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STATUS OF THE CLARA CONTROL SYSTEM

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Abstract

STFC Daresbury Laboratory has recently commissioned Phase 1 of CLARA (Compact Linear Accelerator for Research and Applications) [1], a novel FEL (Free Electron Laser) test facility focussed on the generation of ultra-short photon pulses of coherent light with high levels of stability and synchronisation.

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. Knowledge gained from the development and operation of CLARA will inform the aims and design of a future UK-XFEL.

The control system for CLARA is a distributed control system based upon the EPICS software framework. The control system builds on experience gained from previous EPICS based facilities at Daresbury including ALICE (formerly ERLP) [2] and VELA [3].

This paper presents the current status of the CLARA control system and discusses the systems deployed for Phase 1 and future plans for later phases.

INTRODUCTION

CLARA will be primarily an FEL R&D facility [4] and will inform the aims and design of a future UK-XFEL. It is intended to be flexible such that different FEL schemes can be investigated, with the emphasis on the generation of short, temporally coherent pulses via HB-SASE, mode-locking and seeding [5, 6]. Figure 1 shows the facility layout.

CLARA is being constructed across three main phases. Phase 1 is the front-end of the facility which has recently been commissioned. It includes the photo-injector and first linac (up to 50 MeV). Phase 2 will begin installation early in 2019 and includes all of the accelerating sections (up to 250 MeV). Phase 3 is the FEL section and will be installed following commissioning and a short operational period of the accelerator section.

The front-end sits alongside the VELA photo-injector allowing beam from the front-end to be switched into the VELA beamline via a new dipole and dog-leg transfer line.

The control system for CLARA is an evolution of the control system developed for VELA. It retains the use of the EPICS [7] software toolkit and Input/Output Controllers (IOCs) running the Linux operating system on the PC/x64 platform but extends this architecture to support the additional requirements of CLARA. After their intentional absence on VELA, the implementation of the control system for CLARA sees a return to VME architecture for several systems due to the requirement for an integrated timing system and demanding data acquisition systems.

In this paper we give an overview of the current status of the major sub-systems of the control system.

MOTION CONTROL

In the past, solutions for motion control on our accelerator projects have used a variety of manufacturers' custom interfaces. This has led to a disparate range of systems which become difficult to maintain and support.

Since the facility will require several hundred axes of motion control it is desirable to have a consistent approach throughout. Similar technology will be used to serve a wide range of requirements including the positioning of diagnostic screens, electron beam conditioning equipment, laser transport mechanisms, and magnet array positioning in undulators. Beckhoff EtherCAT fieldbus motion control systems have been chosen to satisfy the requirements of CLARA.

In Phase 1 a system has been implemented using Beckhoff TwinCAT 3 and CX5020 embedded PCs with EtherCAT modular I/O terminals. A virtual PLC running in this environment handles feedback from sensors and controls motors and servos in a closed loop. A network service running on the embedded PC provides access to, and control of, TwinCAT virtual PLC parameters via the Modbus TCP protocol. Integration into the EPICS control system is implemented via this interface.

For Phase 1, several one and two-axis systems controlling motion for diagnostic screens and devices, laser transport and beam conditioning devices have been implemented and are currently operational. For Phases 2 & 3, a similar approach utilising Beckhoff EtherCAT will be used for multiple axis systems including a Variable Bunch Compressor and 2 modulator undulators along with an array of 17 radiator undulators as part of the FEL section.

