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STATUS OF CLARA FRONT END COMMISSIONING

D. Angal-Kalinin[1†], A. D. Brynes[1], S. Buckley[1], R. Cash, R. F. Clarke, P. Corlett[1], L. S. Cowie[1], G. Cox, K. Dumbell[1], D. J. Dunning[1], C. Hodgkinson, P. Hornickel[1], F. Jackson[1], J. K. Jones[1], J. W. McKenzie[1], B. L. Militsyn[1], A. J. Moss[1], J. Murphy[1], T. C. Q. Noakes[1], M. D. Roper[1], D. J. Scott[1], B. J. A. Shepherd[1], R. J. Smith[1], E. Snedden[1], N. R. Thompson[1], C. Tollervey[1], D. A. Walsh[1], T. Weston[1], A. E. Wheelhouse[1], J. T. G. Wilson
STFC, Sci-Tech Daresbury, UK, also at [1]Cockcroft Institute, Sci-Tech Daresbury, Warrington, UK

Abstract

CLARA (Compact Linear Accelerator for Research and Applications) is a Free Electron Laser (FEL) test facility under development at Daresbury Laboratory. The progress in commissioning of the CLARA front end focussing on recent investigations into photoinjector (PI) drive laser transport and development/commissioning of high level software scripts are presented.

INTRODUCTION

CLARA is a proposed 250 MeV FEL test facility [1] based at Daresbury Laboratory. The test facility has been designed to test advanced FEL concepts and capabilities for next generation X-ray FELs as well as to provide high brightness beam to academic and industrial users. CLARA is intimately linked to the VELA facility based on the RF photocathode gun, which was commissioned in 2013 and successfully delivered beam to academic and industrial users from 2013-2015 [2]. During 2016-2017, the Front End of CLARA has been installed in the accelerator hall. This consists of a 10 Hz S-band RF gun [3] and a S-band Linear accelerator Linac1. An S-bend incorporating the spectrometer dipole, a quadrupole triplet and a Lozenge dipole transports high energy beam from CLARA FE to the existing VELA beam line. The 10 Hz RF gun, earlier used on VELA is now installed on the CLARA beam line. First results of CLARA Front End commissioning were reported at IPAC18 [4]. This paper gives an update since May 2018 on investigations into PI laser transport and future plans as well as problems in linac wave guide and the remedial actions taken. The progress in commissioning of high level software scripts with beam is presented.

PHOTOINJECTOR LASER TRANSPORT INVESTIGATIONS AND PLANS

Systematic investigation of the laser system (10 mJ Ti:Sapphire, 80 fs @ 10 Hz; frequency tripling from 800 to 266 nm through harmonic generation in consecutive BBO crystals) and transport have been performed with three primary goals: 1) to increase the total UV pulse energy reaching the photocathode and facilitate >100 pC charge extraction from the Cu photocathode; 2) understand and mitigate factors responsible for deterioration of the laser transverse profile (nominally Gaussian); and 3) replace a number of contaminated and damaged optics along the UV transport line.

After optimisation the third harmonic generator at saturation now yields 850 µJ pulse energy at 266 nm. An additional 20% gain in transport efficiency has been obtained by moving the pulse energy control from the UV directly (previously performed using a UV half-wave plate and pair of Brewster polarisers for rejection) to the near infrared (NIR) by exploiting the polarisation sensitivity of the sum-frequency generation process.

Visible contamination of exit face of the sum frequency crystal and first four mirrors in the UV transport line is responsible for a significant decrease in transport efficiency (as much as 40%). The mirror contamination is largely reversible through standard cleaning procedures which must be performed weekly to maintain reasonable transport efficiency. Surface analysis of the contamination reveals primarily hydrocarbon components, likely formed through UV-induced breakdown.

Laser transport consists of relay imaging of a truncated Gaussian beam from an aperture in the Photoinjector Laser Laboratory to the cathode. Investigations have revealed damage to optics in the transport plane due to hot spots in the UV beam profile. These hot spots are generated at source and are not a function of the transport optics. We believe these hot spots originate due to variation in the NIR profile following single-pass amplification (as a result of damage to the Ti:Sapphire crystal), which is then effectively amplified through harmonic generation.

To mitigate damage due to hot spots and improve the transverse profile, a UV-based vacuum spatial filter has been designed with a view to implementation early 2019. With the hot spots removed, an aspheric lens beam shaper will be used to generate a flat-top transverse profile as required for CLARA beam physics.

ISSUES WITH LINAC WAVEGUIDE

Linac1 is a two meter S-band travelling wave linac, and has been in operation on CLARA since November 2017. The waveguide system is operated with 3 bar of SF6 and has a circulator after the klystron. The waveguide is sealed with CPR flat and grooved flanges which seal on a rubber gasket. The klystron power for the system is 35 MW, giving 45 MeV/c of measured momentum gain from the linac. In June 2018 the beam momentum jitter measured on CLARA increased dramatically, and the forward power pulse measured just before the linac was discov-

† deepa.angal-kalinin@stfc.ac.uk

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ered to be dropping off towards the end of the pulse. Breakdown in the waveguide was suspected.

