THE STATUS OF CLARA, A NEW FEL TEST FACILITY

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Abstract

CLARA is a new FEL test facility being developed at STFC Daresbury Laboratory in the UK. The main motivation for CLARA is to test new FEL schemes that can later be implemented on existing and future short wavelength FELs. Particular focus will be on ultra-short pulse generation, pulse stability, and synchronisation with external sources. The project is now underway and the Front End section (photoinjector and first linac) installation will begin later this year. This paper will discuss the progress with the Front End assembly and also highlighting other topics which are currently receiving significant attention.

INTRODUCTION

CLARA will be a dedicated FEL test facility in the UK, capable of testing new FEL schemes that have the capability to enhance the performance of short wavelength FELs worldwide. The primary focus of CLARA will be on ultrashort pulse generation, stability, and synchronisation. Enhancements in these three areas will have a significant impact on the experimental capabilities of FELs in the future.

The wavelength range chosen for the CLARA FEL is 400 – 100 nm, appropriate for the demonstration of advanced FEL concepts on a relatively low energy accelerator. Key drivers for this choice are the availability of suitable seed sources for interacting with the electron beam and the availability of single shot diagnostic techniques for the characterisation of the output. The proposal is to study short pulse generation over the range 400 – 250 nm, where suitable nonlinear materials for single shot pulse profile characterisation are available. For schemes requiring only spectral characterisation (for example producing coherent higher harmonics of seed sources, or improving the spectral brightness of SASE) the operating wavelength range will be 266 – 100 nm. Generating these wavelengths will be readily achievable with the 250 MeV maximum energy of CLARA.

Since the Conceptual Design Report was published in 2013 [1] there has been significant progress in the overall design of the facility, with special attention paid to the Front End injection section (up to 50 MeV) and the FEL layout itself. The injection section is currently being procured and assembled offline and it will be installed in November 2015 with commissioning planned for April 2016. A schematic layout of the full facility is given in Fig. 1.

FRONT END SECTION

The CLARA Front End includes the RF photoinjector, a 2 m long S-band linac, a straight ahead line into a temporary combined Faraday cup/beam dump and a dog-leg to transport the beam into the already operational VELA facility [2]. Initially the existing 2.5 cell S-band RF gun currently used at VELA will be used for the CLARA Front End [3]. This is limited to 10 Hz repetition rate, at bunch charges of up to 250 pC. The gun is fed with a 10 MW klystron with a power available for the gun of 8.5 MW. Maximum beam momentum measured at this

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power is 5.0 MeV/c [4]. To reach repetition rates of up to 400 Hz this will be replaced by a high repetition rate photoinjector which is currently being manufactured [5]. This new photoinjector is a 1.5 cell S-band gun with RF probe included for active monitoring and feedback. The cooling system has been optimised to cope with up to 10 kW of average power which means that at a maximum gradient of 120 MV/m it will be capable of 100 Hz, or alternatively 100 MV/m at 400 Hz. The gun also incorporates a vacuum load lock system for ready replacement of the cathode. CAD models of the gun cavity, which is currently being fabricated, are given in Figs. 2 and 3. The linac will also be capable of 400 Hz operation at a maximum gradient of 25 MV/m. A photo of the linac structure currently being fabricated and tested is given in Fig. 4. Detailed studies of the Front End performance with the existing 10 Hz gun and the new 400 Hz gun as a function of accelerating gradient, photoinjector laser pulse length, and also the impact of a velocity compression mode are all discussed in [6].

