CLARA – A PROPOSED NEW FEL TEST FACILITY FOR THE UK

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Abstract

A Free Electron Laser (FEL) test facility, CLARA (Compact Linear Advanced Research Accelerator), is proposed to be constructed at Daresbury Laboratory in the UK. The aim of CLARA is to develop a normal conducting test accelerator able to generate longitudinally and transversely bright electron bunches and to use these bunches in the experimental production of stable, synchronised, ultra short photon pulses of coherent light from a single pass FEL with techniques directly applicable to the future generation of light source facilities. In addition the facility will be an ideal test bed for demonstrating innovative technologies such as high repetition rate normal conducting RF linacs and advanced undulator designs. This paper will describe the design of CLARA, pointing out the flexible features that will be incorporated to allow multiple novel FEL schemes to be proven.

INTRODUCTION

X-ray FELs with demonstrated outstanding performance characteristics are now operational in the USA and Japan, and others are being constructed in Europe and elsewhere. In spite of these impressive achievements it is clear that the potential for FELs is even greater in terms of further optimising the output performance to match the ever demanding needs of the science community. There are many ways in which FELs could be further improved: better temporal coherence, tighter control of pulse synchronisation, greater intensity stability, shorter pulses, shorter wavelengths, tailored pulse structures, and so on. There are numerous schemes which have the potential to address one or more of the above but which have not yet been tested in practice. We propose to build a dedicated FEL test facility, called CLARA [1], so that several of the most promising schemes can be proven and subsequently be directly implemented into a new national light source facility from conception.

Aims of CLARA

The primary aim of CLARA is to develop a normal-conducting test accelerator, able to generate longitudinally and transversely bright electron bunches, and to use these bunches in the experimental production of stable, synchronised, ultra-short photon pulses of coherent light from a single pass FEL using techniques directly applicable to the future generation of light source facilities.

In the context of the above, stable means with little variation in transverse position or intensity from shot to shot, synchronised means the photon output pulse should be sufficiently well synchronised to a timing signal to simultaneously control a conventional laser used in a pump-probe experiment, and ultra-short means the photon pulse length should be shorter than, or of the order of, the FEL cooperation length.

There are a number of other aims and prerequisites to make maximal use of this dedicated test facility. These include:

- To lead the development of low charge single bunch diagnostics, synchronisation systems, advanced low level RF sysems, and novel short period undulators.
- To develop skills and expertise in the technology of normal conducting RF photoinjectors and seed laser systems.
- To develop novel techniques for the generation and control of bright electron bunches including manipulation by externally injected radiation fields and mitigation against unwanted short electron bunch effects (e.g. microbunching and CSR).
- To demonstrate high temporal coherence and wavelength stability of the FEL, for example through the use of external seeding or other methods.
- To develop the techniques for the generation of coherent higher harmonics of a seed source.
- To develop new photon pulse diagnostic techniques as required for single shot characterisation and arrival time monitoring.

Parameter Selection

The parameters of CLARA are dictated by the requirement to interact with conventional laser seed sources. The primary external radiation source will be a Ti:Sa laser operating at 800nm. This can be used on its own, or to drive an Optical Parametric Amplifier (OPA) covering the range 2–20μm, or a Higher Harmonic Generation (HHG) system giving output from the longest easily available wavelength of 100nm. An additional requirement is the need for ultra-fast, single shot, pulse diagnostics for characterising the FEL performance. It is anticipated that conventional laser single shot diagnostic techniques in the visible region of the spectrum will be