STATUS & INTERLOCKING

The status & interlocking system is responsible for on/off control and interlocking of hardware on the facility. It provides slow (>10ms) machine protection for technical sub-systems by only allowing operation of devices when predetermined conditions are met. The system being implemented was originally designed for the VELA facility [3]. It comprises of Omron CJ2M PLCs with digital input and output modules to marshal signals to and from hardware. ADC modules are also used to allow analog levels to produce interlocks directly within the PLC. The status system operates in a stand-alone nature with supervisory control provided by the EPICS control system. Requests are received by the status system from

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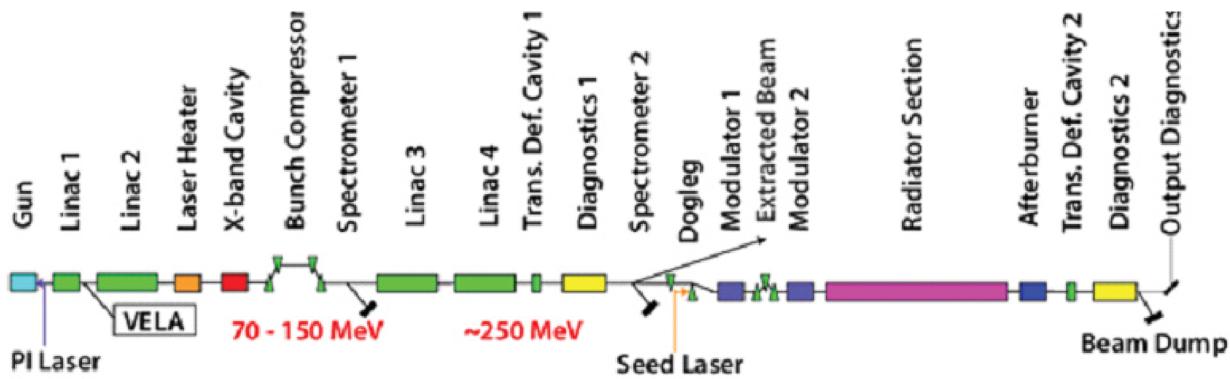

Figure 1: Schematic layout of CLARA.

EPICS to operate hardware; internal logic within the PLCs then determines whether it is safe to execute the requests based upon the interlock inputs from the plant. In this manner, the status system will remain operational and continue protecting the hardware even with a temporary absence of the EPICS control system. An Asyn driver provides the integration with EPICS and communication between the IOCs and PLCs is via the Omron FINS protocol. Memory within the PLCs is organised into blocks containing the system status for each channel along with all the associated digital inputs from hardware. The memory is periodically transferred from the PLCs into the EPICS control system.

The status system for Phase 1 is fully deployed and commissioned and is used to provide control and protection to sub-systems including vacuum, magnet power supplies and high-power RF.

RF CONTROL

The photo-injector re-uses the RF infrastructure from the VELA photo-injector with a remotely controllable RF switch added to transfer power between the existing VELA RF gun (10Hz) and the newly designed high-repetition rate RF gun of CLARA (400Hz).

The existing ScandiNova RF modulator from the VELA gun is integrated into the control system via the manufacturer's proprietary ASCII protocol over TCP/IP. StreamDevice and Asyn are used to communicate directly with the modulator via a private network connection. The RF switch, associated machine protection and logic for directing RF to either gun is integrated into the control system.

High-power RF for linac 1 of the front-end is provided by a Diversified Technologies modulator. The modulator provides a Modbus TCP interface via its internal Beckhoff EtherCAT control system. It is integrated into the control system via this interface using the Asyn & Modbus EPICS modules.

Further higher powered modulators for the 3 linacs of Phase 2 will be provided by Diversified Technologies and integrated with the control system via the same method.

The low-level RF (LLRF) is provided by Libera systems from Instrumentation Technologies. The existing Dimtel LLRF system from the VELA gun has been replaced by a Libera system as part of the implementation of Phase 1 and is shared between the 2 guns of CLARA and VELA. The Libera LLRF systems run an EPICS IOC on board; this only required minor modification to integrate into the control system.

The two modulators and corresponding LLRF systems of Phase 1 have been commissioned for operation via the control system and have already been successfully used for RF conditioning of the 10Hz gun and linac 1.

TIMING SYSTEM

CLARA is a pulsed machine and therefore a stable and reliable timing system is essential. After experiencing unfavourable results on the VELA facility using a stand-alone timing system with minimal supervisory control through EPICS, it was decided to select a fully integrated timing system for the CLARA facility. Due to its successful deployment on other similar facilities a Micro-Research Finland VME based system was selected.