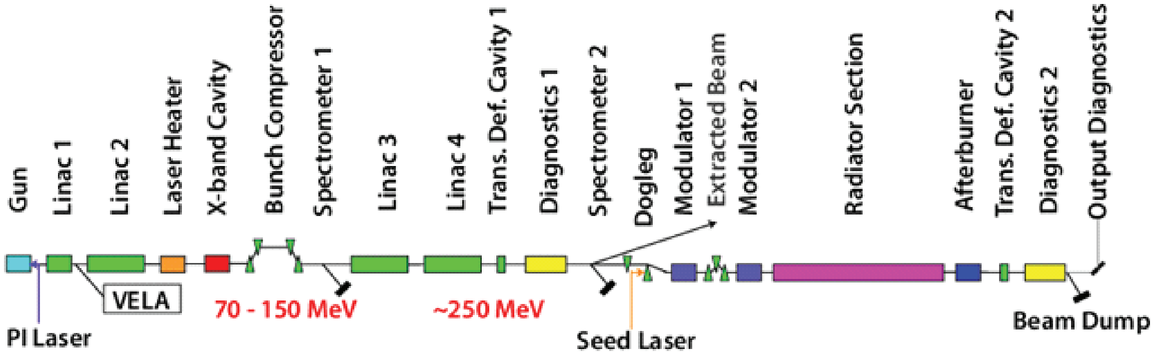

Figure 1: Schematic layout of CLARA.

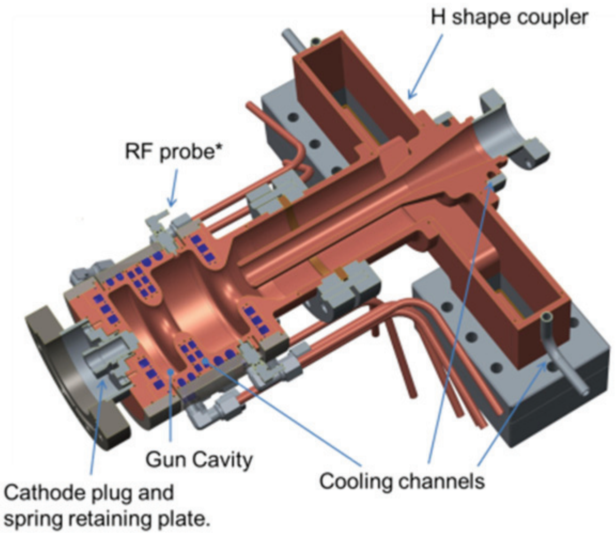

Figure 2: CAD model of the high repetition rate gun showing the key features.

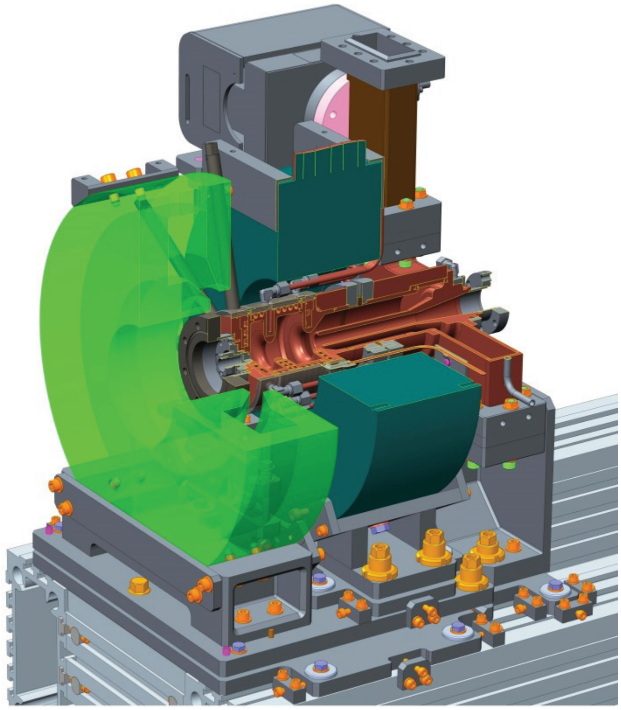

Figure 3: CAD model of the high repetition rate gun mounted on CLARA with the main solenoid in dark green and the bucking solenoid in light green. The load lock system attaches to the back of the gun within this bucking solenoid.

