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ESS DRIFT TUBE LINAC CONTROL SYSTEM ARCHITECTURE AND CONCEPT OF OPERATIONS

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Abstract

The Drift Tube Linac (DTL) of the European Spallation Source (ESS) [1] is designed to operate at 352.2 MHz with a duty cycle of 4% (3 ms pulse length,14 Hz repetition frequency) and will accelerate a proton beam of 62.5 mA pulse peak current from 3.62 to 90 MeV. According to the project standards, the entire control system is based on the EPICS framework [2]. This paper presents the control system architecture designed for the DTL apparatus by INFN-LNL [3], emphasizing in particular the technological solutions adopted and the high-level control orchestration, used to standardize the software under logic design, implementation and maintenance points of view.

INTRODUCTION

The entire ESS linear accelerator and, as consequence, the DTL require dedicated equipment and strategies for the control (Figure 1). DTL system is interfaced with other different apparatus composing the normal conducting linac and transversal systems and services, such as RF system, Machine Protection System (MPS) and Personal Protection System (PPS). Because of the complexity of the project and the number of persons involved at different layers, the DTL Control System (CS) design and implementation must follow precise strategies and solutions, with the aim of optimizing costs and time during the stages of the installation campaign in Sweden.

DTL CS is in charge to provide the software and hardware layer required to operate the apparatus. Not all the functional sub-systems composing the DTL are in charge of the DTL CS Group, so the control system architecture exposed here can cover only a part of them.

All the external sub-systems (e.g. RF system) must exchange data and information with DTL CS. Due to that, a big effort is required at level of coordination among the different parts (ESS and stakeholders).

CONTROL SYSTEM ARCHITECTURE

The architecture realizes the canonical 3-layer structure (Figure 2) where:

- At the lower level there are all the DTL functional subsystems. Under CS aspects, the lower layer defining the field where the I/O signals come from.
- The middle layer defines the set of controllers used to perform the logic and the automation required by the application (Hardware and Software). In this layer all the control units (EPICS Input/Output Controllers - IOCs) run both the low-level interface applications and the high-level state machines (Control System Core).
- At the highest level, all the services provided by ESS-ERIC to performs the normal tasks to operate the Linac. The principal services and tools are:
  - HMI tool, which defines the set of control panels used to control the DTL apparatus. For this purpose, a six-monitors screen is used and EPICS Control System Studio (CSS) application is devoted to implement the control panels.
  - Archiver service provides to the DTL CS the set of tools to archive and retrieve EPICS process variables (EPICS PVs) according to the strategies provided by INFN-LNL.
  - Alarm service provides the interface to the operator to supervise DTL status, indicating cases of warnings (not interlocks).

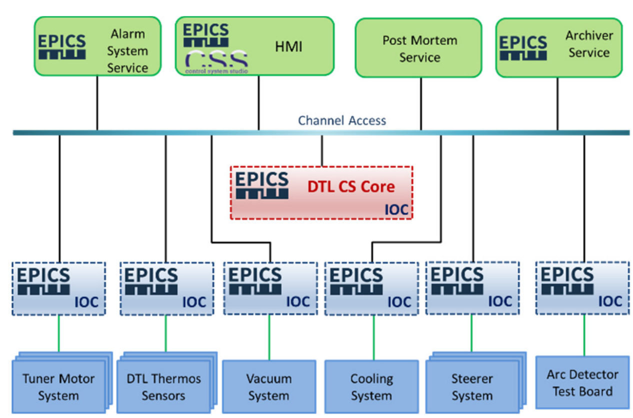

Figure 2: DTL Control System Architecture.

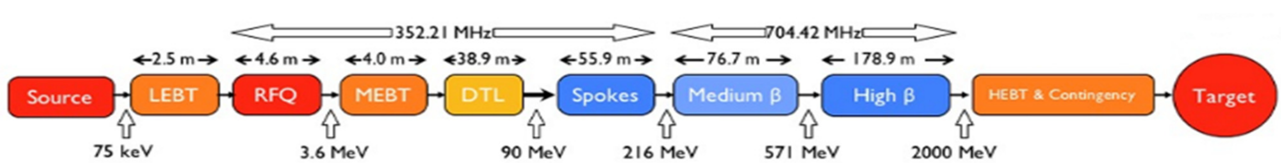

Figure 1: Schematic of the ESS Linac.

