CONTROL AND INTERLOCK SYSTEMS FOR THE LIGHT PROTOTYPE

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Abstract

LIGHT (Linac Image Guided Hadron Technology) is a particle therapy system* 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.

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

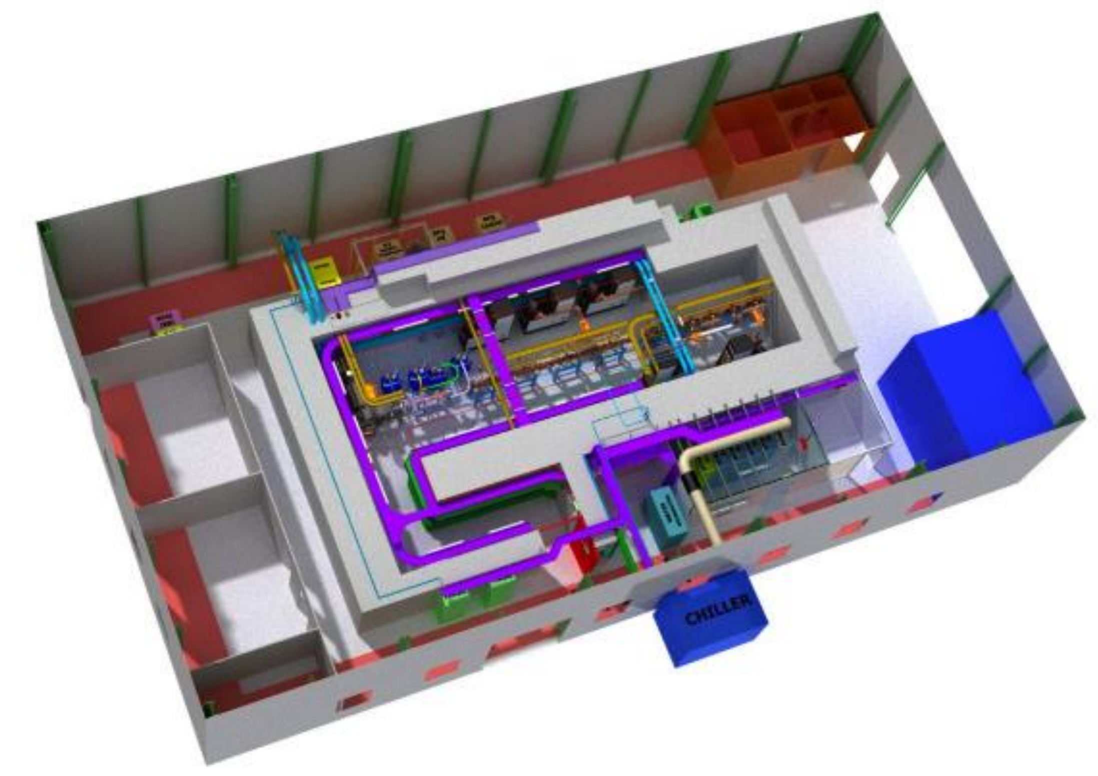

Figure 1: Building layout for the LIGHT Prototype in Geneva, Switzerland).

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].