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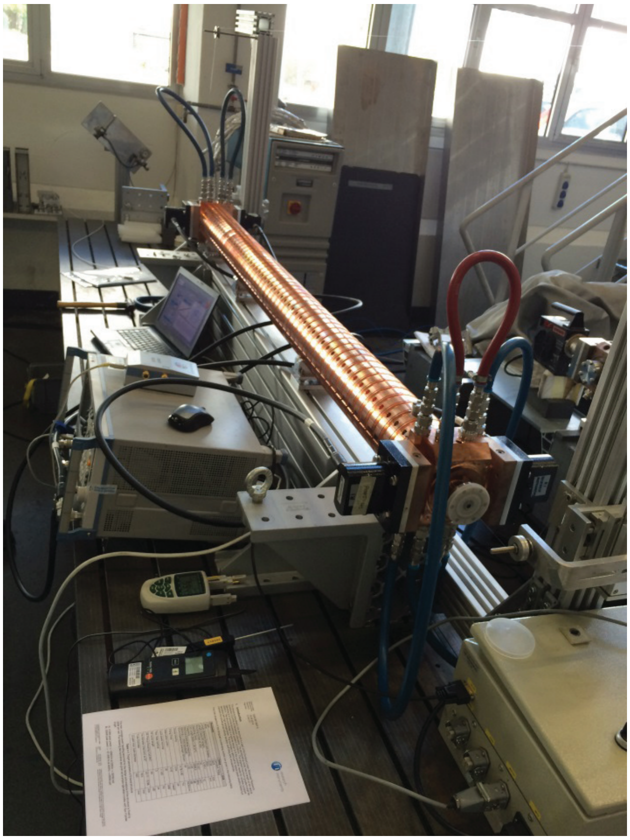

Figure 4: Photo of the 2 m long S-band linac undergoing low power RF testing following manufacture.

LASER HEATER STUDIES

The CLARA linac is potentially affected by longitudinal microbunching instability (MBI) [7-9], as are other accelerators that drive high gain free electron laser (FEL) facilities [10,11], which produces short wavelength (~1 – 5μm) energy and current modulations. These can both degrade the FEL spectrum and reduce the power by increasing the slice energy spread. This instability is presumed to start at the photoinjector exit growing from a pure density modulation caused by shot noise and/or unwanted modulations in the photoinjector laser temporal profile. As the electron beam travels along the linac to reach the bunch compressor, the density modulation leads to an energy modulation via longitudinal space charge. The resultant energy modulations are then transformed into higher density modulations by the bunch compressor. The increased current non-uniformity leads to further energy modulations along the rest of the linac. Coherent synchrotron radiation in the bunch compressor can further enhance these energy and density modulations [12,13]. The main solution to prevent MBI, used in several FEL facilities, is the laser heater [14,15].

A laser heater consists of a short, planar undulator located in a magnetic chicane where an external infra-red laser pulse is superimposed temporally and spatially over the electron beam. The electron-laser interaction within the undulator produces an energy modulation on a longitudinal scale length corresponding to the laser wavelength.

The second half of the laser heater chicane smears the energy modulation in time, leaving the beam with an almost pure incoherent energy spread. This controllable incoherent energy spread suppresses further MBI growth via energy Landau damping in the bunch compressor. A layout of a laser heater is shown in Fig. 5.

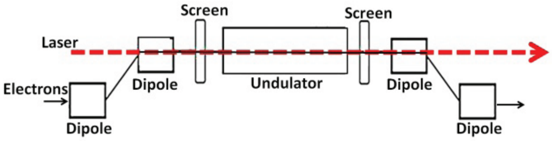

Figure 5: Laser heater layout.

Whilst our studies have shown that a laser heater will not be essential in order for CLARA to lase, the presence of the laser heater in a test facility like CLARA could be exploited to study further some less explored aspects of MBI such as the microbunching induced by the laser heater chicane and the microbunching competition between different sections of the accelerator [16].

The laser heater can also be used to modulate the electron beam energy spread to control the FEL temporal and spectral properties [17] or to deliberately increase the final energy spread to study energy spread sensitivities of the FEL schemes tested at CLARA. The laser heater chicane could be also used to implement the diagnostics presented in [18]. These are all possible experiments of relevance to future FEL facilities. Further details of the CLARA laser heater design and motivation are presented in [19].

