ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPAF003

INTEGRATED PROTOTYPING IN VIEW OF THE 100 MeV LINAC FOR MYRRHA PHASE 1*

D. Vandeplassche†, J. Belmans, W. De Cock, F. Davin, F. Doucet, F. Pompon, P. Della Faille, A. Gatera, C. Angulo, SCK•CEN, Mol, Belgium
F. Bouly, D. Bondoux, LPSC, Université Grenoble-Alpes, CNRS/IN2P3, Grenoble, France
C. Joly, G. Olry, H. Saugnac, IPNO, CNRS/IN2P3, Orsay, France
H. Podlech, U. Ratzinger, IAP, Goethe Universität, Frankfurt, Germany
D. Mäder, H. Höltermann, Bevatech GmbH, Frankfurt, Germany
M. Loiselet, N. Postiau, L. Standaert, Centre de Ressources du Cyclotron, UCL, Louvain-la-Neuve, Belgium

Abstract

The MYRRHA project borne by SCK•CEN, the Belgian Nuclear Research Centre, aims at realizing a pre-industrial Accelerator Driven System (ADS) for exploring the transmutation of long lived nuclear waste. The linac for this ADS will be a High Power Proton Accelerator delivering 2.4 MW CW beam at 600 MeV. It has to satisfy stringent requirements for reliability and availability: a beam-MTBF of 250h is targeted. The reliability goal is pursued through a phased approach. During Phase 1, expected till 2024, the MYRRHA linac up to 100 MeV will be constructed. It will allow to evaluate the reliability potential of the 600 MeV linac. It will also feed a Proton Target Facility in which radioisotopes of interest will be collected through an ISOL system; a target station for fusion studies is also foreseen. This contribution will focus on the transition to integrated prototyping, which will emphasize (i) a test platform consisting of the initial section of the normal conducting injector (5.9 MeV), (ii) the realization of a complete cryomodule for the superconducting linac and of its cryogenic valve box. The cryomodule will house two 352 MHz single spoke cavities operated at 2K.

INTRODUCTION

The MYRRHA project is borne by SCK•CEN, the Belgian Nuclear Research Centre [1]. It aims at realizing an Accelerator Driven System (ADS) consisting of a 600 MeV, 4 mA CW proton linac feeding a 100 MW_{th} fast neutron spectrum fission core. MYRRHA will be a demonstrator plant for ADS-based transmutation of long lived nuclear waste products and a multipurpose irradiation facility applying fast neutrons. A fraction of the beam will be deviated to a dedicated ISOL target facility (PTF).

The approach to the project is phased. At the level of the proton accelerator the first phase consists of building and operating the linac limited to 100 MeV final beam energy. It is well known that the reliability is the main challenge of the ADS driver. In MYRRHA's case this challenge is expressed as a beam-MTBF of 250 hours. Hence, the principle aim of phase 1 is to experimentally investigate the feasibility and efficiency of the reliability and fault tolerance schemes that are envisaged for the 600 MeV linac.

Also in phase 1 it is foreseen to transport a ~10% fraction of the 100 MeV beam to an ISOL production target for innovative medical radioisotopes. MINERVA is the name of the project that combines the phase 1 100 MeV linac, the ISOL target station and all the associated services and buildings.

Fundamental studies and component prototyping in view of the 600 MeV SC linac have been going on for several years, mainly within the successive European Framework Programmes FP5 (PDS-XADS), FP6 (Eurotrans) and FP7 (MAX) — see [2]. Also in the running H2020 programme, WP2 of the MYRTE project still covers essential component prototyping, but now with a clear roadmap towards integration. So, building upon the realizations of component prototyping, today's activities around the accelerator focus on the prototyping of fully operational constituents of the linac, i.e. integrated prototyping. The majority of these activities is supported by several bilateral collaboration agreements. Their scope is restricted to the 100 MeV phase 1 linac. Integrated prototyping for the 100 – 600 MeV sections of the MYRRHA linac is foreseen within phase 1, but will be executed in parallel with the construction/installation of the 100 MeV linac.

STATUS OF COMPONENT PROTOTYPING

The successive collaborations in the Framework Programmes have identified the important R&D and prototyping activities needed for realizing a highly reliable linac. Global studies (essentially beam dynamics, error studies and reliability modeling) provide the framework for the risk evaluation. Accelerator components that carry an increased risk may be considered for component prototyping. The risk increase may be borne by a critical individual component or induced by the multiplication related to the modularity. Components may be localized or represented by a distributed system.