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

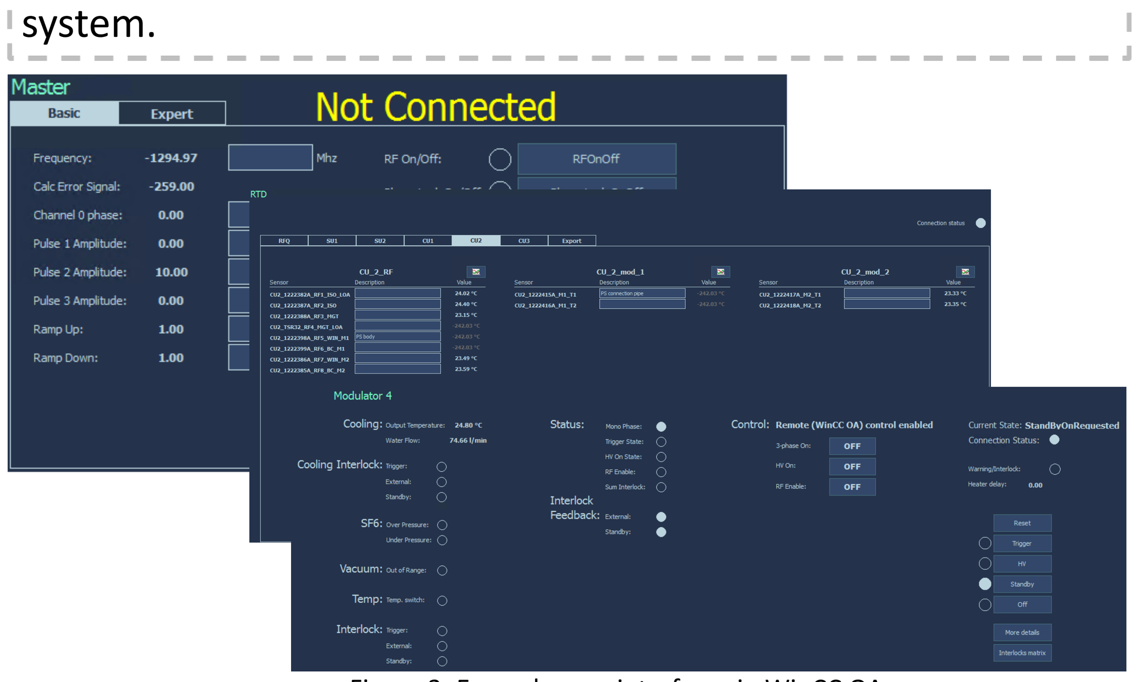

Figure 3: Example user interfaces in WinCC OA.

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 and relies on Siemens/ETM WinCC OA at its core providing the following functionality:

- **User Interfaces** to the connected equipment
- **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.
- **Reporting** of reduced safety related information through a dedicated web server to the CERN Control Centre.

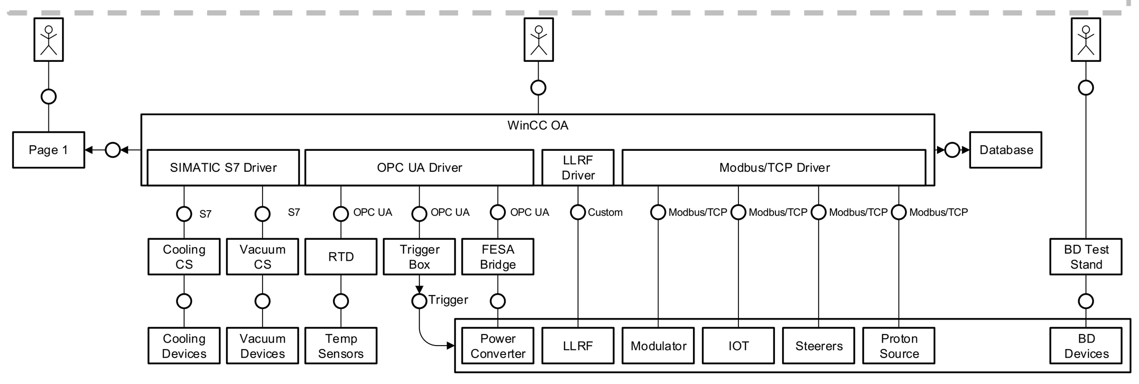

Figure 2: Prototype Control System layout and connections.

Integration

Accelerator and auxiliary systems integrated through:

- **COTS Drivers** for local control systems supported by standard protocol drivers (for example modulators, Inductive Output Tubes, steerers and proton source).
- **Custom Drivers** for the local control system without standard protocol (Low-level radio-frequency system).
- **Front-End Controller** (FEC) for systems without local control (vacuum and cooling) or low-level interfaces (power converters and temperature sensors).
- **Standalone** where no integration with WinCC OA was initially needed (example beam diagnostics).

