DEVELOPMENTS IN THE CLARA FEL TEST FACILITY ACCELERATOR DESIGN AND SIMULATIONS

P. H. Williams*, D. J. Dunning & N. R. Thompson
STFC Daresbury Laboratory & Cockcroft Institute, Warrington, UK

Abstract

We present recent developments in the accelerator design of CLARA (Compact Linear Accelerator for Research and Applications), the UK-XFEL test facility at Daresbury Laboratory. The requirement to co-propagate the beam with laser seeds of very different wavelengths has led to a redesign of the section preceding the undulators, with a dogleg being replaced by a chicane. Additional refinements of the facility design include the inter-undulator sections. With this finalised design we show start to FEL simulations.

INTRODUCTION

CLARA will be primarily an FEL R&D facility [1] and will inform the aims and design of a future UK-XFEL. It is intended to be flexible such that different FEL schemes can be investigated, with the emphasis on the generation of short, temporally coherent pulses via HB-SASE, mode-locking and seeding [2,3]. Figure 1 shows the facility layout.

SEED LASER CHICANE

In order to fully exploit CLARA, the co-propagation of a seed laser with the electron bunch through one of two modulator undulators is required. The wavelengths of the potential seeds covers a large range; from 800 nm to 100 μm. Given the same Rayleigh length, the transverse opening angle of the seed scales with the square root of the radiation wavelength, therefore the aperture of the beamline gives an upper limit on the wavelength, for a fixed seed transmission. To determine the required apertures, standard analytic expressions for power transmission were used, with the requirement of 99% transmission for the expected seed laser beam quality factor $M^2 = 2$. OPC [4] simulations showed negligible diffraction effects. For the, now rejected, original layout of a dogleg with 100 mm transverse offset, Fig. 2 shows that in this case the distance between the modulator and the mirror in the dogleg leads to an unacceptably large aperture. Table 1 shows the minimum mirror radius thereby required for each of the four envisaged laser seed wavelengths at four distances between the mirror and modulator-1 entrance. In order to co-propagate all seeds a mirror radius of 18.8 mm is needed if the separation is 0.5 m. Figure 3 shows a chicane design that fulfills these requirements. We choose the transverse offset in the centre of the chicane to be 30 mm in order to give reasonable margin for engineering constraints. The four dipoles are of pole length 0.1 m and bend angle 100 mrad. The field required for a 250 MeV/c beam is 0.15 T.

Table 1: Minimum mirror radius required (mm) to retain 99% of radiation power transmission for four seed wavelengths.

Distance upstream Mod-1	3 m	2 m	1 m	0.5 m
Seed Wavelength				
100 μm	62.1	44.4	27.1	18.8
20 μm	27.8	19.9	12.1	8.4
3 μm	10.8	7.7	4.7	3.2
800 nm	5.6	4.0	2.4	1.7

In terms of the effect on the bunch compression scheme, with $R_{56} = 5.4$ mm and $T_{566} = -8.2$ mm, it is a perturbation on the main compressor ($R_{56} = 72$ mm in the nominal short bunch mode).

MATCH TO FODO IN FEL RADIATORS

The required optics within the FEL section is a FODO lattice. To ensure flexibility of operation a range of FODO cell phase advances should be accessible. The FEL radiator sections in CLARA do not have the focusing properties of a perfect FODO due to the undulators themselves (which bend vertically in the nominal configuration), and the horizontally bending delay chicanes situated after each radiator. These are required to enable mode locking, HB-SASE etc. To illustrate this, Fig. 4 shows the result of constructing FODO cells broken in both planes, horizontally by the undulators and vertically by the delay chicanes. The average β-function is shown as a function of the dimensionless ratio of focal length to cell length. Also shown are the analytic expressions of Pfluger (thin lens, small phase advance) and Wiedemann (thick lens, arbitrary phase advance), together with the MAD match of the real system for each plane. We use the hard-edge dipole model to construct the undulators, Fig. 5 shows an example match to a FODO k-value of 7.5 m^{-2} through CLARA from the cathode to the beam dump. Matching is performed using ASTRA and bespoke optimisation as space-charge effects are significant. Figure 6 shows an example of initial match using MAD and a final match using ASTRA [5] in the diagnostics section located between the final linac and the FEL, whilst Fig. 7 shows the match through the modulators and first 3 radiators.

