THE MYRRHA LINEAR ACCELERATOR R&D PROGRAM

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Abstract

The outstanding feature of the MYRRHA accelerator is the design requirement of Mean Time Between Failures (MTBF). The issue of reliability is thus considered the main design challenge, and concerns all the R&D activities. The current R&D program aims to provide a detailed accelerator design, suitable for an ADS demonstrator, with provisions for enhanced reliability. Research activities have been organized to specifically address advanced beam dynamics and error studies, reliability modeling studies, optimization of injector design and prototype cryomodules design and test.

INTRODUCTION

The MYRRHA project [1], proposed by the SCK•CEN, aims to demonstrate the feasibility and operability of a safe and efficient transmuter, comprising a subcritical core fed by an external neutron source, in turn obtained by a proton accelerator. The most significant characteristics of the required accelerated beam are summarized in Table 1. These specifications set the MYRRHA accelerator in the high power proton machines category. While the specificity and difficulty of the Continuous Wave (CW) nature of the beam delivery of MYRRHA is acknowledged, the outstanding design feature is the requirement of 250 hours as Mean Time Between Failures (MTBF), corresponding to less than 10 failures (i.e. a beam trip longer than 3 s) over a 3 month operation cycle. The allowed beam trip frequency of the whole accelerator is significantly lower than observed on today's reported achievements of comparable accelerators [2], therefore the issue of reliability is considered the main design challenge, and concerns all the R&D activities.

Table 1: MYRRHA beam characteristics

Particles	protons
Beam energy	600 MeV
Beam current	4mA
Time structure	CW, with 200 μs holes at 250 Hz
Beam delivery to the reactor	Vertically from above, through a beam window
Beam stability	Energy $\pm 1\%$; Current $\pm 2\%$; Position and size $\pm 10\%$
MTBF*	>250 h

*a failure being a beam trip longer than 3 s

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THE ACCELERATOR CHOICES AROUND RELIABILITY

The general philosophy to reach a high natural MTBF on the MYRRHA accelerator is identified in the fault tolerance capability, accompanied by a realistic switching time (fault detection time plus reconfiguration time: in MYRRHA this time is necessarily 3 s) and a Mean Time To Repair (MTTR) shorter than the MTBF of the failing element or chain. The fault tolerance concept is addressed by design, implementing redundancy (with a maximum of the serial version), use of components far from their performance limits, adoption of reliable diagnostics and powerful and fast controls, repairability. For economic reasons the parallel redundancy scenario is avoided when not mandatory. The serial redundancy scheme (replacing a missing element's functionality by retuning adjacent elements with equivalent functionalities) may be accomplished if foreseen from the design phase: this strategy requires an high degree of modularity of the accelerating and focusing structures.

Being the MYRRHA accelerator a high power proton accelerator with strongly enhanced reliability, moreover to be operated in CW mode, and in agreement with several high power accelerators projects [3] [4] [5], the technical solution of a superconducting linac has been adopted [6]. The compatibility of this choice with the three above-mentioned reliability principles is clear: the architecture of a superconducting linac, consisting of a sequence of nearly identical and modular RF cavities, complies with the serial redundancy scheme; besides, the current performances of superconducting linacs allow to handle a 4 mA CW beam current.

The linac will consist of two clearly distinct sections:

1. A medium and high energy section, highly modular, based on individual, independently controlled, superconducting cavities and warm quadrupole insertions. In this section the serial redundancy may be applied successfully to obtain a strong fault tolerance [7]. The function of a faulty cavity may typically be taken over by four adjacent cavities.

2. A low energy section (or injector) [8], in which the modularity and fault tolerance principles are not applicable: in this section the beam optics is frozen by design and the accelerating structures are mainly based on multi-cell cavities. Here redundancy has to be applied in its parallel form, so the adoption of two complete injectors is foreseen. The transition energy between the two sections is fixed at 17 MeV. At this

energy a fast dual input switching magnet will be installed for merging the injector lines.

