COMMISSIONING OF FRONT END OF CLARA FACILITY AT DARESBURY LABORATORY

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Abstract

CLARA (Compact Linear Accelerator for Research and Applications) is a Free Electron Laser (FEL) test facility being developed at STFC Daresbury Laboratory. The principal aim of CLARA is to test advanced FEL schemes which can later be implemented on existing and future short wavelength FELs. The installation of the Front End (FE) section of CLARA, a S-bend merging with existing VELA (Versatile Electron Linear Accelerator) beam line and installation of a high repetition rate RF gun on VELA was completed in 2017. First beam commissioning results and high level software developments are presented in this paper.

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. 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]. VELA and CLARA are installed in the same accelerator hall and share the same RF and photoinjector laser infrastructure for both RF guns. The schematic layout of both beam lines is shown in Fig. 1.

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], a 2 m long S-band Linear accelerator, diagnostics devices, a dedicated collimator, quadrupoles and a spectrometer dipole. 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 quadrupole triplet provides achromatic transport. The spectrometer dipole transports beam to the VELA spectrometer beam line equipped with beam viewer and Faraday Cup (FCUP) for energy, energy spread and charge measurements. The straight-on CLARA line transports beam to a temporary FCUP.

The 10 Hz RF gun, earlier used on VELA is now installed on the CLARA beam line. With this gun, the Front End of CLARA will provide electron bunches at 10 Hz repetition rate and beam momentum up to ~50 MeV/c at the end of CLARA FE and to Beam Area 1 and Beam Area 2 located on the VELA beam line (beam momentum is currently restricted to ~25 MeV/c in Beam Area 2 due to magnet specifications). The CLARA FE will facilitate research into the underlying beam dynamics and accelerator technology sub-system challenges in photoinjector, RF acceleration, timing and synchronisation, beam diagnostics, accelerator controls and feedback processes whilst also providing high quality beam for other applications to be used by industry and academic users.

A new 400 Hz repetition rate RF gun including its load lock system for photocathode exchange [4] is installed on the VELA line for commissioning and characterisation.

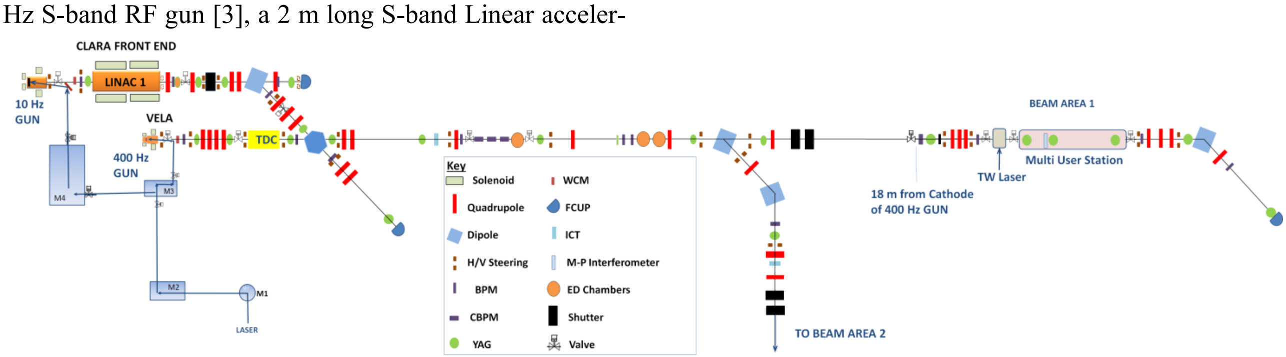

Figure 1: Schematic of CLARA FE and VELA. The S-bend transports high energy beam from CLARA FE to be delivered to beam areas at the end of VELA line.

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This is attractive as the VELA FE provides a full set of dedicated beam diagnostics suite including a Transverse Deflecting Cavity [5, 6]. Once the 400 Hz RF gun is commissioned and characterised using different photo-cathodes on the VELA beam line, the guns will be swapped enabling CLARA operation at the 100 Hz design specification, and ultimately photoinjector technology demonstration at 400 Hz. The VELA beam line thus maintains the capacity of transporting low energy bunches as may be desired for certain applications. This paper presents the current status of CLARA commissioning including high level software developments.