TRACKING IN SHORT BUNCH MODE

We now incorporate the seed laser chicane and a number of other minor changes into the start-to-FEL simulations. As an example operational mode, we choose the short mode [3]

* peter.williams@stfc.ac.uk

ISBN 978-3-95450-182-3

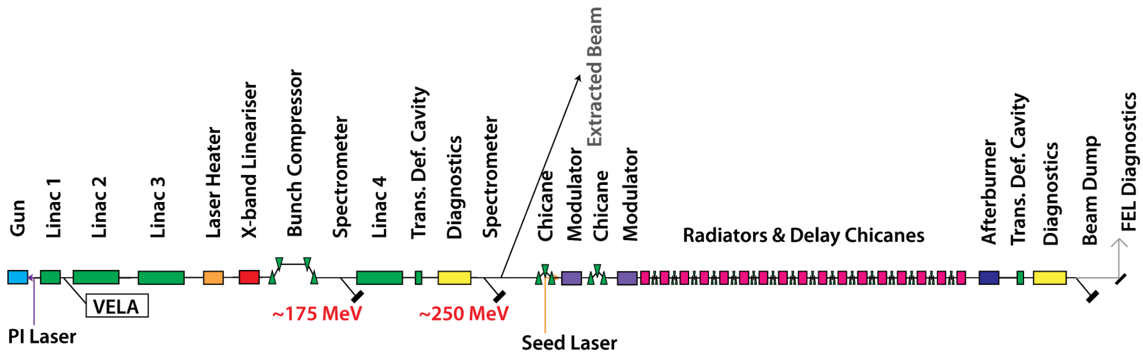

Figure 1: CLARA layout. The total length is ~ 90 m.

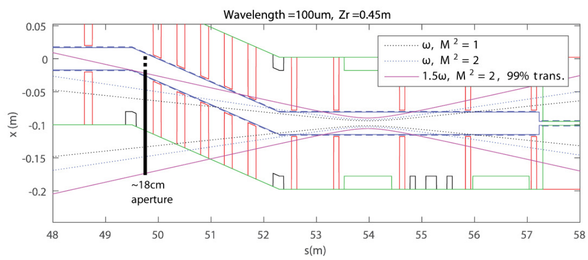

Figure 2: Aperture required by seed laser radiation mode in CLARA modulator-1 in rejected dogleg design.

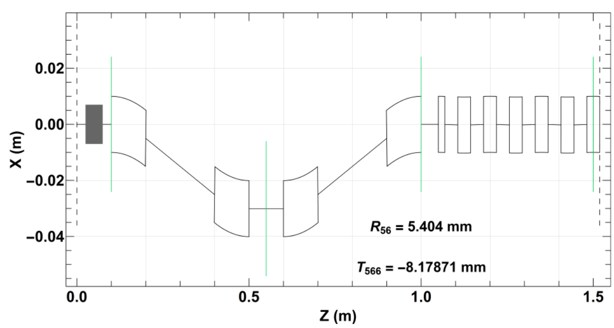

Figure 3: Seed laser chicane allowing for insertion of up to 100 μm seed.

at 240 MeV/c with 250 pC charge. Figures 8 to 10 show the beam sizes, bunch length, energy spread and projected normalised emittances of the example track of 10k particles. Figure 11 shows the corresponding bunch phase spaces and slice properties on entrance to the FEL. These will satisfy the FEL specifications with the addition of a corrugated pipe or dielectric dechirper to flatten the residual correlated energy spread.

SUMMARY

The dogleg design for seed laser insertion has been replaced with a chicane and incorporated into an example track to the FEL in CLARA.

