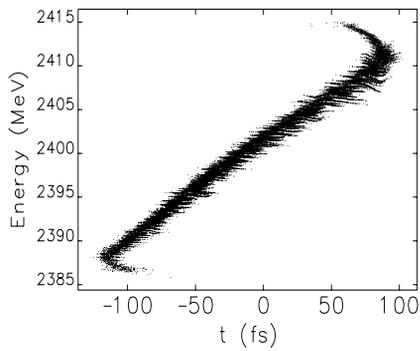


Figure 2: Longitudinal phase space after final compressor. The energy is rather higher than nominal in our optimised settings, however the gradient in the main linac can easily be adjusted to compensate.

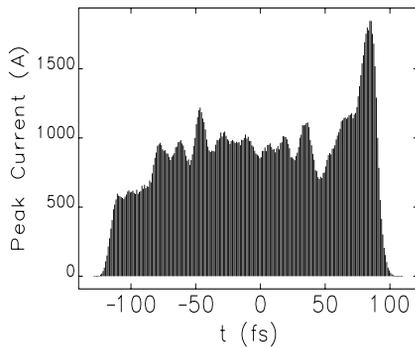


Figure 3: Current profile after final compressor using 1 fs bins.

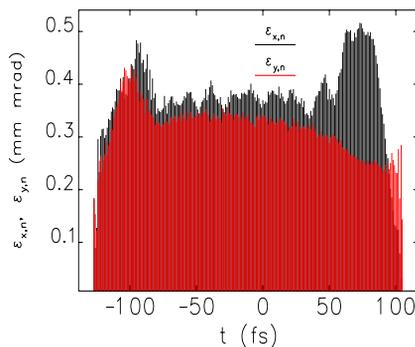


Figure 4: Normalised slice emittances after final compressor using 1 fs bins.

## CONCLUSIONS

A recirculating linac is a promising candidate to drive a suite of seeded FEL's such as that envisaged for the NLS project.

## ACKNOWLEDGEMENTS

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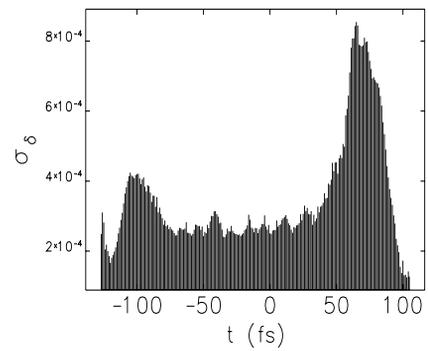


Figure 5: Fractional slice energy spread after final compressor using 1 fs bins.

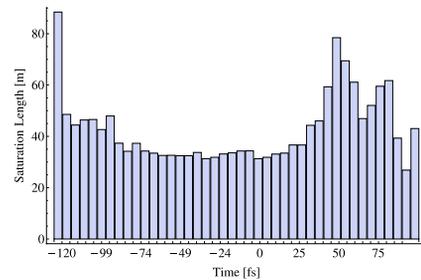


Figure 6: Saturation length per 5 fs slices.

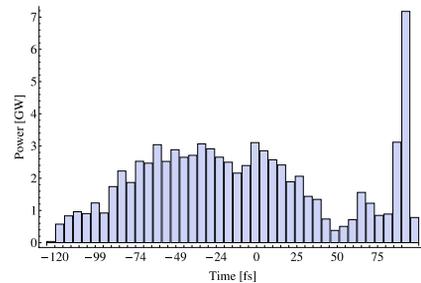


Figure 7: Saturation power per 5 fs slices.

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