MYRRHA CONTROL SYSTEM DEVELOPMENT*

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Abstract

The approach to the MYRRHA Control System (CS) development will be described in this paper. The effort, time and resources needed to develop the control systems are often underestimated by a factor of magnitude. This brings unnecessary setbacks to the projects. Understanding CS requirements at an early machine conception stage is paramount for adequate CS design. Awareness of sheer project size and interdisciplinary complexity is imperative for successful project execution.

In the first part of the paper MYRRHA roadmap, milestones, status and future needs of MYRRHA will be presented. Second part of the paper will give the status of CS development for MYRRHA. Best practices for coherent integration will also be discussed. A paradigm to global CS design needs to be conceived. The CS should to provide an eco-system for integration of devices. Interfaces and services need to be defined early in the integration process. CS integration must start in parallel with device or system to provide timely result. Number of interfaces and platforms used should be should kept to minimum. Mature technologies and solid SW development process needs to be facilitated for high availability.

MYRRHA ROADMAP

The subcritical core of the MYRRHA reactor (~100 MWth) has to be driven by a 600 MeV proton beam with a maximum intensity of 4 mA. The ADS application requires this beam to be delivered in a continuous regime — the resulting beam power of 2.4 MW classifies the driver machine as a High Power Proton Accelerator. This class of accelerators is nowadays mainly populated by superconducting linacs. Already in the early design phase of MYRRHA the choice for this type of accelerator has been endorsed, motivated to a large extent by the expectation of an intrinsic capacity to gracefully deal with failing components.

The design of the MYRRHA linac has been conducted through an intense European collaborative effort and supported by several consecutive Euratom Framework Programmes. Today the design and R&D effort is pursued under the Horizon2020 Programme, and it is complemented by several bilateral collaboration agreements.

The MYRRHA linac consists of 2 fundamental entities: (i) the injector and (ii) the main linac. The injector is fully normal conducting and brings the proton beam from the source through a 4-rod RFQ followed by a series of CH-type multi-gap cavities to 17 MeV. A Medium Energy Beam Transport line matches the beam into the main linac, which is fully superconducting and operated at 2K. 2 families of spoke cavities prepare the beam for final acceleration in a sequence of 5-cell elliptical cavities. The 600 MeV proton beam is then transported through an achromatic line for vertical injection from above into the reactor. A beam window centred in the subcritical core closes the line.

The phased approach of MYRRHA will primarily concentrate on its linac limited to 100 MeV (first spoke family), albeit with 1 injector only. This installation will be a relevantly sized test platform of various fault tolerance mechanisms, and thereby it will allow for a thorough investigation and extrapolation of the realistic capabilities of the full size 600 MeV linac.

CONTROLLING MYRRHA

The paper focuses on the control system of the MYRRHA 600 MeV linear accelerator. The accelerator control system will also interact with the control systems of other subsystems of the facility like the nuclear reactor and experimental section (ISOL). The interaction can be expected in the exchange of safety signals between subsystems for the purpose of machine protection, feedback from reactor to the accelerator for beam power regulation, and provision of accelerator triggering and configuration data to the ISOL for later correlation with experimental results. Subsystems will also have to exchange status information for operation of the complete facility.

MYRRHA has a significantly lower tolerance towards beam trips than the one than comparable accelerators currently achieve [1]. This presents one of the central challenges for MYRRHA accelerator control system. While requirements for high availability of accelerator control system are clear at the highest level, the implications on the control system, device and signal level are explored in this paper.

To study implications of high availability on the accelerator and control system design, MYRRHA will be developed in three phases:

- R&D for 100 MeV LINAC, years: 2017-2020
- 100 MeV LINAC, years: 2020-2024
- 600 MeV LINAC, years: 2025-2030

The R&D phase will focus on prototyping of key control system concepts for availability studies [2]. We plan to focus on two approaches to reach target availability: (1) by efficiently failing-over to pre-prepared scenarios involving redundant equipment, and (2) by

* This work is supported by the European Atomic Energy Community (EURATOM) H2020 Program under grant agreement N°662186 (MYRTE project).

ISBN 978-3-95450-182-3

driving the accelerator components well below their maximum capacity.