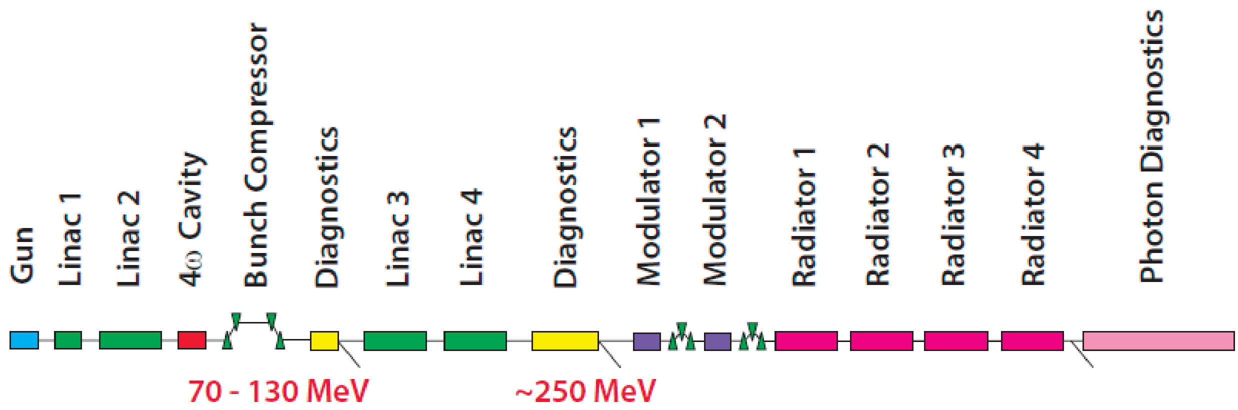

Figure 1: Schematic layout of CLARA. The overall length is ~80 m.

used instead of developing a dedicated technique in the deep UV where material properties tend to not be conducive for such measurements. Given these constraints an FEL output wavelength covering the range of 100 to 400 nm has been selected.

Making the assumption that the minimum undulator gap can be 6 mm then it would be possible to tune over this wavelength range with an undulator period of 29 mm and an electron beam energy of 250 MeV.

The electron bunch charge has been set by the requirement for a peak current of 400 A over a range of different scenarios (SASE, short pulse mode, and externally seeded) in order to reach saturation of the FEL within about 15 m. Given the assumed bunch lengths and distributions this specifies the maximum charge as 250 pC. The diagnostics have been specified to operate down to 20 pC bunch charge.

LAYOUT

Photoinjector

A new photoinjector test stand is currently being assembled at Daresbury (known as the Electron Beam Test Facility, EBTF [2]) and this will act as the electron source for CLARA in the future. The EBTF contains a 2.5 cell S-Band cavity capable of generating up to around 6 MeV electron bunches of high brightness [3]. The EBTF will not only generate high brightness electron bunches for CLARA, it will also be made available to industrial partners, via a side station, for the development and testing of new accelerator technology or related equipment.

Bunch Compression

A number of alternative bunch compression schemes are being explored. One option is to rely on velocity bunching alone, a second option is to use a conventional magnet chicane with additional non-linear elements to linearise the longitudinal phase space, and the third option is to use a conventional chicane in combination with a high harmonic RF cavity for linearisation. No decisions have been made yet on the bunch compression scheme which will be implemented nor the exact energy at which compression will be applied. Further details on the three options and the advantages and disadvantages of each can be found in [4].

FEL

The aim of CLARA is to be able to test a number of alternative FEL schemes, especially in the short pulse regime. Fortunately, the alternative schemes proposed follow a generic layout of one or two modulators where the electron bunch interacts with an external laser and then a long radiator section where the FEL reaches saturation. Our approach with CLARA is to build a very flexible facility which will be able to switch between the different schemes relatively quickly. Our studies show that the long radiator section is common to almost all of the schemes of interest and the area which will require the most intervention will be the short modulator section, perhaps by using a different combination of modulators or external laser wavelengths. For greatest flexibility CLARA will be engineered so that the modulator sections are easy to exchange and align. We currently anticipate that the external laser feedthrough ports and radiator section will remain unchanged for the majority of the schemes that we wish to examine in the first instance. Of course, changes in these areas are also possible but we expect this to be less often. The overall schematic layout of CLARA is shown in Figure 1.

FEL SCHEMES

Initial work has been done to assess the feasibility of demonstrating a number of FEL schemes on CLARA. The emphasis so far has not been to undertake detailed optimisation but to ensure that the outline parameter specification is compatible with the widest range of applications. Initial simulation results for a selection of proposed schemes are shown in Figure 2 to illustrate the range of the ongoing studies. In each case shown here the resonant wavelength is 100 nm but work is also ongoing to assess the schemes for operation in the visible region of the spectrum. The schemes illustrated are as follows: (a)

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single spike SASE with a 100pC tracked bunch compressed via velocity bunching; (b) short pulse generation using an energy chirped electron bunch and a tapered undulator [5]; (c) mode-locked amplifier FEL [6] using the standard CLARA radiator lattice with electron beam delays between undulators; (d) as (c) but the electron beam delays matched to the rms electron bunch length to distinguish a single spike from the pulse train.