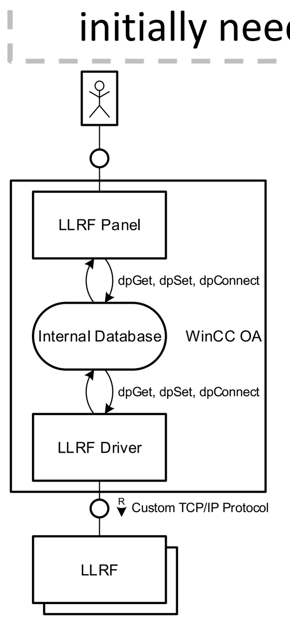

Figure 4: Custom Driver Integration: LLRF.

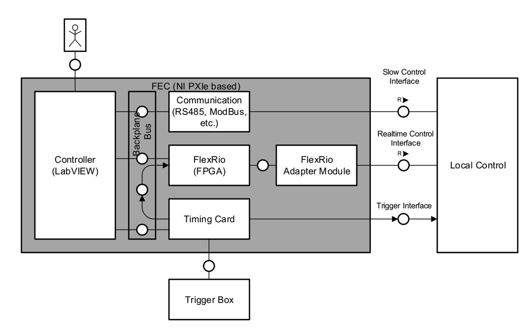

Figure 5: Standalone: Beam Diagnostics.

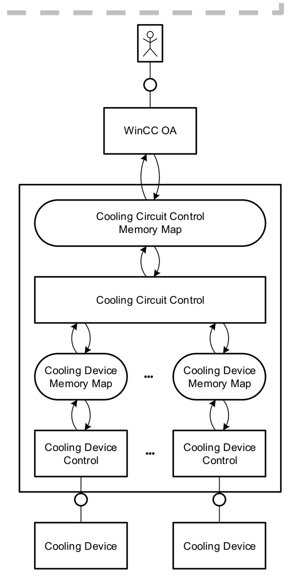

Figure 6: Front-End Controller: Cooling System.

Standalone: Beam Diagnostics

The Beam Diagnostics (BD) Test Stand provides multiple front-end controllers consisting of:

- **Slow control** implemented in LabVIEW and connects the NI PXIe hardware through Ethernet with WinCC OA. An actor-based approach [5] together with hardware abstraction layer ensures the modularity and flexibility.
- **Real-time control and monitoring** implemented on a FlexRIO platform with embedded FPGAs to ensure deterministic behaviour of time-critical systems.

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.

Circuit Layer implements the cooling logic including PID regulation loops. It provides a unified circuit control interface through a memory map connected to the WinCC OA server.

User Interface as WinCC OA panel.

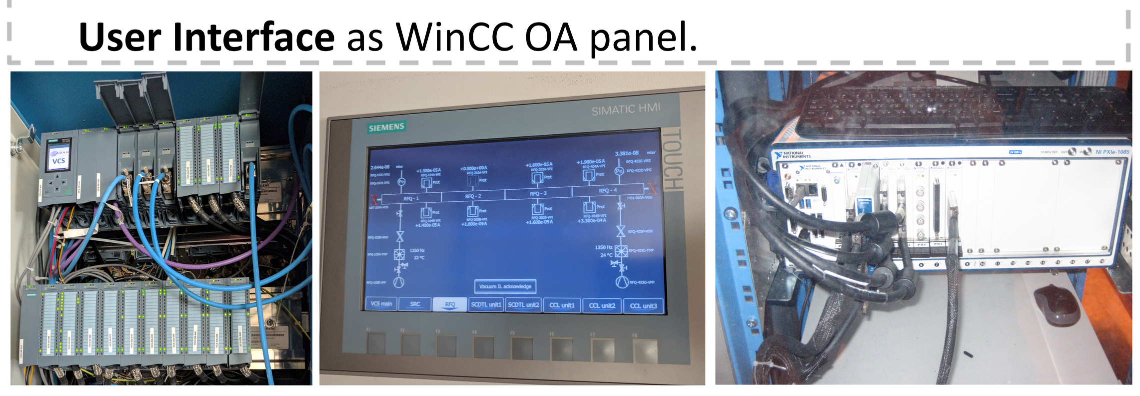

Figure 8: Vacuum Control (left), slow control touchscreen (middle), beam diagnostics (right).

