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A FRONT END FOR THE CLARA FEL TEST FACILITY AT DARESBURY LABORATORY

P. H. Williams , D. Angal-Kalinin, J. A. Clarke, B. D. Fell, J. K. Jones, J. W. McKenzie & B. L. Militsyn, ASTeC, STFC Daresbury Laboratory, Warrington, U.K.

Abstract

The next step towards the full CLARA facility is installation of the CLARA front end to comprise a 2m S-band linac section after the photoinjector gun. This will be suitable for both the velocity bunching and standard booster modes of CLARA. An S-bend will also be installed to deflect the beam into the current VELA line, enabling delivery of higher energy beams to two existing user areas. The current photoinjector beam diagnostics section can then be used to test a High Repetition Rate electron gun currently under development. We describe the proposed CLARA front end design. We define two beam dynamics working points for CLARA, one working point for sending beam from the CLARA Front End to VELA, and one working point to feed an interim user station prior to CLARA full construction in the straight-on position.

INTRODUCTION

The VELA user facility, based on the ALPHA-X photocathode gun, has been commissioned and successfully delivered beam to users in 2013 [1]. The proposed FEL test facility, CLARA [2], is intimately linked to VELA with much common infrastructure. The design of the CLARA Front End (CLARA-FE) has been optimised to meet the requirements of the CLARA injector as well as to transport higher repetition rate, higher energy bunches to the presently operating VELA facility.

The proposed layout shown in Fig.1 has been designed to use common the RF and drive laser infrastructure to feed two photoinjector RF guns. This will allow the flexibility of sending ~5 MeV high repetition rate bunches to existing VELA user areas, and up to 50 MeV bunches transported through the S-bend placed after the first linac on the CLARA line to the VELA user areas. The layout assumes that the present VELA gun moves to CLARA when front end is ready and installed. The ~55 MeV bunches after linac-1 can either be transported to (1) the CLARA line, (2) around the first dipole in the S-bend, then straight ahead to a diagnostic spectrometer line for characterising high energy bunches and (3) around the second dipole in the S-bend to the VELA user areas (the quadrupole triplet can be energised to eliminate dispersion in the VELA line). When the new High Repetition Rate Gun (HRRG) [3] is ready for commissioning and characterisation, it will be installed in the present VELA gun position. This is attractive as it provides a full set of dedicated diagnostics including the Transverse Deflecting Cavity (TDC). After this characterisation the HHRG will be moved to the CLARA line. Depending on the experimental programme either the original VELA gun or another new gun will be installed on the VELA line. This option will make low energy, short bunches available to proposed electron diffraction experiments on the VELA line [4].

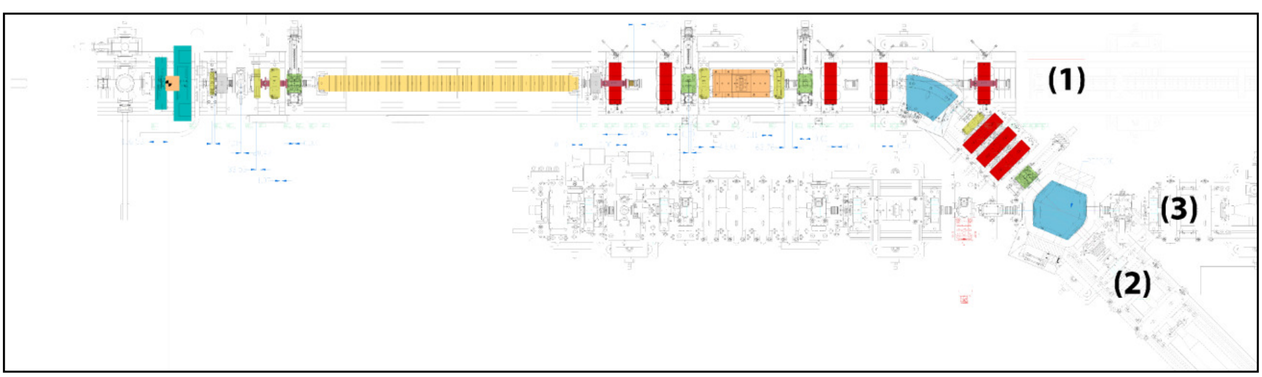

Figure 1: CLARA Front End Layout. The beam can be directed to (1) the rest of CLARA, (2) a diagnostic spectrometer line and (3) the existing VELA line with two user areas. The second “lozenge” dipole also admits beam from the existing VELA gun line allowing to be diverted to (2) or continue to (3).