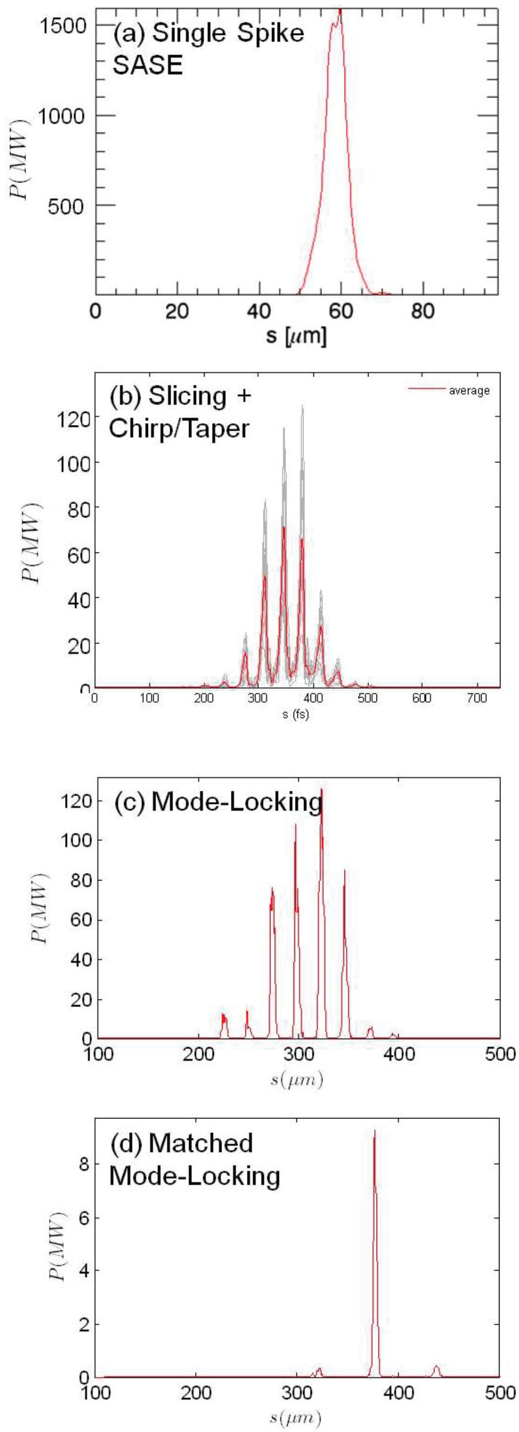

Figure 2: Example simulation results of different FEL schemes. Resonant wavelength is 100nm.

In addition to short pulse schemes the flexibility of the CLARA layout will allow research into methods of improving the longitudinal coherence of SASE, for example: direct seeding in the VUV with harmonics generated in a gas; self seeding; seeding in the IR or UV then harmonic generation via High Gain Harmonic Generation (HGHG) [7] or Echo-Enabled Harmonic Generation (EEHG) [8]; proposals for the use of electron beam delays [9]. Also of interest are methods for the production of higher harmonics of the FEL output, such as: using advanced short period undulators as harmonic afterburners at wavelengths as short as 50nm; proposed schemes for harmonic generation via phase shifters [10,11].

NEXT STEPS

The conceptual design of CLARA will be further developed during 2012. It is anticipated that a start to end model from gun to the exit of the FEL will be generated as part of this study. It will be important during the study to focus on the jitter and tolerance budget for the hardware in order to ensure that the challenging stability and synchronisation targets for CLARA can be achieved. The short pulse FEL schemes will be studied further and the most promising ones selected for implementation. A key issue here will be establishing confidence that a sucessful demonstration of a particular FEL scheme at relatively long wavelength on CLARA can be transferred directly onto a short wavelength FEL facility in the future.

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