The newly developed MRF 300 series boards where chosen. This system is capable of delay and drift compensation [8] to correct variations in timing caused by varying path lengths and local temperature variations in the transmission path between the event master and each receiver.

The event masters are VME form factor and the receivers are a mixture of VME and PCIe. PCIe is used in the systems responsible for diagnostic camera integration and will provide pulse numbering at full machine repetition rate for all acquired images. VME is used for electronic trigger generation across the facility and also for pulse numbering in VME FPGA based data acquisition systems.

The system runs internally at 83.29 MHz, in common with the photo-injector laser, which results in a delay resolution of ~12 ns. A higher resolution delay can be obtained from dedicated delay modules. The system is synchronised to the 50Hz AC mains and is used to synchronise various technical sub-systems with high precision and is also crucial for beam synchronous data acquisition.

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Integration of the timing system with EPICS is achieved via the mrfioc2 device support with modifications made by Paul Scherrer Institute for the timing system of SwissFEL [9].

The timing system of Phase 1 is now fully deployed and commissioned and has been used for RF conditioning of the gun and linac 1 cavities and for production of first electrons from the front-end early in 2017.

In later phases the timing system will be used to introduce timing skew between the photo-injector laser and RF to prevent production of accelerated electrons, this feature will be utilised for fast machine protection.

BEAM DIAGNOSTICS

For beam diagnostics a number of essential new systems are under development and will require full integration into the control system. Most of the diagnostic systems will be required to operate at full machine repetition rate (400Hz) and be capable of recording data in a synchronous manner for correlation and later offline processing. Input from various diagnostic systems will also be used by control algorithms for stabilisation of the electron beam.

YAG Screen Cameras

Very low noise cameras with 5.5 megapixel resolution and a pixel pitch of 6.5um manufactured by PCO have been chosen for viewing diagnostic screens. They are capable of operating at 100fps at full resolution via their fibre optic Camera Link High Speed (CLHS) interface.

The cameras are integrated into the EPICS control system via x64 Linux IOCs with a dedicated fibre optic PCIe frame grabber per camera. Due to the requirement to only operate a single camera at one time; multiple cameras can be interfaced to a single IOC by populating with several frame grabbers. The areaDetector driver pcocam2 from Diamond Light Source has been ported to work with the new PCO SDK for Linux and modified to operate with the fibre optic CLHS interface.

Due to the potential volume of data that can be produced by the cameras a system is being developed to allow images to be streamed in real-time from the cameras to a local M.2 solid state disk on the IOC. A dedicated high-bandwidth network between the camera IOCs and a network attached storage device will allow the images to be streamed off local IOC storage in a background task and allow machine operators to access the images without loading the IOCs which are then dedicated to maintaining reliable communication with the cameras. Options for longer term archiving of the potentially very large volume of camera images are under consideration.

Accelerator physicists are currently working on the implementation of algorithms to calculate beam centroid and size information from the camera images. The algorithms will utilise mean vector and covariance matrices and will run in real-time at the full frame rate of the cameras. The algorithms will be written in C++ and fully integrated into the EPICS control system as areaDetector plug-ins.

Analog Digitisation

Stripline beam position monitors (BPMs) will be used on the accelerator section for determination of transverse beam position. The stripline BPMs are digitised by a VME based system originally developed for the EMMA accelerator [10]. The system has been migrated from the MVME5500/vxWorks architecture of EMMA to the IOxOS IFC1210/Linux [11] architecture for compatibility with the timing system. For CLARA the electronics will operate in single-bunch/single-pass mode at repetition rates up to 400Hz.

For the FEL section cavity BPMs are being developed to provide the high resolution position measurement required to allow accurate steering of the beam into the undulators. In earlier phases we shall have test cavity BPMs for research and development of the systems required the Phase 3 FEL implementation.