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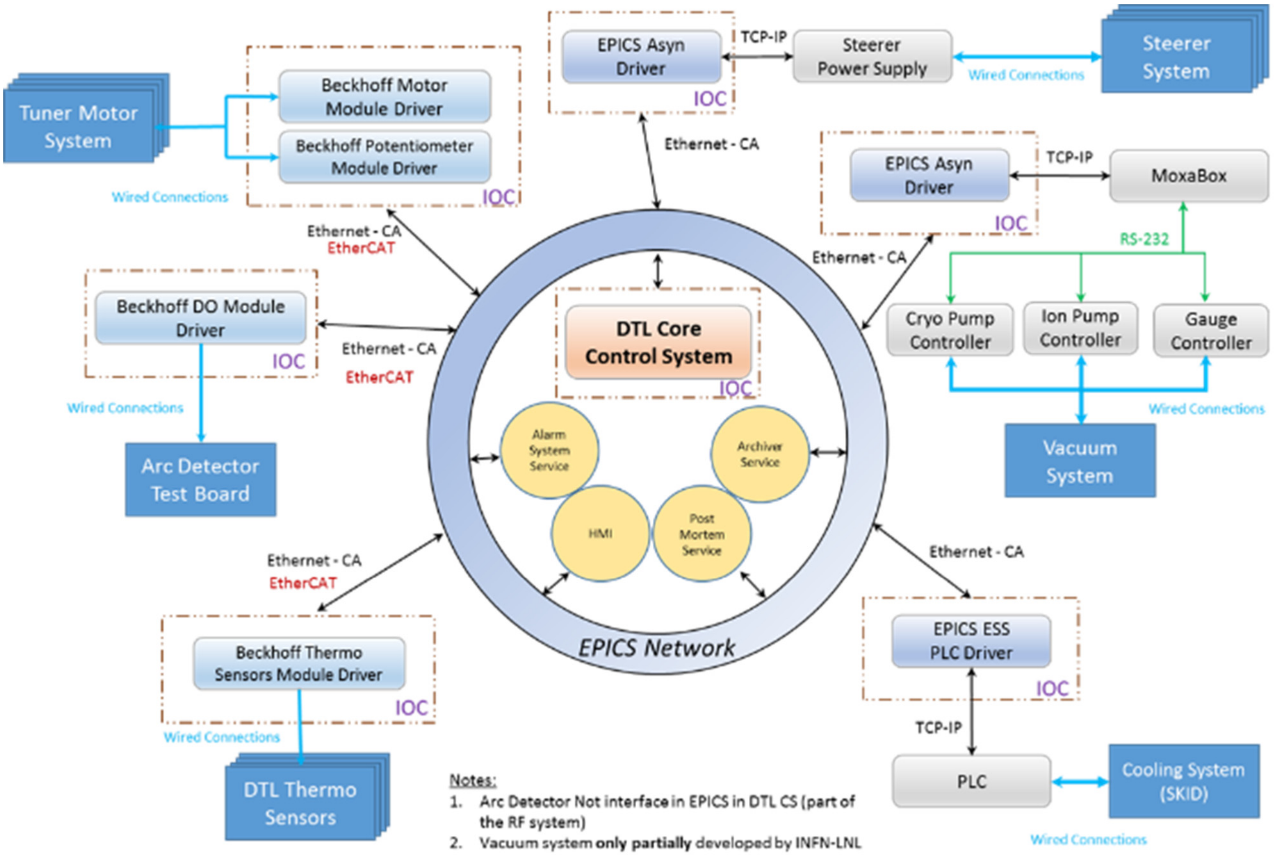

Figure 3: The scheme emphasizes the different technologies used for each functional sub-system to design the DTL control system.

The Archiver and Alarm services will be implemented for the acceptance tests required by contract and executed at LNL before the final installation in Lund. After the final installation, these services will be substituted by the ones provided by the Central Control System. The possibility of having the services duplicated can be useful during the DTL CS installation stage: based on the experience matured in similar projects, this strategy can introduce an additional degree of freedom for the workers involved in the commissioning, letting them be independent from the Central Control System in case of problems of issues with the services.