Table 2: Structures of the superconducting MYRRHA linac

E_{in} [MeV]	Cavity	f_{RF} [MHz]	β	$\frac{cav.}{CM}$	n. CM	E_{out} [MeV]
17.0	spoke	352.2	0.375	2	24	80.8
80.8	elliptical	704.4	0.510	2	17	184.4
184.4	elliptical	704.4	0.705	4	15	600.0

CM: Cryomodule; $\beta = v/c$: cavity geom. value

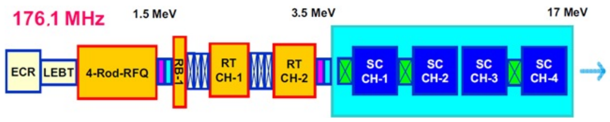

Figure 1: The 17 MeV, 176.1MHz, MYRRHA accelerator injector

THE R&D ACTIVITIES ON THE MYRRHA ACCELERATOR

The MYRRHA accelerator is being developed in a strongly collaborative mode, exploiting the very extensive know-how present in the European accelerator community. The R&D activities have, to a large extent, been organized as subsequent EURATOM Framework Programme projects. A conceptual design of an ADS-type high power proton accelerator has been initiated by FP5 PDS-XADS [9]. Further developments, including the fundamental architectural choices, have been done in FP6 EUROTRANS project [10]. The current R&D program aims to provide a detailed design of the superconducting linac to be adopted by the first ADS demonstrator (i.e. MYRRHA), focusing on provisions for enhanced reliability. To achieve this goal, research activities have been organized to specifically address advanced beam dynamics and error studies, reliability modeling studies, optimization of the injector design and prototype cryomodules design and test.

The R&D program is divided in three lines of investigation, which have the linac reliability as common subject. They are combined in a scheme sketched in Figure 2. In order to support bilateral agreements for common R&D activities, Memories of Understanding (MoU) are stipulated with research institutes.

The MAX program

The ongoing FP7 MYRRHA Accelerator eXperiment (MAX) project[1] [11] is pursuing the R&D toward an accelerator design candidate for the ADS demonstrator.

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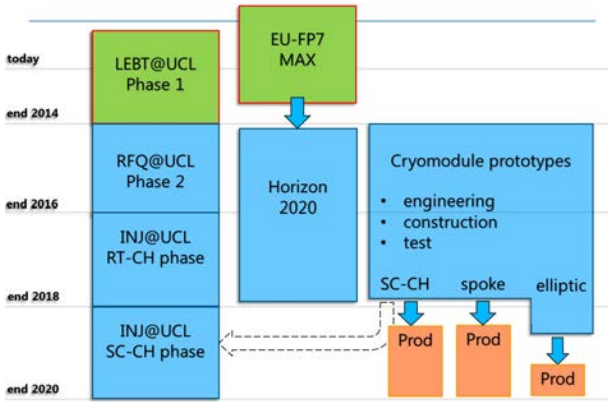

Figure 2: Scheme of the R&D activities foreseen for MYRRHA accelerator

The goal is to deliver an updated consolidated conceptual design of the superconducting linac to be adopted in MYRRHA, with sufficient detail and adequate level of confidence for subsequent global engineering design. This R&D line is led by IPN Orsay, in collaboration with a large number of research institutions and industrial companies. While advanced multi-particles beam dynamics simulations are carried out to entirely define the accelerator lattice, detailed design of the main accelerator components is built up through several prototyping activities. On top of these activities, dedicated studies are focused to produce a reliability model of the machine. These activities have been divided in four main Work Packages, including: Global design coherence (WP1), Injector design (WP2), Main linac design (WP3), System optimization (WP4).