Analysis of the SF_6 gas and inspection of the waveguide showed breakdown products on the inside of the waveguide, plus burn marks on the flanges as well as damage to some of the waveguide o-ring gaskets. The circulator had suffered catastrophic damage to the ferrite and one ceramic dielectric component was detached completely.

The complete waveguide system was removed and cleaned. A survey of the waveguide flanges was completed and found that the flatness was generally poor, between 50 - 100 µm. This could lead to poor RF contact and arcing. However the flanges with the worst flatness did not correlate with breakdown location. The worst burn marks were on a waveguide twist. Work is underway to understand the breakdown locations, including analysing previous mechanical simulations of the effect of temperature changes, and calculations to assess the likelihood of standing wave build-up between bends or twists.

After cleaning, damaged or warped flanges were re-machined and the waveguide was replaced without the circulator. For the short term CLARA will run with this system at a limited forward power of 20 MW. The measured acceleration from the linac is 35 MeV/c at this power. In the longer term the system will be replaced with waveguide with a vacuum flange such as DESY or LIL flange. As these use a soft copper gasket to form a crush seal the RF contact is guaranteed, and gives the option of running under UHV conditions.

HIGH LEVEL SOFTWARE COMMISSIONING WITH BEAM

A software development framework has been built that sits above the EPICS control system. For each main hardware type (magnets, BPMs, LLRF, cameras, etc.) there is a C++ interface to EPICS, These interfaces are extensible and configurable via plaintext configuration files parsed at run-time. Working in concert the C++ modules can be used to perform any reasonable commissioning or machine characterisation experiment. To streamline all high level software is developed in Python, using the C++ interface to EPICS. The first phase of application development aims to provide robust, repeatable daily machine set-ups, basic online data analysis and characterisation of crucial diagnostics such as BPMs.

Charge Scans and RF/Solenoid Centring

A routine to automatically centre the PI laser/beam source on the cathode with respect to the gun RF field and its solenoid has been developed. This uses the final laser mirror and the virtual cathode image to control the position of the spot on the cathode. This routine also enables variations in bunch charge (measured at the first wall current monitor (WCM) as a function of cathode position, to be mapped. Significant variations in bunch charge are observed within the ±3 mm (and even within ±1 mm) around the nominal RF centre, although it is not established with certainty the exact contributions of laser transport, cathode quantum efficiency, and transport to the WCM to this effect.

Respective centres of the RF field and the main solenoid are found, referenced to the virtual cathode x/y position, by measuring the amount of deflection of the beam on a downstream screen or BPM caused by RF phase changes and solenoid strength changes. For example, Fig. 1 illustrates the data gathered to determine the RF centre.

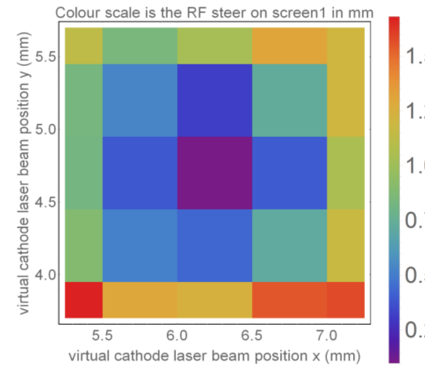

Figure 1: Illustration of position of PI laser on virtual cathode for determining the RF centre.

Image Acquisition and Online Analysis

The CLARA image acquisition system has an image processing module running in EPICS. The data from each image is cropped to a user-defined region-of-interest (ROI), chosen to include the beam spot, the weighted means and covariance matrix of this region are computed giving the beam centroid and RMS (first and second moments) and the x-y correlation (beam tilt). For smooth changes in these properties the ROI can be updated using simple feedback algorithms to give an online diagnostic of beam position, size and intensity. This system currently works at 10 Hz and is being developed to be more robust and operate at higher repetition rates. The system will be used in many procedures, particularly those that require the beam covariance and cross-checking beam position with BPMs. Figure 2 shows online analysis of the laser beam spot.

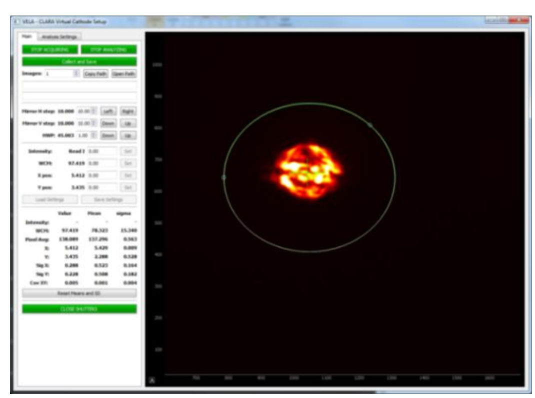

Figure 2: Online analysis of the laser beam spot. The ellipse is an ROI, with cross hairs indicating the beam centroid and widths; the analysis results are also in a table in the left hand panel.