INJECTOR FOR CLARA

The CLARA-FE is designed to serve as the future injector for CLARA, with linac-2 placed just after the first dipole of the S-bend on the CLARA line. For all simulations, an intrinsic transverse emittance from the copper photocathode is included as per LCLS measurements of 0.9 mm mrad rms per mm of a flat-top laser spot [5]. A laser diameter of 1 mm and a Gaussian longitudinal laser profile of 76 fs rms has been assumed, commensurate with the current VELA photoinjector laser output. The short pulse length allows the gun to operate in

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the so-called "blow-out" regime, where the bunch length expands due to space-charge. A 250 pC bunch expands to 1.3 ps rms during traversal of the gun and does not evolve afterwards until the bunch compression points. The beam was simulated from the cathode until the exit of linac-1 using ASTRA [6] to include the effects of space-charge.

CLARA Standard Acceleration

To provide beam for the seeded FEL schemes we define a standard (or booster) mode for CLARA. A 250 pC bunch, is accelerated to modest energy for further compression after linac-2 by a variable deflection magnetic chicane. In this scheme linac-1 is operated at a phase 20° off-crest to provide part of the chirp needed for compression. The resulting beam properties are shown in Fig. 2. The transverse emittance of the beam can be further reduced by increasing the solenoid fields surrounding the first linac. However, increasing these fields too much results in formation of a "halo" around the main beam core. The solenoids are thus set to reduce the emittance to the point before halo begins to form.

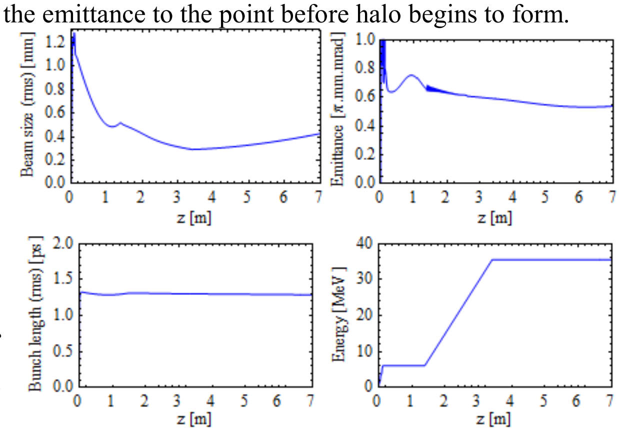

Figure 2: Beam size, transverse emittance, bunch length and energy for a 250 pC bunch in CLARA standard accelerating mode.

CLARA Velocity Bunching

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 to impart a time-velocity chirp along the bunch. The bunch then compresses in the following drift space. For the full CLARA machine linac-2 will be positioned at the waist of the bunch length evolution to rapidly accelerate the beam and "capture" the short bunch length. As the CLARA-FE initial installation will not include linac-2 an experimental station placed at the end of the CLARA-FE may utilise the velocity bunching scheme to provide ultra-short bunch lengths. The position of the waist may be varied with machine tuning at the expense of ultimate bunch length. The plots in Fig. 3 show beam properties along the beam line for a 100 pC bunch.