Diagnostic signals from cavity BPMs, bunch charge monitors, pulsed photo-injector laser power meters and beam loss detectors will be sampled via systems using FMC data acquisition cards mounted on IFC1210 boards running EPICS. These systems will make use of IOxOS ADC3110/1 FMC cards for higher rate (250Msps) acquisition, and ADC3117 FMC cards for lower rate (5Msps) signals. Asyn driver based device support for these cards is almost complete and will enable beam synchronous pulsed waveforms to be captured at a rate of up to 1 KHz.

Integration of these diagnostics systems with the timing system will provide shot numbering and acquisition triggers and any required beam-synchronous clocks. The digitised waveforms will be processed after acquisition to determine shot-by-shot synchronous beam diagnostic information which shall be made available to machine operators via the EPICS control system and also used for future orbit stabilisation control.

Feed-Forward Stabilisation

Active stabilisation of transverse beam position and time-of-arrival will be necessary for CLARA to successfully operate in all its operation modes. This will involve implementing a combination of feedback and feed-forward systems.

Although the systems involved and the precise nature of the algorithms are not yet defined we have developed all of our beam-synchronous digitisation systems to be compatible with the control system infrastructure planned for feed-forward. This infrastructure will likely include IFC_1210 (or similar) nodes connected together via fibre optic PCIe links to distribute beam diagnostic data shot-by-shot to a central processing algorithm which will run the control loop and feed control responses out to the nodes connected to the hardware (e.g. fast corrector magnets, low-level RF).

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PERSONNEL SAFETY SYSTEM

The Personnel Safety System (PSS) controls the generation of ionising radiation by enabling the operation of the electron gun and RF cavities. The gun and RF cavities may only be operated when the appropriate accelerator areas have been searched and interlocked. Like its predecessor, the VELA Personnel Safety System [12], the CLARA PSS uses SIL 3 (Safety Integrity Level) rated Omron Safety Network Controllers and DST1 series safety I/O terminals to construct a safety control network, providing safety logic operations and a DeviceNet Safety protocol. A master-slave relationship is established for each connection on the DeviceNet Safety network and the status of the safety I/O data in the Safety Network Controller is mapped to the memory of an Omron CJ2M standard PLC in order to integrate the PSS into the EPICS control system. This enables real-time monitoring of all PSS interlocks by the operations team.

The PSS for Phase 1 was successfully implemented in early 2017 and the design of Phase 2 & 3 is currently being developed. This involves the integration of a significant number of additional systems and new operational procedures (including Limited Access) and this will add extra levels of complexity to the existing PSS. To satisfy these requirements multiple DeviceNet Safety networks will need to be configured and methods of transferring large amounts of safety I/O data between networks will have to be developed.

VIRTUAL ACCELERATOR

For CLARA the accelerator physics group are developing high level physics software, automated procedures and beamline trajectory routines. To aid in the development of these applications the control system presents a unified interface to the many complex accelerator sub-systems. Common sub-systems, for example magnet power supplies, are presented in a consistent manner despite differing manufacturers and model types.

To allow physicists to rapidly prototype and test their applications whilst the facility is undergoing construction an EPICS integrated virtual accelerator model has been developed that will allow rapid test and optimisation of these applications against a simulation before they are commissioned and operate on the real machine.

The EPICS control system provides an interface to the physics simulation. The electron beam transport is modelled using the particle tracking code ASTRA. Input to EPICS process variables (PVs) are fed to the online-model which calculates the electron beam trajectory and feeds the results back to EPICS PVs including bunch charge values and BPM positions. The virtual accelerator also includes simple emulation of several technical systems which are not integrated with the particle tracking code, for example the motion control of diagnostic devices.

The virtual accelerator is now being used by several members of the accelerator physics group as a rapid application development framework for their high level software. The existence of simulated EPICS PVs provides a platform to develop and test their high-level applications whilst construction continues.

