CLARA ACCELERATOR DESIGN AND SIMULATIONS

P. H. Williams*, D. Angal-Kalinin, J. A. Clarke, F. Jackson,
J. K. Jones, B. P. M. Liggins, J. W. McKenzie & B. L. Militsyn
STFC Daresbury Laboratory, Sci-Tech Daresbury, UK

Abstract

We present the accelerator design for CLARA (Compact Linear Accelerator for Research and Applications) at Daresbury Laboratory. CLARA will be a testbed for novel FEL configurations. The accelerator will consist of an RF photoinjector, S-band acceleration and transport to 250 MeV including X-band linearisation and magnetic bunch compression. We describe the design of the accelerator. Beam dynamics simulations are then used to define an operating working point suitable for the seeded FEL scheme.

INTRODUCTION

The aims of the CLARA project are presented in an accompanying paper [1] and the recently published conceptual design report [2]. CLARA will build on VELA, a 6 MeV injector currently being commissioned at Daresbury Laboratory. Previously presented work has detailed the RF photocathode gun design, longitudinal phase space linearisation scheme and variable magnetic bunch compressor [3], the diagnostics sections and dogleg for transferring the beam to the seed laser axis [4] and initial studies of tolerance and jitter [5]. In this paper we detail the full machine layout and electron transport including modulator and radiator sections together with full tracking simulations.

LAYOUT

A major aim of CLARA is to be able to test seeded FEL schemes. This places a stringent requirement on the longitudinal properties of the electron bunches, namely that the slice parameters should be nearly constant for a large proportion of the full-width bunch length. In addition, CLARA should have the ability to deliver high peak current bunches for SASE operation and ultra-short pulse generation schemes, such as velocity compressed bunches. This flexibility of delivering tailored pulse profiles will allow a direct comparison of FEL schemes in one facility. An overview of the proposed layout is shown in Fig. 1. The S-band (2998 MHz) RF photocathode gun [6] is followed by linac 1. This is a short ($\sim$ 2 m long) structure, chosen such that it may be used in acceleration or bunching configurations. A spectrometer line which also serves as injection to VELA branches at this location. Linac 2 follows which is $\sim$ 4 m long and capable of accelerating up to 150 MeV. Space for a laser heater is reserved at this point, initially this will not be installed however we expect that in the ultra-short bunch mode the beam properties will be degraded by microbunching instability (predominantly driven by longitudinal space-charge impedance). This effect will be quantified and the case for installing the laser heater determined in the future. A fourth harmonic linearising X-band cavity (11992 MHz) is situated before the magnetic compressor to correct for longitudinal phase space curvature. A variable magnetic bunch compressor is then followed by the first dedicated beam diagnostics section, incorporating transverse deflecting cavity and spectrometer, enabling measurement of emittance, bunch length and slice properties. Linacs 3 & 4 (each $\sim$ 4 m long) accelerate to 250 MeV, these are followed by a second diagnostics section. It has also been proposed to divert this high energy beam for other applications. The beamline then passes a dogleg, offsetting the FELs from the linacs transversely to enable co-propagation of long wavelength laser seeds. Immediately following the dogleg is the energy modulator and phase-space shearing chicane. A dedicated matching section ensures that periodic optics is achievable in the radiators for the entire wavelength range. Seven FEL radiators and a space for a FEL afterburner complete the accelerator and the beam is then dumped.

ELECTRON TRANSPORT

The full machine optics are shown in Fig. 2. Particular care was taken in the FEL section. We require an offset of the FEL transversely from the linacs as we must insert the seed laser co-linearly with the undulator axis. A dogleg was chosen instead of a chicane in order to min-

Table 1: Machine Parameters for Seeded Bunch

Section	Value	Unit
Gun Gradient	100	MV/m
Gun ϕ	-25	°
Linac 1 V	21.0	MeV/m
Linac 1 ϕ	-20	°
Linac 2 V	11.5	MeV/m
Linac 2 ϕ	-31	°
Linac X V	7.3	MeV/m
Linac X ϕ	-168	°
BC θ	95.0	mrad
Linac 3 V	22.5	MeV/m
Linac 3 ϕ	$+0$	°
Linac 4 V	22.5	MeV/m
Linac 4 ϕ	$+0$	°

