CONTROL AND INTERLOCK SYSTEMS FOR THE LIGHT PROTOTYPE

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Abstract

LIGHT (Linac Image Guided Hadron Technology) is a particle therapy system[1] developed by Advanced Oncotherapy plc. Accelerator, control and interlock systems are developed by its subsidiary A.D.A.M. SA, a CERN spin-off. The system is being designed to accelerate protons up to 230 MeV using a modular and compact 25-meter-long linear accelerator. It is being designed to operate in pulsed mode where beam properties (energy, pulse charge and spot size) can be changed at 200 Hz.

A proof-of-concept accelerator is being assembled and tested at CERN (Geneva, Switzerland). Control and interlock systems are developed using an exploratory prototyping approach and COTS hardware. Requirements for the final LIGHT control and interlock systems are iteratively clarified through creation and refinement of these prototypes. We will continue to support the proof-of-concept accelerator activities while starting to design the final LIGHT control and interlock systems in parallel, building upon the knowledge acquired with the proof-of-concept accelerator. The matured final LIGHT control and interlock systems will gradually replace the prototypes to automate procedures and test the system before deployment.

INTRODUCTION

ADAM S.A. is a CERN spin-off founded in 2007 in Geneva (Switzerland) developing applications of detectors and accelerators to medicine and is a subsidiary of London-based Advanced Oncotherapy PLC. ADAM S.A. is developing the linear accelerator to be used in the Linac for Image Guided Hadron Therapy (LIGHT) project of Advanced Oncotherapy PLC [1].

Current proton therapy solutions mostly rely on synchrotron and synchrocyclotron accelerators for accelerating protons. Driven by the recent advancements in linear accelerator technology, ADAM S.A. has designed a new linear proton accelerator.

The LIGHT prototype is situated in Geneva, Switzerland (building 2250, Point 2, CERN), which hosts a control room, a mechanical and electronic workshop, a rack room and a shielded space for the accelerator referred to as a bunker, as depicted in Figure 1. The complete LIGHT prototype is anticipated to produce beam up to 90 MeV. The rack room placed at the bunker wall hosts 18 racks for electronic equipment.

The control and interlock systems for the LIGHT bunker support conditioning and beam commissioning activities for the accelerator. Additionally, CERN rules and

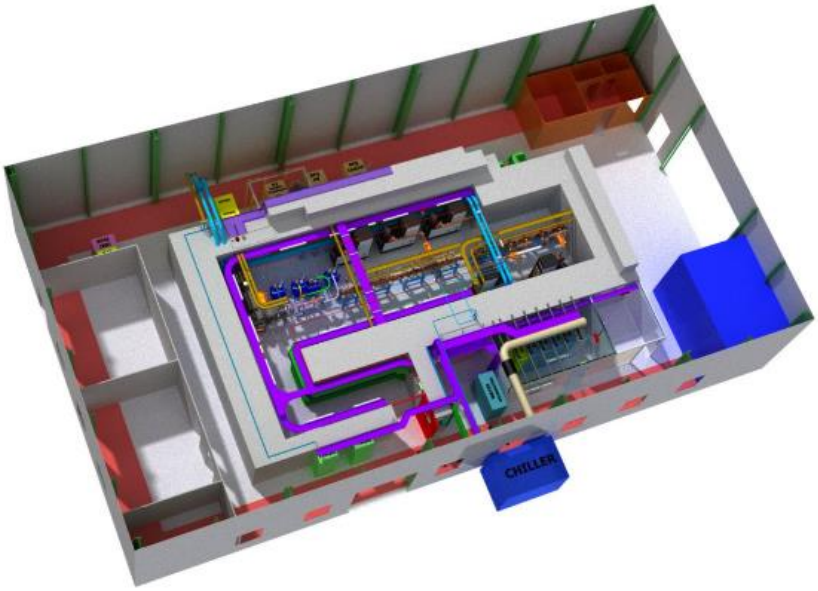

Figure 1: Building layout for the LIGHT Prototype in Geneva, Switzerland (building 2250, Point 2, CERN).