REVISED FEL SECTION

The layout of the FEL section has been revised since the publication of the CDR. The previous layout included a single modulator undulator to provide an interaction between seed/modulating lasers and the electron beam. It was found in simulations however that for the 30 – 120 μm seed wavelength range the amplitude of the modulation obtained was smaller than that required for optimum performance in some modes. This was due to the modest seed power available and the fact that the slippage limited the interaction length to only a few undulator periods. The revised layout comprises two modulators with dispersive chicane in between, i.e. an optical klystron configuration. The small modulation induced in the first modulator can be bunched in the chicane giving strong coherent emission in the second modulator which then slips over the whole bunch driving the energy modulation more strongly. The amplitude of the energy modulation is expected to be enhanced by nearly an order of magnitude, compared to the original design comprising a single modulator.

The layout of the radiator section has also been revised. The length of the individual undulator modules has been reduced from 1.5 m to 0.75 m and the gaps between modules have also been halved in length from 1.1 m to

0.5 m. The number of modules is now 17 compared with 7 previously. There are several motivations for this change. First, two of the schemes to be investigated on CLARA, Mode-Locking [20] and HB-SASE [21], have been seen in simulations to perform more effectively for a lattice comprising a greater number of shorter undulators, in agreement with other research [22]. Second, reducing the FODO period reduces the FEL gain length which benefits all CLARA FEL schemes. Third, the natural focussing of the FEL undulators becomes less significant allowing easier matching into the FODO channel. In order to reduce the length of the intermodule gaps the diagnostic screens and vacuum components will now be incorporated within the length of the undulator modules, rather than in the gaps. Design of the vacuum solution and diagnostic screens is ongoing.

UNDULATOR TAPERING STUDIES

Undulator tapering is a well-known and widely used technique for improving the performance of free-electron lasers. It was originally proposed as a way to improve the energy extraction efficiency of an FEL, but has since found many other applications. For example, when tapering is combined with self-seeding, it provides a route to coherent, high-power, hard x-ray FELs. Alternatively, it can be used in combination with an external laser modulator to generate short, fully coherent radiation pulses by restricting high FEL-gain to the energy-chirped sections of the electron bunch. Similarly, energy-chirps arising from velocity bunching or longitudinal space charge can be compensated using an undulator taper. A reverse undulator taper can also be used to suppress FEL power, whilst still allowing a high degree of bunching to develop within the electron bunch. This can then be used for a variety of applications, such as generating circularly polarised light in a helical undulator after-burner.

In view of this diverse range of applications for undulator tapering, the topic is currently one of interest for study with CLARA. An investigation has been carried out into the suitability of the proposed FEL layout for improving both the final FEL pulse energy and spectral brightness via undulator tapering. The results have confirmed that the proposed layout is suitable for effective tapering experiments [23].

X-BAND DEVELOPMENTS

Initially CLARA will be based on S-band linac sections to achieve the required energy of 250 MeV. However, a study has shown that the replacement of the last 4 m linac section by an X-band linac designed for FEL applications does not have any adverse impact on the bunch quality and would have the useful advantage of increasing the maximum energy of CLARA to approximately 430 MeV, assuming a gradient of 65 MV/m [24]. This would enable CLARA to prove that X-band technology developed initially for the CLIC particle physics collider at CERN is applicable to FELs [25]. In the long term, as this technology matures and is further industrialised, X-band acceleration could form the basis of a future FEL user facility for the UK.

BUILDING UPGRADE

CLARA is being installed into an existing building on the Daresbury site. This building is approximately fifty years old and is 34 m by 110 m which is more than sufficient for CLARA (approximately 10 m by 95 m). However, the temperature variation within the building due to seasonal variation is very large due to poor environmental control and insufficient insulation. As a result the temperature control required within the shielded enclosure, which is specified to be within 0.1 °C, would be very difficult to achieve. Furthermore, the ancillary equipment outside of the shielded enclosure, such as the RF infrastructure, control racks, power convertors, cables, fibres, and lasers, also require the temperature to be well controlled in order to be able to achieve the extreme levels of synchronisation and stability required by CLARA. Therefore the building is being upgraded to stabilise the temperature within the complete building to within 1.0 °C. The walls and roof are being completely replaced by modern insulated panels, and all windows removed, in order to achieve this specification with the minimum of active control required. This building upgrade will be completed within approximately 18 months.

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