10 Hz GUN RF CONDITIONING, DARK CURRENT AND BEAM

Installation of the 10 Hz RF gun, additional waveguide and the waveguide switch was completed in March 2017. A new 10 cm, diamond-turned, Argon plasma cleaned copper cathode was installed. The gun cavity was RF conditioned manually. Conditioning was problematic and took more than a month. There was breakdown in the waveguide at high power, and on inspection the RF window had debris and possible scorch marks on it. The window was cleaned and the issue was resolved. The cavity itself exhibited odd conditioning behaviour as power levels already achieved and conditioned resulted in high vacuum activity later in the process. Problems with the modulator and klystron meant that the klystron also had to be re-conditioned during this time.

Due to issues with breakdown and likely high levels of dark current (the current monitors and camera systems were both under commissioning and so quantitative measurements could not be confirmed), a new diamond-turned, oxygen plasma cleaned copper cathode was installed in September 2017. Re-conditioning of the gun cavity was very smooth, using, and developing in parallel, a basic early version of a python RF auto-conditioning script. Conditioning took nine 12 hour shifts.

This cathode had low dark current (<100 pC per RF pulse, subject to uncertainty due to the noise on the Wall Current Monitor (WCM)), but also low beam charge (maximum charge of ~75 pC was measured away from the gun RF centre at laser energy of ~72 µJ). Details of cathode investigations and dark current are described in [7]. The RF losses due to the longer waveguide and RF switch are higher than previously seen on the VELA beam line. The maximum cavity forward power at 10 MW klystron power is 6 MW, compared to 8 MW on the VELA beam line in 2015. However we were still able to reach similar core beam momentum of ~5.0 MeV/c as measured at the VELA position. The changes made to achieve better field flatness have increased momentum as predicted in [8].

Following Quantum Efficiency (QE) measurements carried out in the lab on photocathodes prepared using different procedures [9], and mimicking the short exposure to air before installation, it became apparent that a cathode prepared using Argon plasma cleaning gave much higher QE. The cathode prepared with Argon plasma cleaning was therefore installed in February 2018. The cavity was re-conditioned. The conditioning was the first test of the full RF auto-conditioning program at high power. More details can be found in [10]. Conditioning took 60 active hours. Beam was extracted and a bunch charge > 250 pC was measured. The dark current was higher than the previous cathode and detailed measurements are planned.

LINAC 1 FIRST OPERATION

CLARA Linac 1 is a 2 m 2.9985 GHz travelling wave structure designed and fabricated by Research Industries GmbH. It is a constant power dissipation structure, rather than constant gradient or impedance. The design gradient is up to 25 MV/m. A 45 MW Thales klystron and Diversified Technology modulator provide the RF power. The LLRF was provided by an I-tech Libera system.

The linac conditioning was performed at 50 Hz with a basic early version of the auto-conditioning script. See [10] for more information. It took 15 active hours to reach 27 MW at the cavity. The klystron saturated at approximately 34 MW. The cavity conditioned smoothly, although recurring arcing in the klystron protection circulator occasioned a disruption in the conditioning whilst cleaning was performed. Conditioning was completed in October 2017.

First operation of CLARA with the linac achieved a maximum on-crest beam momentum of 48 MeV/c, which corresponds to the cavity gradient of 21.5 MV/m. Systematic measurements of gun dark current through the linac and dark current generated in the linac were carried out with the photocathode installed in September 2017.

PHOTOINJECTOR LASER BEAM TRANSPORT AND COMMISSIONING

The photoinjector laser for the CLARA photocathode generates pulses at 266 nm via third harmonic generation of an amplified Ti:Sapphire system (Coherent Legend Elite Duo HE). A prism-based pulse stretcher has been implemented to transform the 750 µJ, ~80 fs FWHM long Gaussian profile pulses at the output of the harmonic generator into the target range of 2-8 ps (FWHM Gaussian). The pulse stretcher is a 4-prism type, incorporating paired UV fused silica (Heraeus Suprasil 311) in minimum deviation geometry. The path length between prism pairs can be varied between 530 and 3250 mm with little or no realignment of the subsequent transport optics required. The transmission through the complete stretcher system is ~75 %; losses are attributed to stress-induced birefringence in the prisms. Difference-frequency cross-correlation of the stretched UV pulses with the compressed output of the amplifier has experimentally confirmed the length of the pulse duration to between 1.8 and 19.8 ps (FWHM, Gaussian) over the full range of travel. Degradation of the spatial beam profile through the stretcher has been observed and is the subject of ongoing investigation.