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[1] The LIGHT Proton Therapy System is still subject to conformity assessment by AVO's Notified Body as well as clearance by the USA-FDA

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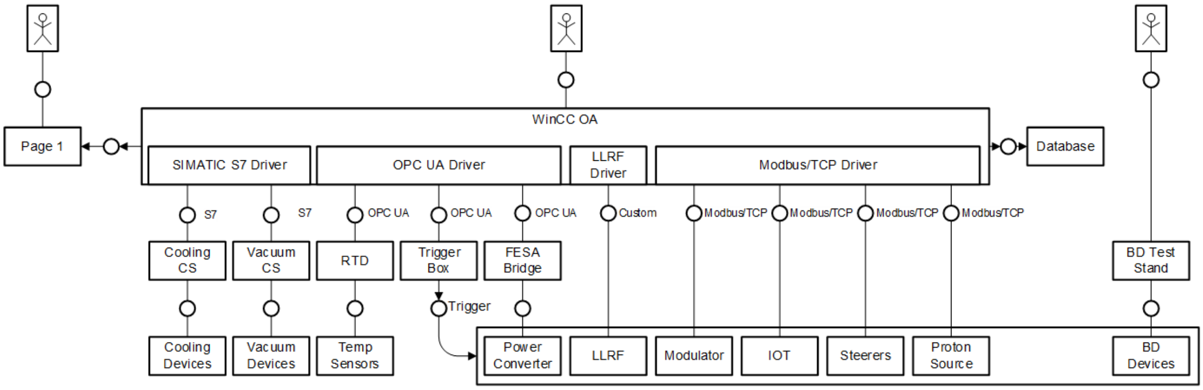
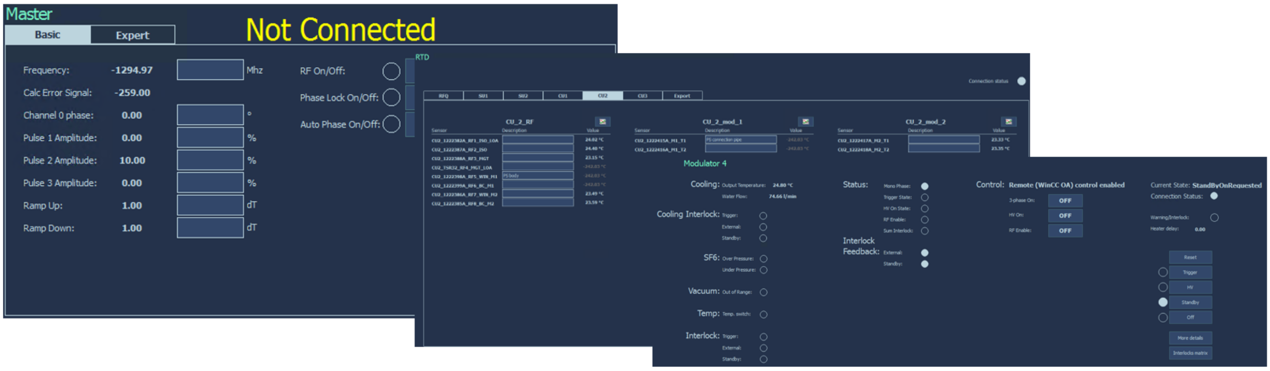


Figure 2: Prototype Control System layout and connections.



Frequency: -1294.97 Mhz
Calc Error Signal: -259.00
Channel 0 phase: 0.00 °
Pulse 1 Amplitude: 0.00 %
Pulse 2 Amplitude: 10.00 %
Pulse 3 Amplitude: 0.00 %
Ramp Up: 1.00 dT
Ramp Down: 1.00 dT
RF On/Off: ○
Phase Lock On/Off: ○
Auto Phase On/Off: ○

Figure 3: Example user interfaces in WinCC OA.

regulations had to be considered during design and implementation. Thus, the needs differ from the final LIGHT system [2]. Nevertheless, the aim was to keep the architecture close to the final layout to reuse hardware and software in the LIGHT system.

PROTOTYPE CONTROL SYSTEM

The Prototype Control System (PCS) requirements and differences to the final system can be summarized as follows:

- **Remote monitoring** to allow for beam commissioning and interaction through a single interface without the need to enter the bunker.
- **Remote archiving** of essential monitoring information for further analysis in dedicated standalone expert applications.
- **Local control systems** for equipment without dedicated control such as vacuum and cooling.
- **Standalone test systems** to execute 200Hz pulse tests on individual accelerator devices. Operating while changing settings concurrently on different devices at 200Hz is not anticipated.
- **No unified interfaces** are required as the system is operated by system experts.

Architecture

The PCS controls the accelerator to generate beam and monitor beam parameters. It relies on Siemens/ETM WinCC OA at its core as outlined in Figure 2 providing the following functionality:

- **User Interfaces** to the connected equipment as shown in Figure 3.
- **Integration** of equipment for control, monitoring and archiving through existing or custom protocol drivers.
- **Archiving** of monitored information to a central Oracle database for further processing by external standalone applications.
- **Reporting** of reduced safety related information through a dedicated web server (page 1) to the CERN Control Centre.