An overview of the component prototyping activities that have been considered is given in Table 1. It also mentions some near-future performance tests still to be performed.

* Work partially supported by the European Commission Framework Programme H2020, MYRTE project nr. 662186
† dvandepl@sckcen.be

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPAF003

Table 1: Component Prototyping Activities

item	status	remark	ref.
ECR source	achieved	ready for recommissioning	
LEBT	achieved	ready for recommissioning	[3]
chopper, RFQ injection cone	final adjustments	recommissioning	
4-rod RFQ	constructed	power RF conditioning	[4]
SS RF power amplifier	assembled	ready for SAT	[5]
CH cavity	constructed	initial RF testing	[6]
single spoke cavities	tested	in vertical cryostat	[7]
power couplers for single spoke	designed	under review	
spoke cryomodule	designed	under procurement	[8]
LLRF 176 MHz	final realization	tests with RFQ upcoming	
LLRF 352 MHz	designed, procurement	µTCA-based	
global beam dynamics	finalized for nominal layout	full start-to-end and error studies upcoming	
reliability modeling	elaborated	to be fed with data (e.g. Linac4)	
global control system	preliminary architecture	to be implemented on injector	[9]

The superconducting single spoke cavity (see Fig. 1) is a particularly important item. In view of later series production, the qualification of the cavity preparation recipe has to be carefully established. This activity is being finalized under MYRTE. The latest results give a strong indication that the nominal operation point in the Q_0 vs. E_{acc} diagram may now be improved. This allows for increasing the longitudinal acceptance of the linac (of vital importance for the ability to compensate for a failing cryomodule) without imposing a significant length increase.

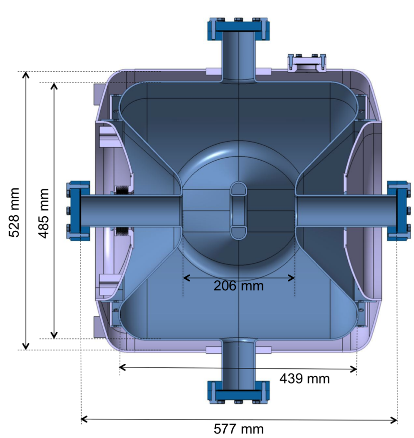

Figure 1: Cut view of the single spoke cavity and its helium vessel, with main dimensions — design by IPNO.

The component prototyping program being achieved now opens the way to the present focus, namely integrated prototyping, in which components are combined into operational entities (including all related services and controls).

TOWARDS INTEGRATED PROTOTYPING

The lines of integrated prototyping under consideration are:

1. Construction and operation of the fully operational injector, at full beam intensity (4 mA CW) but limited to a final energy of 5.9 MeV.
2. Construction and operation without beam of one fully equipped single spoke cryomodule which is the basic building block of the 100 MeV superconducting linac.
3. Construction and operation without beam of the beam extraction system that will allow to feed the ISOL target station.

The 5.9 MeV Injector

An overview of the 5.9 MeV injector is shown in Fig. 2. This entirely normal conducting injector is being set up in a specially constructed bunker within the Centre de Ressources du Cyclotron at UCL, Louvain-la-Neuve, Belgium.

It combines the following linac elements:

- The ECR proton source, commercially procured from the company Pantechnik [10], able to deliver up to 20 mA and operated at 30 kV.
- The LEBT, designed, assembled and commissioned by LPSC Grenoble [3], using 2 magnetic solenoids for proper beam matching and featuring a diagnostic chamber with Faraday cup, beam slits and Allison-type emittancemeters.
- The beam chopper and its associated water cooled collimator, with a typical repetition rate of 250 Hz and a rise time in the µs range (to be optimized).
- The injection cone for connecting to the RFQ, with an electron repeller and an ACCT.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPAF003

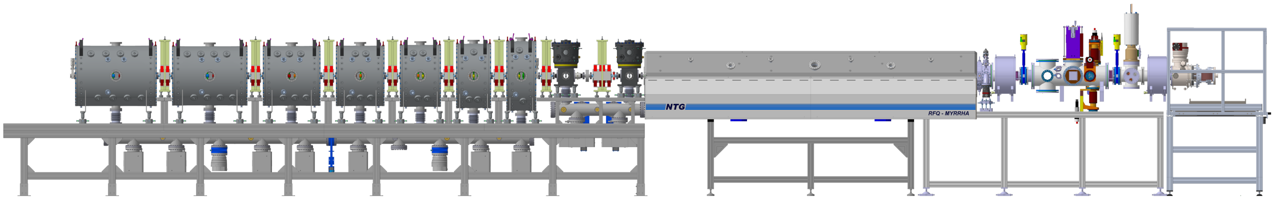

Figure 2: Overview of the 5.9 MeV injector.