The UV transport to the photocathode has been modified so that an aperture placed after the stretcher is relay imaged to the cathode. The optical demagnification is 2.5:1 with a 2.5 mm aperture used to give a 1 mm diameter spot on the cathode, with about 70 % beam transmission through the aperture. Current efforts are focussed on improving the spatial quality of the beam on the cathode, which is currently very uneven and highly sensitive to pointing fluctuation. Systematic measurement of the 800 nm and 266 nm wavefront along the laser transport will be used to inform the appropriate rectification of the transverse profile, with a view to the potential implementation of adaptive optics for mitigation and feedback during 2019.

During recent operations the charge from the cathode was mapped as a function of laser beam position in a 2 mm grid around the RF centre, with variation up to ~200 % found. A large fraction of this variation has been attributed to damage in the aluminium-coated copper lightbox mirror; we believe this was damaged during laser transport commissioning prior to implementation of the UV pulse stretcher, in which the pulse duration was ~180 fs (FWHM) long. Not all of the charge variation observed can be attributed to lightbox mirror damage and will be the subject of further studies.

CONTROL SYSTEM AND HIGH LEVEL SOFTWARE DEVELOPMENT

The control system for CLARA [11] is a distributed control system based upon the EPICS [12] software toolkit and Input/Output Controllers running the Linux operating system on the PC/x64 platform, but extends this architecture to support the additional requirements of CLARA. An API containing python libraries is written in C++ to control and monitor various hardware components on the machine through EPICS. A number of high level applications have been developed, such as the virtual machine [13]. Other applications are briefly described below.

Scope Data Acquisition

This allows signals digitised on a scope to be sent to EPICS. These include charge measurement devices, such as WCM, FCUP and ICT. This can be as the raw waveform, or with filtering algorithms applied. Scope traces can also be processed to give an integral, peak, max to min range etc. and these single numbers exported to EPICS. Work is ongoing to digitise these measurements directly in order to fully integrate them within the control system.

Magnet Data

CLARA has operating modes with different beam momenta, and this application ensures correct scaling of the magnet fields as well as saving/applying magnet set-ups, monitoring and degaussing.

Striptool++

An enhanced plotting package that can plot time series data from multiple EPICS variables in real-time. It can also calculate data-binning for histogram plots, Fourier transforms and correlation plots of one variable against another. Striptool++ can also be embedded in any GUI application as a widget.

Camera Image Saving and Analysis (online/offline)

Image acquisition on CLARA is achieved using an API written in C++. This is contained within a python wrapper and provides python functions to users who can choose which camera to save images from, determine the number of images to save in a burst, start saving images, and then choose to save in JPEG or HDF5 file formats. Another similar API was created to support live analysis of images from a selected camera. The method of analysis has been implemented as a plugin on the EPICS control system and provides measurements on: the beam's centroid position, horizontal and vertical widths, any vertical and horizontal correlation and average pixel intensity of the image. Within this method of analysis the user can: subtract a background image, scale the image intensity, overlay a mask to remove data and choose to analyse a lower quality image. This flexibility can help to improve the accuracy and speed of data analysis.

Generic Set-up / Characterisation Experiments

Most machine set-up and beam characterisation experiments rely on only a few hardware drivers (laser spot position/intensity, magnetic fields and RF amplitude/phase) and diagnostics (BPMs, charge measurements and screen images). These drivers and detectors work iteratively to form an experiment. Therefore a framework has been developed that takes in a human readable configuration file that specifies the required state and data for each iteration. After parsing the input file, the required hardware controllers are instantiated from existing python libraries and used to control and monitor the machine to automate the experiment. Examples of first procedures using this tool are the transverse emittance measurements. It is planned to bring all general set-up and characterisation procedures into this framework.

SUMMARY

The Front End of the CLARA test facility at Daresbury Laboratory has been recently commissioned. A bunch charge of >250 pC was achieved using an Argon plasma cleaned cathode and a stretched photoinjector laser pulse. A beam momentum of ~5 MeV/c was achieved at lower RF power validating the tuning procedure developed. The beam was further accelerated in a 2 m long S-band linac to ~50 MeV/c and was transported through the S-bend to the VELA beam line. A programme of implementation of high level software and beam characterisation will be followed by a period of user experiments in 2018. It is also planned to share time with RF conditioning of the 400 Hz gun on VELA using an automated RF conditioning script at higher repetition rate, followed by beam commissioning and characterisation of this gun. Off-line build of CLARA phase 2 (full energy accelerator) is being carried out and is expected to complete in 2019.

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