Accelerator and auxiliary systems have been integrated through:

- **COTS Drivers** where the local control systems are connected through an existing standard protocol driver such as Modbus/TCP. Only a simple mapping is performed between the memory map of the system and WinCC OA, for example modulators, Inductive Output Tubes (IOT), steerers and proton source control.
- **Custom Drivers** where the local control system did not provide any standard driver, for example the Low-level radio-frequency (LLRF) system.
- **Front-End Controller** (FEC) where either no local control system was available (i.e. vacuum and cooling) or where direct connection to WinCC OA was not feasible due to low level

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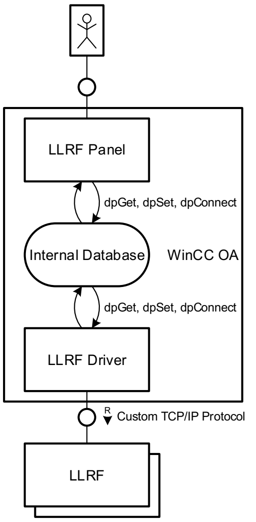

Figure 4: Custom Driver Integration: LLRF.

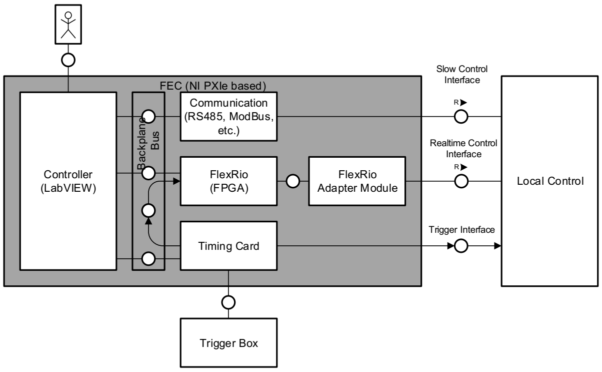

Figure 5: General hardware layout of the BD Test Stand.

interfaces (e.g. power converters and temperature sensors).

- **Standalone** where no integration with WinCC OA was initially needed, for example beam diagnostics.

Custom Driver: LLRF

The current LLRF system only provides a custom slow control interface. In this case the user interface (LLRF panel) interacts with the WinCC OA database through dpGet, dpSet and dpConnect. The LLRF driver is implemented as a library which in turn connects to the WinCC OA database through the same mechanism and translates changes to the data point element into custom request messages sent to the LLRF systems over TCP/IP connections as depicted in Figure 4. Furthermore, the LLRF driver periodically polls the LLRF system and publishes them to the internal WinCC OA database.

Standalone: Beam Diagnostics

The Beam Diagnostics (BD) Test Stand provides multiple front-end controllers following the principal layout in Figure 5 consisting of two parts:

- **Slow control** software is implemented in LabVIEW and connects the NI PXIe hardware through Ethernet with the services in the processing tier, i.e. SCADA (OPC UA) and configuration servers (http). An actor-based approach [3] together with hardware abstraction layer ensures the modularity and flexibility of the system. This allows the number of hardware cards to be changed upon application start-up, depending on the current physical configuration of the accelerator. For instance, the number of PXIe-4357 cards for temperature readout is changing frequently.

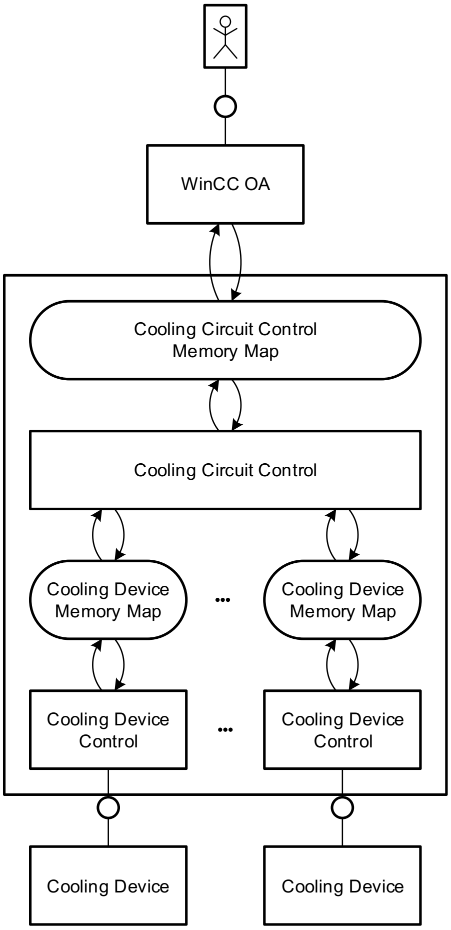

Figure 6: Cooling System Software Layout.