The principal functional sub-systems of the Control System Architecture are (Figure 3):

- High Level Control: it can be considered as a software layer over the other sub-systems and it is in charge to define the applications (controls loop and logic) accordingly to the Concept of Operations designed. It can be considered as the brain of the DTL control system (DTL Core Control System).
- Tubes Thermos Sensors: set of thermos sensors placed along the DTL provides the apparatus's temperature. This can be considered a crucial sub-system because DTL temperature monitoring is used as part of safety system to prevent damages to the apparatus (in particular the steerer sub-system). Beckhoff® hardware [4] and EtherCAT protocol technologies were chosen for this sub-system;
- Vacuum System: it provides the hardware and software for creating the vacuum in the DTL. While the hardware part is in charge of ESS-ERIC, part of the functionalities will be developed by INFN-LNL. In this case, software implementation will be done directly integrating the hardware into EPICS and defining the algorithms for this functional sub-system.
- Water Cooling Controls: it is devoted to maintain the cavity at normal operating temperature and for the frequency rough tuning. A skid system, built by an external company, will be controlled locally by a Siemens® PLC [5] and remotely through EPICS. According to the standard defined by the project, a dedicated service, PLC factory, will be used to provide the integration layer between the industrial solution and the EPICS environment: this approach is based on both Modbus protocol and TPC/IP server for data exchange, in order to provide asynchronous and synchronous communication. The interface task is in charge to INFN-LNL.
- Tuning Motor System: using the frequency detuning information coming from the RF system, this system implements the fast closed loop to automatically keep the cavity tuned at nominal frequency (frequency fine tuning). Beckhoff® hardware and EtherCAT protocol will be used also for this sub-system;
- Power Supplies Controls: the DTL has 30 steerers placed along the cavity to proper manipulate the beam.

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As previously mentioned, this sub-system is monitored by the Tubes Thermos Sensors one because the steerers are designed and built using permanent magnets and, as consequence, it is crucial to control the working temperature for every device in order to prevent demagnetizing effects. These devices will be directly integrated in EPICS through a serial communication protocol.

- Arc Detector: the RF window is an important component for the accelerator. To guarantee its integrity it is mandatory to observe the presence of arcs on the RF windows and in case to stop the RF power. Periodic test procedures must be realized in order to verify the efficiency of the detection apparatus. For this sub-system, a specific test board, developed in house, will be used and interface to EPICS via Beckhoff® technology.

Table 1: Hardware, Software and Protocol Assumed to Develop Every DTL Functional Sub-System

Sub-System	Technologies (HW, SW, Protocols)
High Level Control (CS Core)	• EPICS framework • No dedicated hardware
Tubes Thermos Sensors	• EPICS framework • Beckhoff hardware • EtherCAT protocol
Vacuum System	• EPICS framework • Hardware provided by ESS • Serial and TCP-IP communication
Water Cooling Controls	• Siemens PLC low-level logic and EPICS integration • PLC factory tool for integration
Tuning Motor System	• EPICS framework • Beckhoff hardware • EtherCAT protocol
Steerer System	• EPICS framework • Hardware provided by the tender • Serial and TCP-IP communication
Arc Detector	• EPICS framework • Hardware system based on AFT Microwave • Custom electronic test board with Beckhoff interface • EtherCAT protocol

TECHNOLOGY ASSUMPTIONS

The DTL CS was designed following as much as possible the guidelines and the standards provided by the project. The choices of the kind of hardware, software and protocol were done keeping in mind these conditions and, at the same time, trying to provide a modular, robust system easy to maintain.

As consequence, the control system designed and under development follows these assumptions:

- It has been chosen a unique hardware standard where possible. Most of the functional systems use Beckhoff® hardware for their implementation: this solution is supported by the Project and the maintenance operation can be easily managed (spare parts required and intervention times).
- Where Beckhoff® hardware is chosen, EtherCAT protocol is the standard used for communication. Under EPICS there are different modules available to perform EtherCAT communication, and the ESS EPICS Environment (E3) used to implement the control software provides a subset of them. In order to standardize the applications, we decided to use the EPICS ecmc module developed by the Motion Control & Automation Group (MCAG): this module was designed to integrate Beckhoff® technology into EPICS through EtherCAT protocol; it is focused in Beckhoff® motion modules, but it is possible to extend the usage to any kind of Beckhoff® module. Because of that, the DTL CS adopted in every functional sub-system the EPICS ecmc module where Beckhoff® hardware must be integrated (a recap is available in Table 1).
- For sub-system where dedicated devices were required (cooling system, steerer system, etc.), the CS used different communication protocols for the implementation:
  - Serial communication via TPC/IP where possible, in order to provide an easy maintainable software.
  - Modbus and TCP/IP server/client communication where PLC technology is required.

