CONTROL SYSTEM DEVELOPMENTS FOR THE MYRRHA LINAC*

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Abstract

The goal of the MYRRHA project is to demonstrate the technical feasibility of transmutation in a 100 MWth Accelerator Driven System by building a new flexible irradiation complex in Mol (Belgium). The MYRRHA facility requires a 600 MeV linear accelerator delivering a maximum proton flux of 4 mA in continuous operation, with an additional requirement for exceptional reliability. The control system of the future MYRRHA linac will have an essential role to play in this extreme reliability scenario. On the one hand the intrinsic reliability of the entire control system must be ensured. On the other hand control system will have to take up very high level duties of complex decision taking. This paper summarizes the ongoing developments for the concept design of such a control system. The related experimental activities performed and planned around the MYRRHA injector platform (ECR ion source + LEBT + RFQ) will also be described.

MYRRHA OVERVIEW

The MYRRHA project is borne by the Belgian Nuclear Research Centre SCK•CEN at Mol, Belgium. MYRRHA will be an Accelerator Driven System (ADS) with the following characteristics:

Accelerator		Fission Reactor	
particle	protons	thermal power	85 MW
energy	600 MeV	fuel	MOX 30-35% Pu
current	2.4 – 4 mA	coolant	Pb-Bi eutectic
time structure	CW with holes	n-flux	2.10^{17} E > 2 MeV
beam trip grace time	3 s		
MTBF	250 hours		

The fundamental aim of MYRRHA lies in the field of the transmutation of long lived nuclear waste through a demonstration pilot facility for the ADS technology at relevant power level, and for the GenIV line of fission reactors using a fast neutron spectrum. By doing so, MYRRHA will be a flexible fast neutron irradiation facility with a large portfolio of applications. It will run as an open user facility and it is presently setting up an international consortium in view of its construction.

The European Commission's support for the MYRRHA project is long standing, and this has in particular allowed for a broad collaborative effort during subsequent Euratom FP programs (FP5, FP6, FP7, H2020) leading today to a well advanced conceptual design of its accelerator. It is fully acknowledged that the main challenge of this accelerator is its unprecedented level of reliability, and hence this topic has been and still is the principal focus of the different R&D programs. The key concept is fault tolerance — if consistently implemented to support critical functionalities the reliability goal can be achieved, as shown by advanced reliability modelling. It is considered that the most promising accelerator topology is that of the modular linac. Combined with the ADS constraint of CW high power beam delivery, the choice of the superconducting linac appears to be particularly adapted.

Work Package 2 (WP2) of the ongoing MYRTE* program is fully dedicated to the accelerator for MYRRHA. This program is particularly focused on the prototyping aspect in support of the overall reliability. Indeed, the level of reliability of individual components is another key to the global performance, as is the guaranteed obtention of their nominal characteristics. Furthermore, diagnostics and controls have a fundamental and essential role to play. The prototyping activities programmed under MYRTE WP2 aim at covering all these aspects through construction of the fully equipped entity ion source – LEBT – RFQ, followed by its experimental exploitation with beam. This will allow to obtain a thorough characterization of the beam exiting the RFQ (1.5 MeV) and to match it with the subsequent accelerating structures (CH-type multi-gap cavities).

The realization of MYRRHA will be obtained in a phased manner. In a first phase the energy of the linac will be limited to 100 MeV. Therefore, a room temperature injector (0 – 17 MeV) will be followed by an MEBT (prepared for the addition of a possible 2nd injector) and a superconducting section consisting of 48 single spoke cavities arranged in 24 cryomodules (with warm focusing/diagnostics insertions). This array will be installed in a dedicated and extendable building, from where the beam will be guided to a target building featuring up to 3 target stations. The commissioning of the 100 MeV linac will essentially aim at investigating the adequacy of its fault tolerance schemes, thereby allowing for a sound decision taking with regard to the full ADS.