- **Real-time control and monitoring** is implemented on a FlexRIO platform with embedded FPGAs to ensure deterministic behaviour of time-critical systems. Synchronised with the other systems through a central trigger box, FlexRIO cards trigger the accelerator hardware and monitor incoming signals at a frequency of up to 200 Hz. A plethora of adapter cards available for this platform makes it possible to interface with various types of devices. In particular, the NI 5751B multi-channel ADC cards are used extensively for triggered signal readout of beam diagnostics devices such as beam current transformers and beam profile monitors.

Front-end Controller: Cooling System

The cooling control system also follows a layered approach as outlined in Figure 6:

- **Device Layer** provides function blocks for each device type that implement the device-specific communication logic and map them to an internal memory map for the Circuit Layer.
- **Circuit Layer** implements the cooling logic including PID regulation loops. It provides a unified circuit control interface through a memory map connected to the central WinCC OA server in the processing tier.

A dedicated remote user interface is implemented as WinCC OA panel interacting through WinCC OA with the circuit memory map. This modular approach decouples device and cooling circuit logic and allows for a seamless migration to a different supplier or newer equipment with minimal impact on the overall cooling control system logic.

Trigger Generator

The purpose of the Trigger Generator is to generate triggers on 16 outputs via the IO board connected to the MicroResearch Finland EVR 300I card [4]. All triggers are generated periodically from an internal trigger, configurable between 1 and 200 Hz. Trigger output specific configuration includes:

- **Enable/Disable** trigger output.
- **Delay** in steps of 100 nanoseconds from the internal trigger.
- **Pulse length** in steps of 100 nanoseconds.
- **Divider** indicating upon which internal triggers, the output shall be triggered. For example, 5 indicates that only every fifth internal trigger shall generate a trigger pulse on the output.

PROTOTYPE INTERLOCK SYSTEMS

The Prototype Interlock Systems (PIS) reduce the risk of harm to the personnel and the machine caused by erroneous situations or conflicting commands [5]. The general layout and connections of the PIS are depicted in Figure 7.

The general design of the PfIS had to be adapted to CERN specific systems and requests. However, the main requirements are the same as for the LIGHT Interlock System [2]:

- **Mode independency** is required for the interlock systems to react the same way in all accelerator modes.
- **Uniform interlock interfaces** for the compatibility of all devices to the interlock system.
- **Failsafe interface design** assures the safe state of the connected equipment upon a disconnected wire or a wire break.
- **Manual acknowledgement** of the interlocks by an operator is required to reset the interlocks upon a resolved interlock condition.

LIGHT Access Safety and Access System

The scope of the LIGHT Access Safety System (LASS) is the access control to the bunker and to assist in the patrol to make sure that no person is accidentally left in the bunker. It reduces the risk of harm to personnel by interlocking

- **Beam Generation** through the proton source
- **RF generation/High Voltage** through modulator and inductive output tubes.

The RF/HV equipment is connected to the LIGHT-Access PLC which distributes the interlocks and, upon feedback from the devices, generates a sum feedback for the LASS. The source is connected directly to the LASS to have redundancy in case the LIGHT-Access PLC fails.

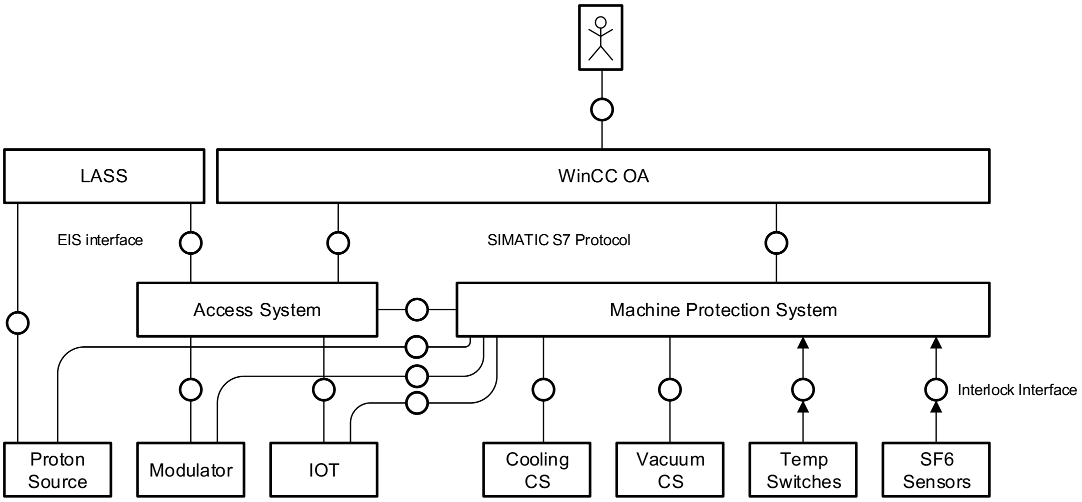

Figure 7: Prototype Interlock System layout and connections.