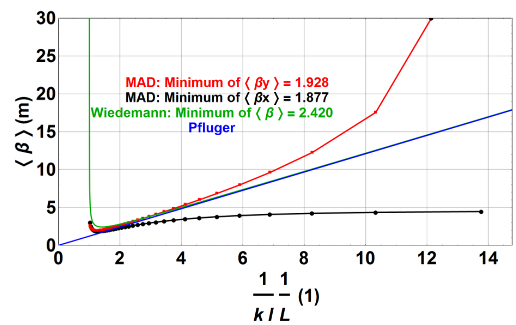

Figure 4: Deviation in both planes of optics from ideal FODO cell conditions in Pfluger and Wiedemann approximations. The vertical plane is broken by the delay chicanes, the horizontal plane by the radiator undulator focusing.

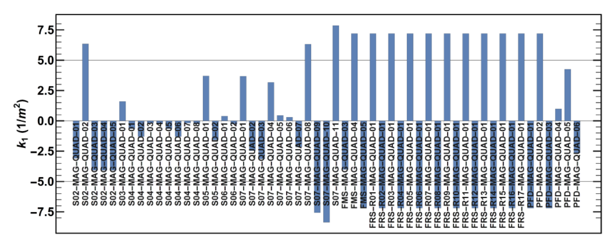

Figure 5: Quadrupole k-values from cathode through FEL to dump. Matched using ASTRA

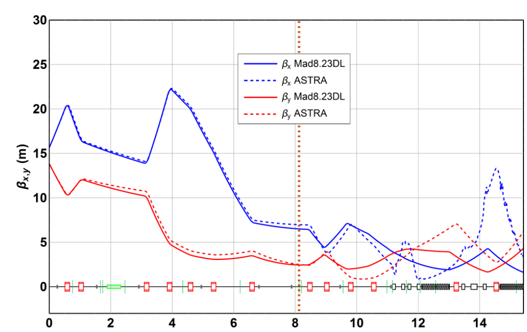

Figure 6: Optics matched from Linac-4 through TDC diagnostics section, seed laser chicane and modulators to radiator-1 in Mad and ASTRA.

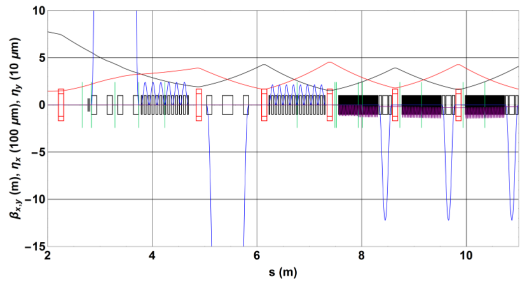

Figure 7: Optics (black/red) and dispersion (blue/purple) in both planes in chicane, modulator and radiator sections.

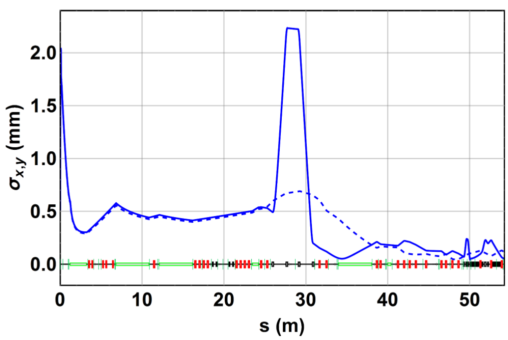

Figure 8: Matched beam sizes along CLARA for Short 240 MeV/c mode.

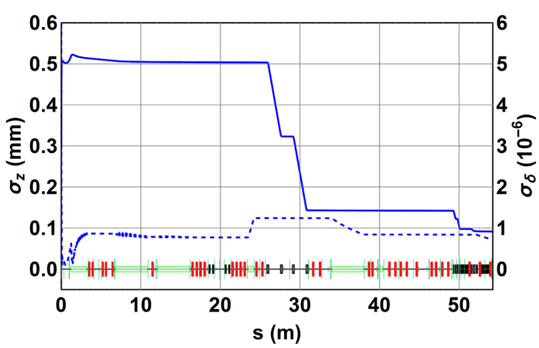

Figure 9: Bunch length and energy spread along CLARA for Short 240 MeV/c mode.