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Diagnostic Characterisation

Characterisation of the BPMs requires accurate calibration at various bunch charges and then cross-checking the BPM response with a downstream screen. During commissioning of the auto-phase application it was noticed that severe mis-steering of the beam into the vessel walls upstream of a BPM can generate spurious ‘false-positive’ signals in the BPMs. This effect is being further investigated to with the aim of including ‘false-positive’ tags to all BPM data.

Auto-Phasing RF Structures

Accurate phasing of the gun and linac cavities is required to find the phase of maximum energy gain (crest). This is achieved through an automated procedure that can start from any starting phase. An initial estimate of the gun crest is found by scanning the gun phase and finding the centre of the emission range as measured on a Wall Current Monitor directly after the gun. The beam is transported to the spectrometer line where a BPM and screen are used to fine crest the gun. Figure 3 shows the Auto-crester panel for the gun and linac.

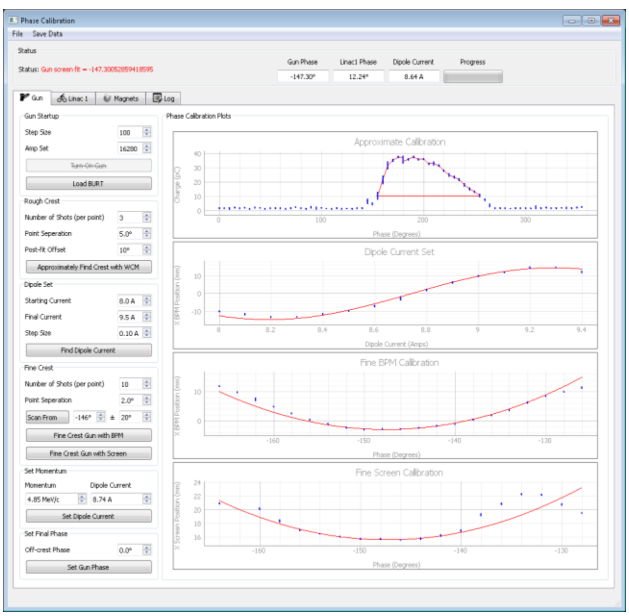

Figure 3: Auto-crester panel for RF structures.

Beam Orbit and Steering

Before more sophisticated beam steering and orbit correction algorithms are developed a simple point-to-point steering app that minimises positions on BPMs using the first upstream corrector has been developed (see Fig. 4). This automated procedure allows for a quick initial steering set-up to be found, saved and re-applied. The sum signal from BPMs is used to infer charge transport through the beamline.

Measurement of Momentum

Measuring the momentum combines many aspects of the above applications, as well as overlapping with the auto-cresting. BPMs and online image analysis is used to accurately steer the beam into the spectrometer dipole and then use the dipole field, known bend angle, position on the spectrometer BPM to measure the beam momentum.

Figure 4: Beam orbit and steering through the beam line, with charge transport.

Steering Through the Linac

Automatic scanning of parameters is easy to accomplish with the different Python modules. Figure 5 shows the app developed for steering through the linac using set of steering magnets located before the linac. A broad ‘valley’ of different steering gives optimal steering through the linac. This is being investigated further, for example including the steering through downstream quadruples, thereby finding an optimum orbit through both RF and magnetic elements.

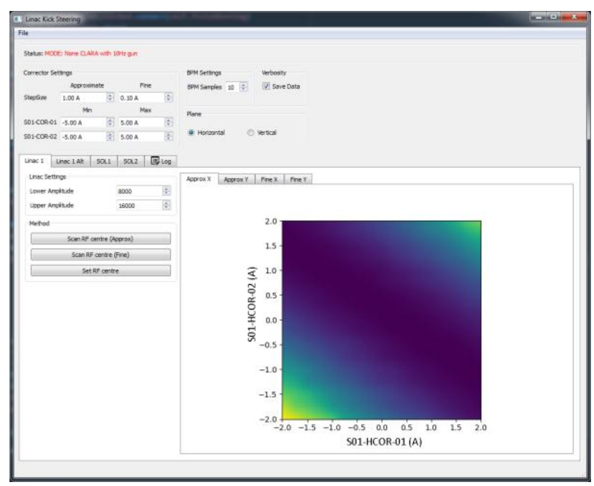

Figure 5: Beam position on screen located downstream of linac as a function of steering through linac.

SUMMARY

The Front End of the CLARA test facility at Daresbury Laboratory has been recently commissioned. Investigations into the photoinjector laser and transport line, and linac waveguide system, have demonstrated the areas which require improvements during the shutdown in 2019. A number of high-level software applications have been developed and tested with beam, this will help reliable beam delivery during beam exploitation period scheduled for the remainder of 2018.

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