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THE MYRTE PROJECT

Very significant progress has been made during the FP7 MAX project [1] on the path towards the accelerator for MYRRHA. A particularly strong achievement of the results generated by the project and of the outcome of the associated International Design Review is the global level of confidence, in both the concept and additionally the feasibility of its components. This level of confidence is coherent with the fact that MAX has now brought MYRRHA to the first major milestone on the road towards the realisation of its linac. The milestone may be labelled "ready for prototyping". It is the starting point of a new set of mandatory R&D activities where the emphasis should lay on experimental optimisation.

In the frame of the new H2020 Euratom research and training programme, some of these activities have been started in April 2015 in the frame of the MYRTE (MYRRHA Research and Transmutation Endeavour [2]) 4-year project, gathering 27 European partners for a total cost of 12M€. Following the recommendations of the MAX project final report, the MYRTE WP2 “Accelerator R&D for MYRRHA”, coordinated by CNRS/IN2P3, aims at addressing the topics that have been identified as priority to successfully pursue the research, design and development of the MYRRHA accelerator and prepare for its actual construction. These topics are organized around two principal lines, prototyping and modelling, and a strong emphasis is put on the deployment of the first part of the MYRRHA injector, i.e. the RFQ and its associated Low Energy Beam Transport line. It is indeed foreseen that even this short accelerating section, together with all its ancillaries and equipped with a complete 3-tier control system, might become a relevant test platform to demonstrate the actual feasibility of a complete ADS-type linear accelerator with unprecedentedly enhanced reliability levels. The different tasks of this MYRTE WP2 programme are summarized in Table 1.

Table 1: MYRTE WP2 tasks list

Leader	Task description
IAP	Realisation of a full-size MYRRHA-type RFQ demonstrator
IBA	Construction of a prototype Solid State RF power amplifier
CNRS	Digital Low Level RF development
CEA	Beam diagnostics development
Cosylab	Control system development in a highly reliable accelerator context
CEA	Beam simulation code development, global coherence
SCK•CEN	Injector commissioning
CNRS	Space-charge experiments
CERN	LINAC4 reliability analysis
CNRS	MYRRHA SRF spoke R&D
IAP	SRF CH demonstration with beam
SCK•CEN	MYRRHA linac cost estimation

THE LEBT TEST STAND

A prototype of the MYRRHA Low Energy Beam Transport (LEBT) line have been built and is currently installed at LPSC Grenoble [3]. The construction of the line was funded by SCK-CEN and thanks to the MARISA* project. The ECR proton source is from Pantechnick (France) and the two focalisation solenoids were manufactured by SigmaPhi (France). Each solenoid contains two steerers to adjust the transversal beam position of the beam: one applying a magnetic field in the horizontal plane the other one in the vertical plane. For proton beam characterisation, we make use of two Allison’s scanners, also provided by Pantechnick. A system of four individually motorised collimators enable to intercept a part of the beam for halo cleaning and to remove the H_2^+ and H_3^+ from the source and which are less focussed by the first solenoid. At the end of the line an electrostatic chopper will enable to mitigate the overall beam current in the MYRRHA linac. Short beam interruptions (200 µs, with a 250 Hz repetition rate) are also mandatory to monitor the sub-criticality of the ADS reactor.

A beam experimental program is ongoing with the MYRRHA LEBT in the frame of the MYRTE project, dedicated to the study of the beam space charge compensation (SCC). Systematic measurements of the beam emittances have been carried out by changing the solenoid focalisation, the residual gas pressure and the injected gas (up to know Argon and Helium). The measurements analysis is in progress and will be confronted to simulation results obtained with a dedicated PIC code (WARP [4]). The aim is to have a better understanding and modelling of the complex SCC mechanism. The last goals of the experimental program will be focused on the LEBT commissioning which consists in: 1st- adjusting the residual gas pressure to ensure a reliable operation of the source (avoid breakdowns) with an efficient SCC scheme in the line; 2nd - measure the LEBT beam transmission map and determine the best operation point for RFQ injection (optimised emittance and Twiss parameters); 3rd - Carry out SCC steady state studies with the chopper and evaluate its operation reliability.