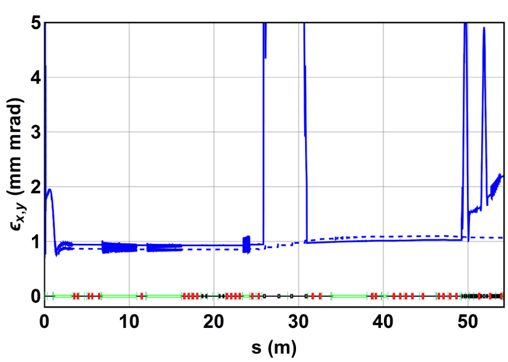

Figure 10: Normalised emittances along CLARA for Short 240 MeV/c mode.

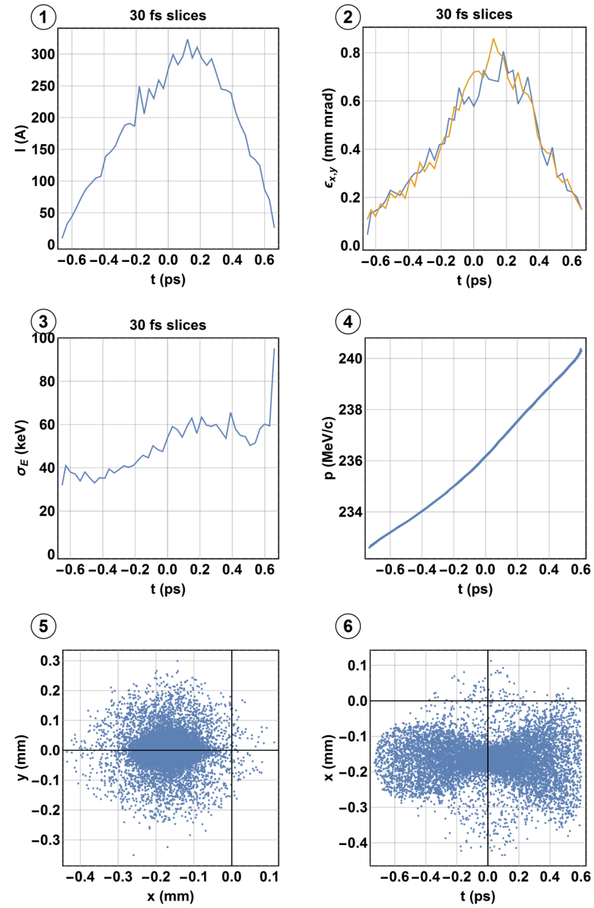

Figure 11: Tracked 10k bunch properties at FEL entrance, 30 fs slices where relevant. 1) Current profile. 2) Slice emittances. 3) Slice energy spread. 4) Longitudinal phase space. 5) Screen image. 6) x-t projection

REFERENCES

[1] J. A. Clarke *et al,* CLARA Conceptual Design Report, *JINST*, 9:T05001, 2014.

[2] P. Williams, D. Angal-Kalinin, A. D. Brynes et al, "Developments in CLARA Accelerator Design and Simulations", Proceedings of International Particle Accelerator Conference, 2015.

[3] P. Williams, D. Angal-Kalinin, A. D. Brynes et al, "Developments in the CLARA FEL Test Facility Accelerator Design and Simulations", Proceedings of International Particle Accelerator Conference, 2016.

[4] P. J. M. van der Slot & K.-J. Boller, "Recent Updates to the Optical Propagation Code OPC", Proceedings of FEL 2014.

[5] K. Floetmann, ASTRA, `http://www.desy.de/~mpyflo`

ISBN 978-3-95450-182-3