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* peter.williams@stfc.ac.uk

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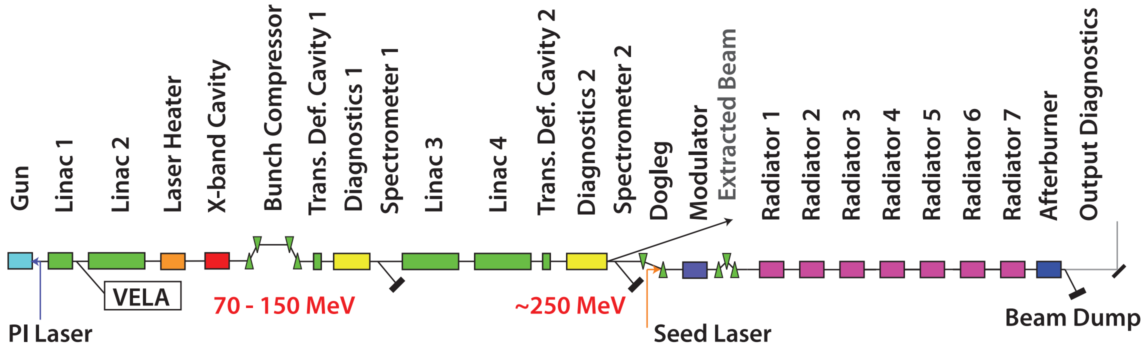

Figure 1: CLARA layout overview

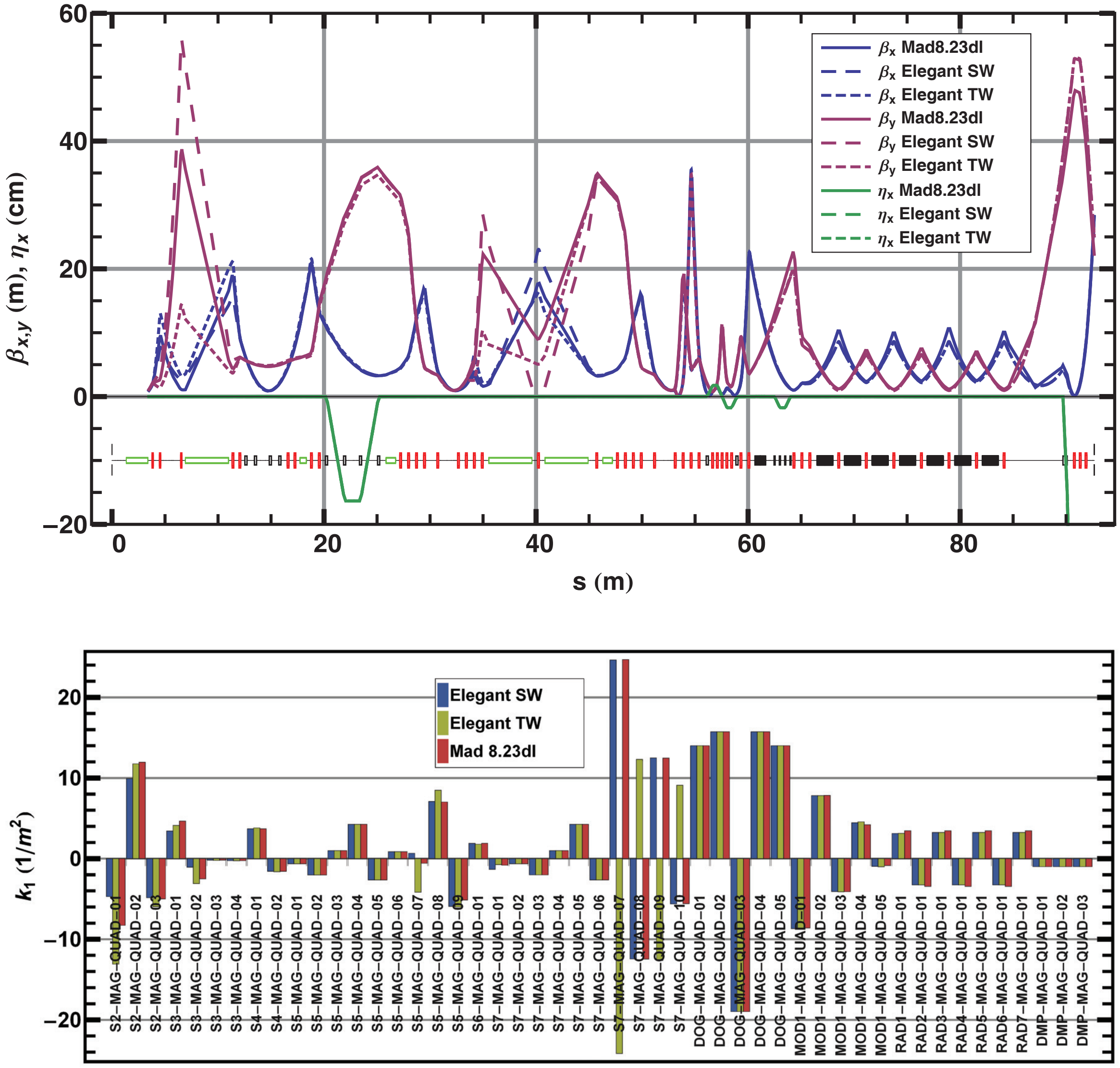

Figure 2: CLARA optical functions (top) and quadrupole geometric strengths (bottom). Matches were performed in Mad8.23dl (undulator focusing implemented in hard-edge model) and Elegant (using both standing wave (SW) and travelling wave (TW) linac structures). Undulator K is 5 for the modulator and 1.25 for the radiators.