The RFQ@UCL program

The second R&D line, RFQ@UCL, is devoted to the injector engineering design and subsequent construction, followed by extensive test and feedback to design. The principal motivation is to experimentally address the MYRRHA injector design, gaining experience from a tangible prototype. On the other hand, the Injector@UCL turns in a tool for relevant reliability oriented experiments, bringing experience, education, and innovation in this field. This activity is led by SCK•CEN in close collaboration with the Cyclotron Resources Center (CRC) of the Catholic University of Louvain, UCL, at Louvain-la-Neuve, Belgium, where the experimental test line will be located. The program is based on bilateral collaboration agreements with the CNRS/IN2P3 laboratories IPN Orsay (IPNO) and LPSC Grenoble and with the IAP Frankfurt laboratory. Moreover, the RFQ@UCL program is interacting with the FP7 MAX program. An overview of the foreseen experimental setup is shown in Figure 3.

The first scope is globally oriented on the 4-rod RFQ. After a successful construction and assessment of a short section (400 mm) for thermal behavior investigation, to be conducted by IAP in the framework of MAX, the full-

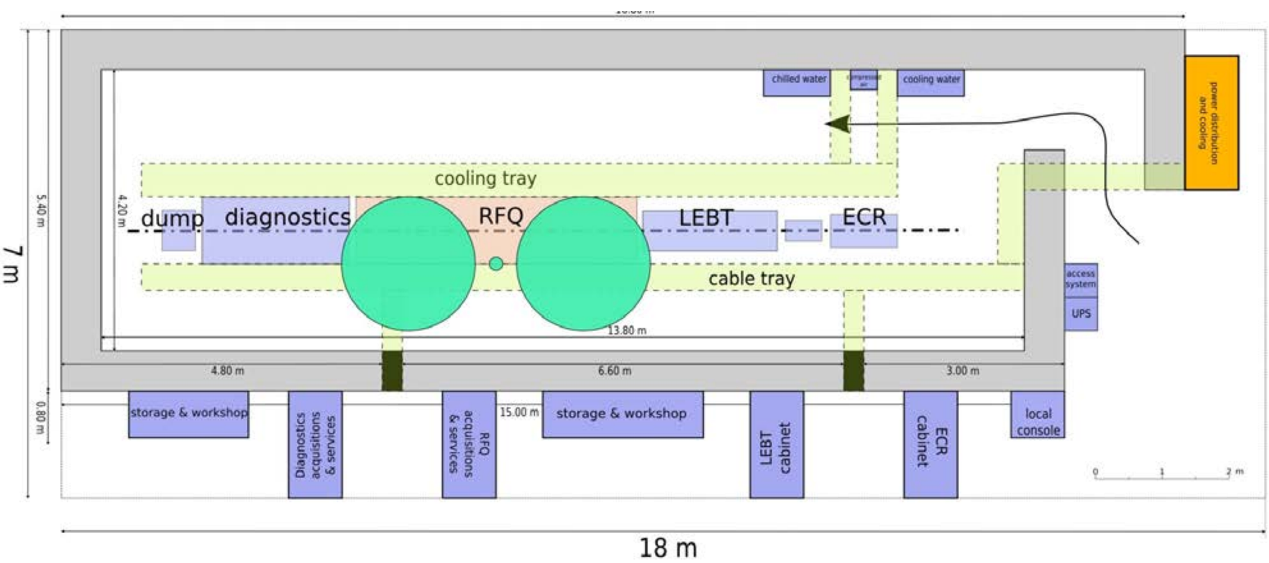

Figure 3: General layout of the experimental setup of RFQ@UCL R&D program

size 4-rod RFQ prototype is foreseen to be constructed and installed for beam tests. The experimental program includes full investigation of CW operability of the 4-rod RFQ, with beam characterization, matching and transmission efficiency measurements.

The experimental test stand is constituted by a commercial 30 keV proton source followed by a Low Energy Beam Transport (LEBT) section, injecting a matched beam into the RFQ. A diagnostics section followed by a beam dump close the line. In a second stage, the RFQ@UCL activity could be eventually extended towards subsequent higher beam energy structures of the MYRRHA injector, adding copper CH-type accelerating cavities to the existing setup for long reliability runs (RT-CH phase). A full injector comprising SC structures (SC-CH phase) will need a dedicated cryogenic plant.