CONTROL SYSTEM

Control system (CS) needs to support accented reliability of MYRRHA with a selected software and hardware platform. Platform is expected to offer maturity and reliability.

For control system framework CODAC is selected. It allows for simplified configuration management, build, deployment and updating from central location. CODAC relies on EPICS framework. EPICS is mature platform widely used as the control system infrastructure for large scientific installations. As an open source endeavour is supported by user community. Scientific Linux is used as operating system for the CS computers also called IOCs

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(input-output controller). It is best suited for various tasks and can host graphical user interface. Real time performance shall be implemented below the IOC level where needed. EPICS framework is easily scalable by introducing new IOCs and PVs (process variables) to the network. This PVs are then accessed via highly optimized CA (Channel Access) protocol.

Hardware platform selected must also feature maturity, reliability, widespread use with support and longevity. The performance requirements for MYRRHA are moderate. Hardware form factor suitable for MYRRHA is cPCI.

Control System takes care for configuration and monitoring of the complete system. Control logic is implemented in dedicated sub-system controllers like: PLC, Vacuum, Motion, Timing controllers.

Design

An attempt is made to standardize on interfaces. The number of different controllers and protocols is kept to the minimum. Standard EPICS integration mechanisms are used. With help of NDS [5] (Nominal Device Support) device integration is streamlined.

Data acquired needs to be stored in achieve and monitored for alarms. Machine configuration can be implemented via save-restore mechanism. Dedicated service machine shall be set-up. With the use of virtualization IOCs for required services shall be set-up. E.g. Alarm IOC might host alarm PVs. Alarm PV status can in turn be determined from combination of other PVs. This logic is also implemented in Alarm IOC.

Availability is achieved by making control operation of subsystems redundant and independent from Control System. In case of failure CS should facilitate short switch over time (less than 3 seconds) to avoid harmful beam trips.

IOCs can be made redundant [6], [7]. PLCs are standard industrial controllers and come equipped with redundant topologies and hot swappable modules. Network redundancy can be implemented e.g. via 2-tier redundant topology where HSRP/VRRP/RSTP algorithms manage routing. Network uses virtual switch, stack, ether channel, port channel technologies [8]. Network clients normally host 2 NICs configured in ACTIVE/Standby mode.

Another important consideration is Machine protection system behaviour during switch-over in case of recoverable failure. MPS must facilitate timing synchronous change of interlock logic to continuously protect the machine but avoid unnecessary interlocks.

Implementation

With support of MYRTE project Control System of MYRRHA demonstrator will integrate LLRF (developed by IPN Orsay), SSA PS (Power supply) for RFQ (developed by IBA) and additional diagnostics: post-RFQ 4D emittance meter (led by CEA), beam position/phase monitors, high-accuracy current measurements and/or wire-scanner (led by CNRS). Effort is made in direction above devices come with a standardized interface. E.g. LLRF shall feature EPICS IOC and its configuration will be accessible via CA. SSA PS will be equipped with Profibus, connected to PLC configured via IOC through Ethernet connection with PLC. Alarm and archiving service like BEAUTY and the BEAST will be set up. Vacuum and cooling will be integrated. Fully redundant Machine protection system MPS [9] will be evaluated. MPS also comes with fully featured EPICS support. MRF timing system topology shall be extended, diver set elevated to latest mrfioc2 release to accommodate for triggering and timestamping of newly introduced devices.

SUMMARY

MYRRHA ADS is pioneering the roadmap towards sustainable nuclear power, transmutation and research. It is an endeavour of 27 EU partners. MYRTE WP2 studies the accelerator part of MYRRHA ADS. Required availability and redundancy requirements are high. MYRRHA test stand is used to study outstanding aspects of the Linac. Experiments, Sub-system and Control System Design upgrade is ongoing for introduction of RFQ to existing LEBT test stand. MYRTE project is pursuing final MYRRHA design to be finalized in 2019.

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