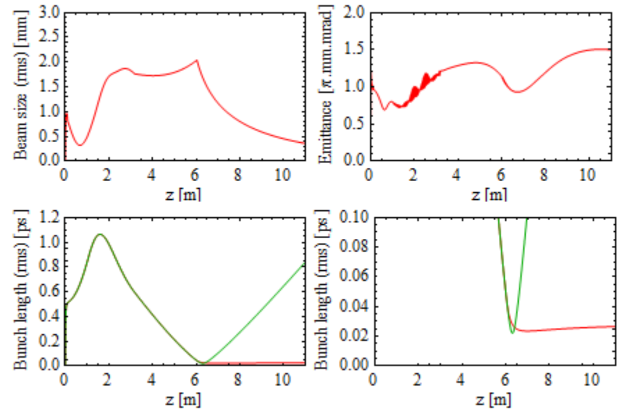

Figure 3: Top: (L) Beam size and (R) transverse emittance for a 100 pC bunch in velocity bunching mode (plots are for full CLARA design including linac-2 from ~6m). Bottom: (L and R - zoomed) Bunch length for 100 pC bunch in velocity bunching mode (red – full CLARA design including linac-2 from ~6m, green – CLARA front end without linac-2 installed).

CLARA TO VELA S-BEND DESIGN

The S-bend has been designed for a 1 m offset between the VELA and CLARA lines, however the offset will be increased to 1.2 m to improve access between the machines. The S-bend consists of two 45° dipoles, a symmetric quadrupole triplet and a "lozenge" dipole. The first dipole is sector-type with zero edge-angle on entrance and exit. It has been specified to operate at up to 55 MeV/c, which will allow characterisation of highest energy beam from linac-1 in the spectrometer line. The quadrupole triplet is specified to make the system achromatic in the VELA line. The lozenge dipole is designed such that the beam experiences zero edge-angle at all entrances and exits. This is important because the restricted geometry implies strong focusing to meet the achromatic condition. A consequence of this is that lack of space precludes the correction of any further vertical focusing caused by non-zero edges. The beam from linac-1 to the VELA line accumulates a first order momentum compaction (R_{56}) of -78 mm and second order momentum compaction (T_{566}) of -2.794 m. The optics of the S-bend with upstream matching from linac-1 is shown in Fig.4.

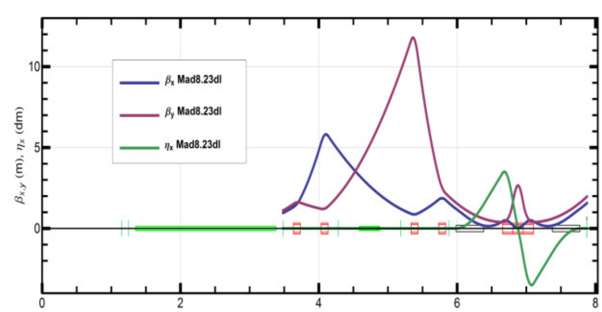

Figure 4: Optics of the S-bend and upstream matching from the exit of linac-1.

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OPTIMISATION FOR HIGH DENSITY PLASMA USER EXPERIMENTS

It is proposed to use both VELA user area 1 and the end of CLARA-FE for high electron density plasma experiments. Optimisations have therefore been performed to determine achievable bunch lengths at these positions. GPT [7] has been used to be consistent with existing VELA simulations and to ensure the correct treatment of bending elements.

CLARA-FE to VELA Optimisation

The beam properties in the VELA user areas when operating with CLARA-FE will be affected by the strong optics in the S-bend. A 2 m standing-wave linac structure was modelled in GPT because travelling wave structures are not available. Benchmarking with ASTRA using a travelling wave structure shows no significant differences. The gun and linac phases and gradients are varied in order to minimise the bunch length at user area 1. Given the large momentum compaction of the S-bend, the required energy chirp is not large and a beam momentum of 54 MeV/c is achieved. Fig. 5 shows the beam sizes and Fig. 6 shows the bunch length and energy spread for a 100 pC bunch for 54 MeV/c. It should be noted that additional focusing elements have been added in the user area to produce a spot size suitable for the experiments. The simulation results shown here do not include wakefields in linac-1 or coherent synchrotron radiation in the S-bend. These effects will be included in further work.