The virtual accelerator is in active development and currently contains the emulation of Phase 1 magnets, diagnostic screens, BPMs, high-power and low level RF. The next goal is to develop a more sophisticated simulation for the cameras and BPMs. Another objective is to distribute the particle tracking code onto external servers to increase the number of particles tracked and the number of scenarios that can be simulated at a given time.

FUTURE PLANS

Future plans for the control system include the deployment of the system for the completion of the accelerator section in Phase 2 and the FEL section in Phase 3.

Beam synchronous data acquisition systems will be prototyped and tested during Phase 1 operation for deployment as systems come online. The timing system will be integrated into these BS-DAQ systems to provide correlated diagnostic data across the plant for processing and feed-forward. This will include integration of newly developed systems including cavity BPMs and beam arrival monitors.

A fast machine protection system will be developed for protecting magnetic arrays in the undulators of the FEL from damage caused by beam losses.

EPICS Version 4 will be introduced for transporting complex data structures and producing consistent high-level interfaces to hardware for more tightly integrating physics applications into the control system.

CONCLUSION

The control system for CLARA Phase 1 is a successful evolution of the control system of VELA. Experience gained during the development and operation of the VELA control system gave confidence that the core functionality and reliability would be suitable for CLARA. However, the greater demands presented by CLARA, particularly in data acquisition and synchronisation of events in the control system, required further development and extension of the system. These developments have proven to be a success with Phase 1 fully installed and advanced commissioning in progress.

Further development continues into Phase 2 and 3 of the project with particular challenges coming in deploying analog digitisation systems for beam-synchronous data acquisition leading to feed-forward control. Other challenges include demonstration of stable operation at 400Hz and integration of newly developed systems including cavity BPMs and beam arrival monitors.

REFERENCES

[1] J.A. Clarke *et al.*, "The Status of CLARA, a new FEL Test Facility", MOP011, in *Proc. FEL'15*, Daejeon, Korea

ISBN: 978-3-95450-193-9 doi:10.18429/JACoW-ICALEPCS2017-THPHA063

[2] B.G.Martlew *et al.*, "Status of the ERLP Control System", TPPB38, in *Proc. ICALEPCS'07*, Knoxville, USA
[3] A.Oates *et al.*, "Control System Design for the VELA Test Accelerator at Daresbury Laboratory", in *Proc. PCaPAC'14*, Karlsruhe, Germany, paper WPO039.
[4] J. A. Clarke et al, CLARA Conceptual Design Report, JINST, 9:T05001, 2014
[5] P. Williams, D. Angal-Kalinin, A. D. Brynes *et al.*, TUPJE054, "Developments in CLARA Accelerator Design and Simulations", in *Proc. IPAC'15*, Richmond, USA
[6] P. Williams, D. Angal-Kalinin, A. D. Brynes *et al.*, MOPOW037, "Developments in the CLARA FEL Test Facility Accelerator Design and Simulations", in *Proc. IPAC'16*, Busan, Korea
[7] EPICS – Experimental Physics and Industrial Control System; http://www.aps.anl.gov/epics
[8] J.Pietarinen, MRF Timing System with Active Delay Compensation; `http://mrf.fi/pdf/workshop2015/01-Jukka.pdf`
[9] B.Kalantari, SwissFEL Timing System; `http://www.mrf.fi/dmdocuments/TIMING_WORKSHOP/05-BabakKalantari/EliBeams_WS_SwissFEL_Timing.ppt`
[10] A.Kalinin *et al.*, "The EMMA Accelerator, a Diagnostics System Overview", WEPC158, in *Proc. IPAC'11*, San Sebastian, Spain
[11] D. Zimoch, "A new intelligent FMC/XMC/PMC carrier board / IOC for VME", in Proc. EPICS Collaboration Meeting, May 2013, Harwell, UK
[12] D.M.Hancock, B.G.Martlew, "A Modular Personnel Safety System for VELA based on Commercial Safety Network Controllers", in *Proc. PCaPAC'14*, Karlsruhe, Germany, paper WPO038.