Both systems are considered Element Important for Safety and as such need to be tested and certified by the CERN Departmental Safety Officer after every change.

Machine Protection System

The Machine Protection System (MPS) in the prototype accelerator is based on a SIMATIC S7 PLC. Since the personnel protection functionality is part of the LASS and access system, the MPS is not subject to test by CERN safety. As anticipated in the final system, the MPS collects inputs from a number of sub-systems and ancillary systems and upon evaluation of the internal interlock chains it re-generates interlock signals for distribution to all the affected subsystems/devices that are connected. To avoid hazardous situations each device/subsystem is responsible for the generation of status information for the MPS and to react on the interlock signals received from the MPS. The definition of facility-wide safety mechanisms for risk reduction purposes using interlock signals is defined at the MPS level. In the prototype accelerator, the devices are equipped with more interlock inputs and outputs than in the final LIGHT interlock system. The purpose is the collection of data and the evaluation of the behaviour of the individual subsystems/devices. Upon evaluation, the specific interlock requirements of the subsystems/devices will be derived.

CONCLUSION

Most of the initial development of the accelerator subsystems has been carried out using the LIGHT prototype accelerator installed on the CERN premises. All groups performing commissioning and test activities with the LIGHT prototype have been using the provided control systems extensively (Figure 8).

Current activities for the Prototype Control and Interlock systems include (a) porting to LIGHT software and hardware stack, (b) development of additional test procedures and (c) development of standalone commissioning systems.

Software reuse remains a concern, partly due to changing requirements and changing suppliers that result from the commissioning and test activities on the LIGHT prototype.

Everything considered, hardware reuse for control and interlock systems look very promising with more than 90 percent anticipation for the LIGHT system. So far, National Instruments PXIe and Siemens SIMATIC S7 hardware and software stacks provided all the means to implement requested functionality without reverting to custom electronics development.

An early involvement of the control system group is essential to keep the additional work load for developing test and commissioning systems for prototypes to a minimum. Suppliers must provide remote user interfaces and test equipment covering all requirements upon delivery. Working on the LIGHT prototype has shown to be a good learning experience for software and electronics developers new to accelerator control system development. The control system group will continue to provide support for the accelerator prototype, but has started to work on the final LIGHT system in parallel, building upon the knowledge acquired with the prototype accelerator.

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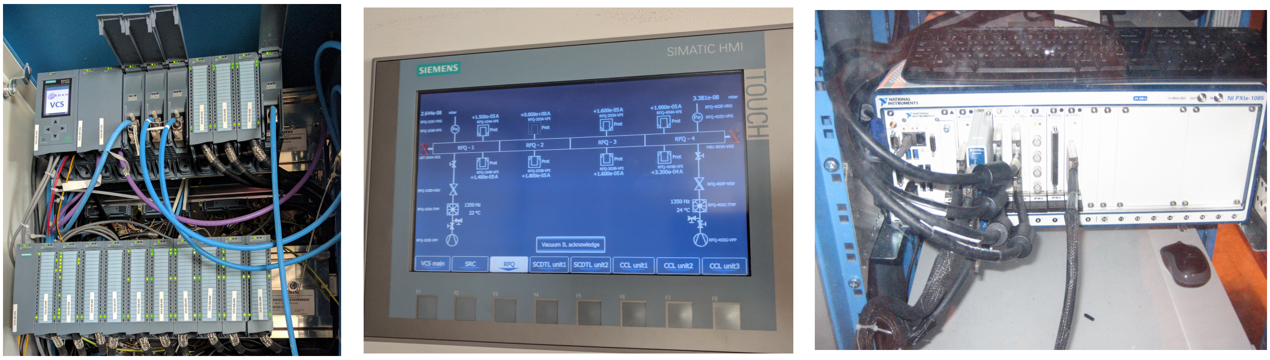

Figure 8: Vacuum Control (left), slow control touchscreen (middle) and beam diagnostics with BD Test Stand (right).