For part of these functional sub-systems, dedicated test benches have been prepared with the aim of testing and verify the technologies chosen and described (in particular the Beckhoff® hardware): in Figure 4 an example of test bench used to perform preliminary test on the hardware devoted to the tuners control system and thermos sensors monitoring.

As part of the contract, all the control system designed and the technical assumptions adopted were discussed and approved by the project during the Critical Design Review (CDR) meeting.

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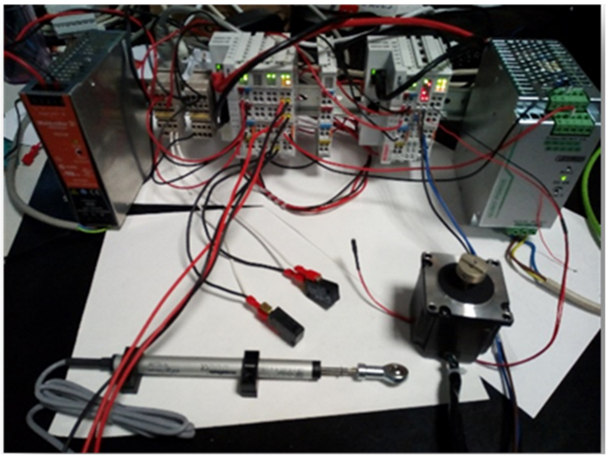

Figure 4: Test bench for the tuner system.

CONCEPT OF OPERATIONS

Considering the DTL machine and its characteristics in terms of design and functionalities, a dedicated automation will be realized for each tank (Figure 5): the aim of this approach is to have the maximum degree of freedom during the operations the DTL has to perform: 1) RF conditioning and 2) Beam operation.

In addition to the DTL-tank automation, for each functional sub-system a dedicated self-check logic will be designed in order to execute dedicated initialization procedure and verify continuously sub-system's health: in case of fault, the information will be propagated to the central core system. Every single functional automation also foresees to operate into a degraded condition, which is reflected at main core level. In this situation, the DTL apparatus can performs its operations conditioned to the acknowledge made by the operator. Every functional algorithm will implement the same logic flowchart, in order to standardize the code structure and, as consequence, the maintenance. All the logic composing the DTL control and automation will be part of the DTL control system core which will manage the configurations and I/Os at all the levels in the architecture.

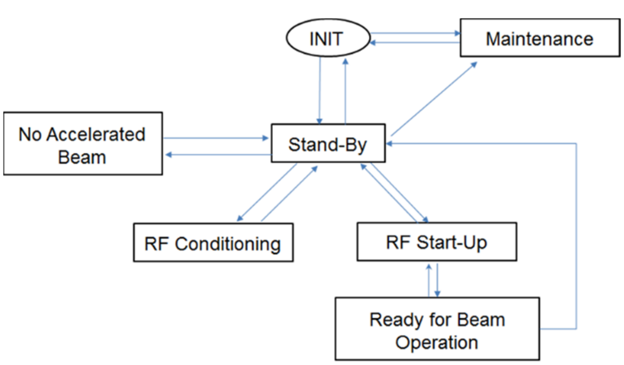

Figure 5: DTL-tank state machine schema.

CONCLUSION

The DTL control system architecture design was based on preliminary tests and evaluations in order to determine the most performant hardware in terms of costs, integration, robustness, modularity and maintenance.

Based on the guidelines, documentation and standard adopted by the project, the entire DTL control system will be developed in EPICS: the framework will provide the main features in terms of integration and robustness at low level (logic to the field) and at high level (services and automation). Under software and logic aspects, a big effort has been required to define the automation devoted to manage and control the entire DTL apparatus: this approach will significantly reduce operation downtimes and, at the same time, will give us additional degrees of freedom during the installation stage in Sweden.

REFERENCES

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[3] EPICS INFN webpage, `https://web.infn.it/epics`

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