imise the longitudinal momentum compaction (R_{56}), thus preserving bunch length. A five quadrupole achromat with bend angle of 2° has been chosen, providing 100 mm offset in total length of 3.5 m. As this point the relative energy spread in the bunch is small, so chromatic contributions from the quadrupoles are less significant, the maximum kl is 2.85 m^{-1}. The longest wavelength seed laser pulse proposed is 50 μm. This must propagate to the modulator immediately following the dogleg in as short a distance as possible, as it is highly divergent. For example at 3.5 m from the laser pulse waist the 3σ spot radius is 70 mm. However, as the dogleg is necessarily strongly focusing to ensure achromaticity, the Twiss functions are reasonably divergent in both planes at its exit. This requires doublet focusing prior to the modulator otherwise this results in unacceptably large beam sizes. A triplet following the phase space shearing mini-chicane ensures a periodic solution through the radiators. An initial study of the flexibility of periodic matching has been undertaken, the intention is have the capability to continuously tune the resonant wavelength over a large range.

BEAM DYNAMICS

The beam was simulated from the cathode until the exit of linac 1 using ASTRA [7] to include the effects of space-charge, wakefield effects have not yet been included. The rest of the machine was then tracked using ELEGANT [8]. Linac wakefields, longitudinal space-charge and coherent radiation effects were included.

The seeded operating mode is the most challenging as it requires that the bunch slice properties are constant for a large fraction of the bunch length, i.e. 300 fs out of 500 fs FW, and that the peak current is above 300 A for this fraction, without significant energy chirp. This is to ensure that expected jitter between the laser seed and the electron bunch does not result in unacceptable photon output jitter from pulse to pulse. To achieve this an optimisation was performed on the longitudinal phase space of the bunch at the FEL. At each step a transverse rematch was necessary to preserve the projected emittance. The optimisation variables are the voltages and phases of the S-band and X-band linacs, and the bunch compressor bend angle. The optimisation constraints are:

- There exists a 300 fs window where the mean current exceeds 300 A
- In that window, the minimum current in a 20 fs slice is greater than 270 A
- In that window, the standard deviation of the charges in a 20 fs slice is less than 20 pC
- In that window, the chirp is no larger than 1% of the energy spread in the central 20 fs slice

In Fig. 3 we show the optimised longitudinal phase space, current profile, slice emittance and slice energy spread at the FEL.

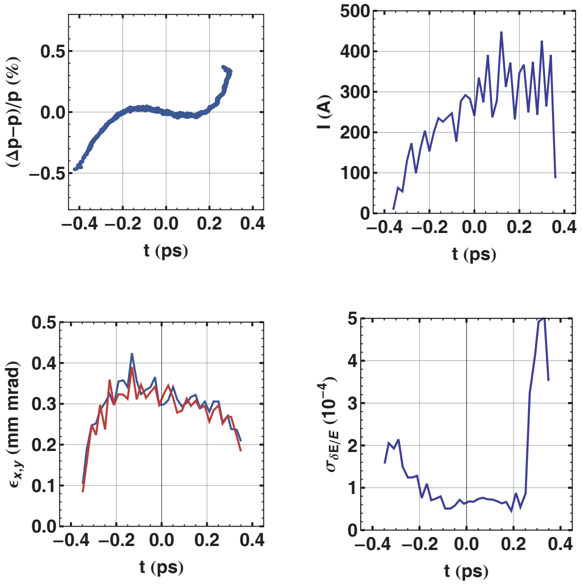

Figure 3: Seeded bunch longitudinal phase space, current profile, normalised slice emittance and slice energy spread.

For the unseeded modes, an alternative to magnetic compression is to use velocity bunching in the low energy section of the accelerator. Linac 1 is set to the zero crossing phase to impart a chirp along the bunch. The bunch compresses in the following drift space. Linac 2 then rapidly accelerates the beam and "captures" the short bunch length. Simulations suggest that this mode of compression can produce a similar bunch to that produced by the magnetic compression scheme if the X-band cavity is not used. Thus both compression modes can be used to meet the unseeded mode of CLARA operation. Preliminary simulations [3] suggest that for a 100 pC bunch, a peak current $\sim$ 1 kA can be achieved with slice energy spread of $\sim$ 250 keV rms and normalised slice emittance of $\sim$ 1 mm mrad. With such a short bunch in the injector, wakefields have a significant effect which will be investigated further.

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