Trigger Generator

Trigger Generator provides 16 trigger 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:

- **Enable/Disable** trigger output.
- **Delay** in steps of 100 nanoseconds.
- **Pulse length** in steps of 100 nanoseconds.
- **Divider** indicating upon which internal triggers, the output shall be triggered.

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 [3]. The main requirements include [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.

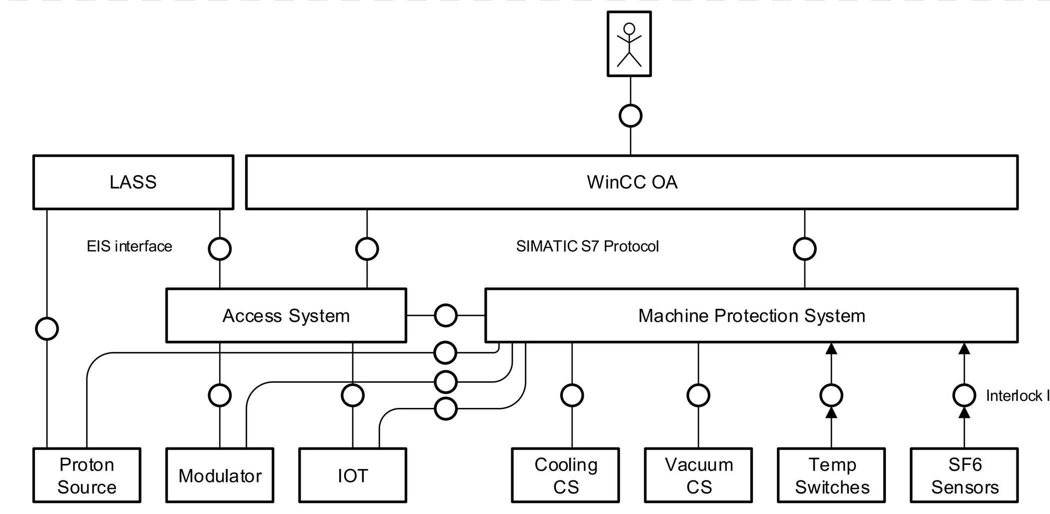

Figure 7: Prototype Interlock System layout and connections.

LIGHT Access Safety and Access System

The LIGHT Access Safety System (LASS) provides **access control** and **assists 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.

Machine Protection System

Machine Protection System (MPS) is responsible to reduce the risk to the accelerator equipment of harm caused by erroneous situations

Since the personnel protection functionality is part of the LASS and access system, the MPS is not subject to test by CERN safety.

Conclusion

Most of the initial development of the accelerator subsystems has been carried out using the LIGHT prototype accelerator installed on the CERN premises and used extensively for commissioning and test activities.

- **Software reuse remains a concern**, partly due to changing requirements and changing suppliers.
- **Hardware reuse looks promising** with more than 90 percent reuse anticipated for the LIGHT system.
- **No custom electronics development** so far for the control system.
- **Early involvement** of the control system group **essential** to minimize prototype specific developments and risks.
- **Good learning experience** for software and electronics developers new to accelerator control systems.

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

The control system group started to work on the final LIGHT system in parallel, building upon the knowledge acquired with the prototype accelerator.

References

[1] U. Amaldi, A. Degiovanni, "Proton and Carbon LINACs for Hadron Therapy," Proc. LINAC2014, Geneva, Switzerland.
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[4] J. Pietarinen, "MRF Timing System," Timing Workshop CERN, February 2008.
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