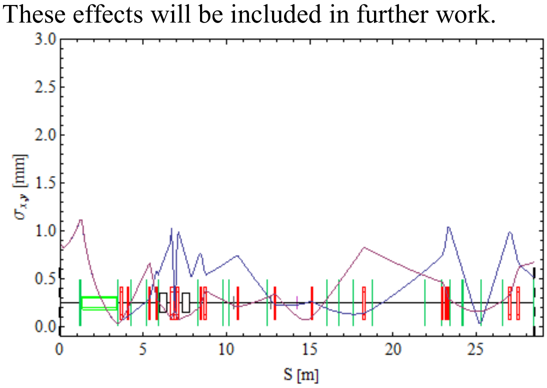

Figure 5: Beam sizes for a 100 pC bunch propagating from CLARA-FE to VELA user area 1.

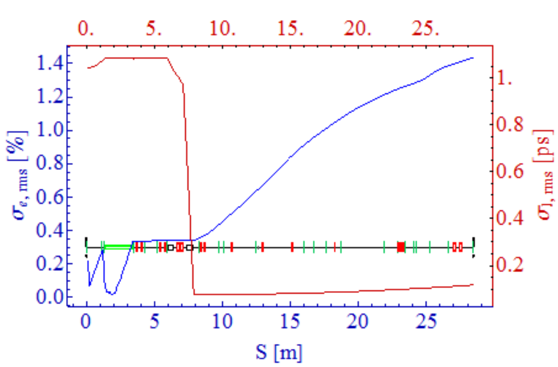

Figure 6: Energy spread and bunch length for a 100 pC bunch propagating from CLARA-FE to VELA user area 1.

CLARA-FE Straight-Ahead Optimisation

When CLARA-FE is installed, there will be a possibility of using the beam straight on from linac-1 before rest of the CLARA is constructed. As we do not traverse the strongly-focusing S-bend system, this set up will enable the achievement of shorter bunches at lower energy through velocity bunching. However, operating at zero crossing does increase the energy spread. Fig. 7 shows the beam sizes and Fig. 8 shows the energy spread and bunch lengths of a 100 pC tracked bunch. Final beam momentum achieved is 15.35 MeV/c.

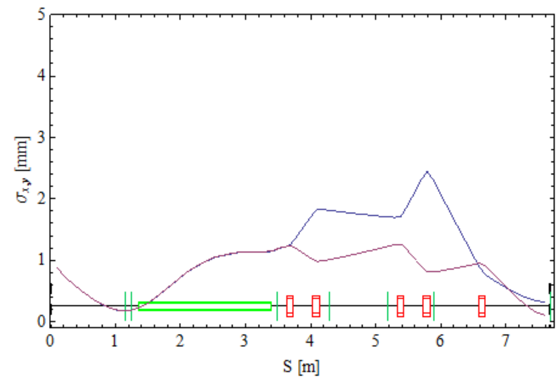

Figure 7: Beam sizes for a 100 pC bunch propagating from CLARA-FE to a straight-ahead station.

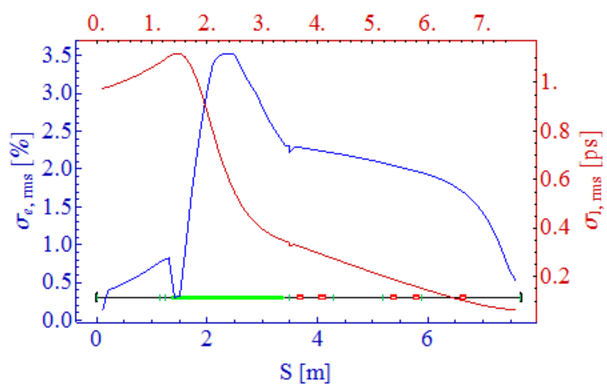

Figure 8: Energy spread and bunch length for a 100 pC bunch propagating from CLARA-FE to a straight-ahead station.

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