The proton source has been procured by Pantechnik, France. Pantechnik design choices include an Electron Cyclotron Resonance (ECR) 2.45 GHz ion source, with a specific magnetic confinement configuration provided by two Permanent Magnets (PMs). A tapered axial RF injection up to 1200 W is adopted. This source should be capable to deliver a 30 keV proton beam up to 20 mA DC, with transverse beam emittances of 0.1π·mm·mrad RMS norm. at 5mA.

The LEBT design and engineering is provided by LPSC Grenoble, under a bilateral agreement signed between CNRS and SCK•CEN. IPNO supports the design with beam dynamics simulations and error analysis. The goal of the LEBT line is to efficiently inject the proton beam into the RFQ, providing, at the RFQ entrance, a centered beam with matched transverse emittances, lower or equal to the RFQ design value, that is 0.2π·mm·mrad RMS normalized. The overall length of the line, from the plasma chamber extraction hole to the RFQ entrance (inner flange), is around 2500 mm long. The beam focusing is demanded to a couple of magnetic solenoids, including additional coils for dipole corrections (H&V). Beam instrumentation comprises a Faraday cup system, an Allison scanner emittancemeter, a 2-axis collimating slits system. The engineering design of the LEBT, its subsequent production and the installation in UCL/CRC Louvain-la-Neuve will follow during the next 2 years. The LEBT line ends with a RFQ interface that hosts an electrostatic beam chopper (required to give a precise time structure to the beam delivery towards the MYRRHA reactor), a RFQ collimator, a beam current monitor (probably a short ACCT) and an electron repeller. The design of this section is ongoing at SCK•CEN in collaboration with UCL/CRC.

Such an initial injector will evaluate the choice of RFQ itself, and furthermore, it will be an efficient test platform for a large number of related critical issues. Currently, interest is focused on:

- the adoption of a high power, modular, Solid State RF amplifier at 176.1 MHz.
- interceptive and non-interceptive diagnostic devices for high intensity CW beams.
- a robust and comprehensive control system, based on 3-tier approach of typical large machines control systems, adopted in physics research. The candidate architecture is EPICS. The RFQ@UCL thus turns in a test platform, significantly representative for the final MYRRHA accelerator control system, where architectural choices and on-line beam simulations at small scale can be tested.
- Space Charge Compensation (SCC) phenomenon behavior and global efficiency assessment in the LEBT, both during steady-state and transients, including gas injection techniques. This study will determine the best location of the LEBT beam chopper.
- full experimental characterization of the low energy beam, with optimal initial beam configuration at the

entrance of the RFQ.

The Cryomodules R&D program

The third R&D line addresses the cryomodules prototyping and operation. A proper prototyping phase is envisaged for each of the superconducting CH, spoke, elliptical cavities cryomodules. The goal is to provide solid engineering design choices to be experimentally proved in prototypes, intended for operational tests. This activity is a milestone for the subsequent final series industrial procurement. The program should be coordinated by SCK•CEN, after 2014, and executed by the respective principal architects. Partnerships based on a commercial agreement, with research institutes or selected industrial companies, are expected, in order to realize prototypes in a highly interactive mode.

CONCLUSIONS

The MYRRHA accelerator R&D program is pursuing the previous activities carried out in EU FP5 PDS-XADS and FP6 EUROTRANS programs in order to deliver a detailed design of the superconducting linac accelerator for MYRRHA. The whole R&D program is set around the specific reliability demand and will provide solid bases in view of the final engineering phase of the machine. The activities cover both conceptual studies and experimental activities, through advanced simulations of beam dynamics and error studies, reliability modeling studies, experimental and optimized injector design, prototype cryomodules design and operation.

While the FP7 MAX project will deliver an updated consolidated conceptual accelerator design by end of 2014, the RFQ@UCL program is set to address important design choices of the future MYRRHA injector. Moreover, this is the first step toward the entire machine realization. The Cryomodules program will provide important design choices of the superconducting structures, to be followed by the next industrialization phase.

The study, evaluation and solution of issues and risks arising from this R&D design and prototyping phase will provide feedback and eventually a complete package of consolidated solutions for the final MYRRHA accelerator engineering design.

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