The R&D phase will also put in place the fundamentals for organization and standardization. A team responsible for control system integration will be established, which will provide a common standardized framework for all who contribute to the control system. The standardized framework will consist of hardware platform recommendations, software toolkits, development processes, core CS services like alarms, archiving, timing etc. The goal of the standardized framework is to drastically minimize integration effort and need for re-work in the integration stage of the R&D phase, since the components would not only use common communication protocols, but would also follow similar development processes, and would therefore be easier to maintain by the integration team. The control system integration team will also oversee the design and acceptance of deliverables from partner institutes with the objective to streamline the partner institute's development activities by offering advice and support, and by ensuring compliance to the development process.

At the point of this writing it is unclear whether the ISOL experiment will be controlled by the accelerator control system, or whether it will require different control system design. It is, however, clear that the nuclear reactor will have to comply with highest nuclear safety directives. Since these directives place heavy burden on the development process, the reactor control system is out-of-scope of the accelerator control system, which doesn't have as strict safety standards to follow.

PRINCIPAL REQUIREMENTS

Following key requirements are driving MYRRHA CS architecture.

Availability: the number of beam trips longer than 3s must remain under 10 during a 3-months operational period of the MYRRHA reactor. Assuming that probability of a beam trip is constant, and that time to recover is still negligible, the MTBF of the accelerator should be longer than 250 hours [1].

Beam recovery: Mitigation of beam trips will be achieved through failover scenarios. For this purpose, parallel redundancy of the injector and serial redundancy of the medium and high energy sections will be used. During failover, either of serial or parallel redundancy, there should be no beam in the accelerator beyond the ion source.

Beam splitting: The beam to the reactor is basically continuous wave, except for 2 ms periods repeated at 25 Hz, required for sub-criticality monitoring. During these periods the beam is sent to a Proton Target Facility (PTF) for production or fundamental physics.

RF frequency: For the injector, the frequency will be 176.1 MHz. Spoke RF cavities will operate at 352.2 MHz (2x 176.1 MHz). Two sections of elliptical cavities operate at 704.4 MHz (4x 176.1 MHz).

Beam current regulation: Control system will regulate beam current on the target to regulate neutron flux and consequently drive reactor power.

Safety: Safety systems will need to ensure personnel and equipment are protected from hazardous and damaging situations.

Control system architecture shall further follow the principles of reliability, availability, serviceability and maintainability.

ARCHITECTURE

Three tier architecture of the CS is considered [3] to structure and minimize the number of interactions between control system components.

Control system core shall provide accelerator-level services as: machine and personal safety, timing, archiving, alarming, logging, post mortem, failover etc.

MYRRHA should adopt a control box methodology based on the development philosophy established by SNS and further developed at ITER [4] and ESS [5]. The main advantages of the control box approach are that it allows independent and yet standardised equipment controls development, and encourages and enforces consistency and integration of equipment and subsystems across the machine.

Configuration management tools shall be available from the start. They will manage building blocks of the machine, facility, systems and their interconnections to make up the static configuration of the accelerator. As MYRRHA design matures, the number of components and systems grows, putting intrinsic importance to centralized configuration management [6]. Modelling and predictive diagnostics shall support failover workflow.

During construction, MYRRHA will accept contributions from partner institutes and commercial partners. The development environment shall be provided. It will provide services that ensure a simple and consistent software design and development workflow while enforcing a modular approach through the use of artefacts (Table 1).

Table 1: Considered Development Environment Services

Service	Functionality
Jenkins	Continuous integration [7]
Jira	Issue and project tracking tool [8]
Git	Distributed version control [9]
Bitbucket	Central repository server for git [10]
Ansible	Configuration management [11]

User interfaces (HMI) will enable effective and control and monitoring of the machine. Role based access shall be granted to different user profiles: Operator, Accelerator physicist, Engineer. The control room is the central location from which operations activities for the MYRRHA accelerator will be coordinated. The hierarchy of HMIs shall represent different levels of machine detail, from High-level Overview Screens, through Operator screens to most detailed Engineering screens.

PROTOYPING

R&D phase (100 MeV LINAC, years: 2017-2020) shall serve as base for design and testing of organizational and availability principles, mainly:

Provision of standardized Control Eco-System: standardization of SW and HW platforms, development and configuration, HMI and Core services.

Design, implementation and assessment of CS for availability and reliability that shall be determined by reliability analysis.

Organizational and management aspect of collaboration.

Exercising this principles at an early stage shall prepare the SCK and contributors for upcoming challenges as the scale and complexity of the project increases with 100 MeV LINAC and later full 600 MeV MYRRHA implementation.

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ISBN 978-3-95450-182-3