- The 4-rod RFQ accelerating to 1.5 MeV over 4 m, RF frequency of 176 MHz, designed by IAP Frankfurt and built by the company NTG [11].
- The RF power amplifier in Solid State technology, entirely developed by the company IBA [5], delivering up to 192 kW CW at 176 MHz.
- The LLRF controls being developed by IPNO.
- A short matching section named MEBT1, consisting of 2 quarter wave rebuncher cavities and a magnetic quadrupole triplet.
- A series of 7 individual room temperature CH-type accelerating cavities with magnetic quadrupole doublet focusing between the cavity tanks. The global design is from IAP Frankfurt, the practical execution is supported by the company Bevatech [12].
- A versatile diagnostic test bench, allowing for obtaining the fundamental beam characteristics, applicable at several levels of beam energy.

Further details on the features of MEBT1, the CH series and the diagnostic test bench are given in [6].

The services (electricity, cooling, vacuum, ...) have been designed with the help of MYRRHA's Balance of Plant team and are presently being installed in very close collaboration with the CRC crew.

The Spoke Cryomodule

The prototype spoke cryomodule is designed by IPNO [2] and is going to be realized under a bilateral collaboration SCK•CEN - IN2P3. The cryomodule will operate at 2K. All the tests will be performed at IPNO (Orsay, France). For this cryomodule, 2 new Nb single spoke cavities inserted in their He vessel (Ti) are being procured. The call for tender for manufacturing the cryostat is launched. Tendering for the magnetic shield and for the cold tuning mechanisms will follow soon. The conceptual design of the cold valve box is presently undertaken by the company ACS [13]. The power coupler has been deeply redesigned by LPSC (Grenoble, France), and is now under internal review. The couplers will be tested and conditioned at LAL (Orsay, France).

The 352 MHz LLRF based on the µTCA platform and compatible with the fault tolerance scheme is being developed by IPNO.

A local control system specific to the test platform (including the cryogenic supervision) is foreseen.

Status of the Control System

The controls of the 5.9 MeV injector shall be prototypical for the full linac, including provisions for increased reliability and/or redundancy. Special attention has to be paid on the scalability of the implementations and on maximizing the homogeneity of the system. Also the compatibility with the fault recovery scheme of the SC linac needs attention. Besides the basic choice of the EPICS framework on a classical 3-tier layout, the presently considered design options are presented in the subsequent list. The global architecture based on these principles will be worked out in the near future, and applied to the 5.9 MeV platform.

- In the absence of communication to the higher levels, the low level control units are able to keep the accelerator alive until eventually a safety interlock occurs.
- The use of industrial PLC's is maximized for control and supervision of slow processes. The preferred local field bus is Profinet, but support for other field buses (Profibus, Modbus, Ethercat, ...) is required as well.
- The Low Level RF and, in general, the acquisition of fast signals related to the bunch structure are based on the µTCA.4 platform.
- For signals up to few MHz an NI-PXI acquisition system is available.

OUTLOOK TO THE 100 MeV PROJECT

Industrialisation

The 100 MeV linac has 30 cryomodules, each housing 2 single spoke cavities. Each cryomodule is connected to the cryogenic supply via its individual cold valve box. Although from an industrial point of view the series are small, an industrial approach to the activities of cavity preparation and of clean room assembly of the complete cryomodules is compulsory. The investigation of this approach is another task of the cryomodule's integrated prototyping.

Reliability Issues

The goal of the 100 MeV linac is to establish the feasibility of the 600 MeV ADS driver linac satisfying the reliability requirements. This needs to

- Confirm experimentally the fault recovery procedure(s).
- Feed a reliability model allowing extrapolation.

The former is based on 2 fast procedures:

1. A virtual accelerator-based reconfiguration tool (fast beam simulation).

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPAF003

2. A global hardware reconfiguration tool (fast setpoint changes and readback).

Both these procedures may be initiated at the prototyping level on the 5.9 MeV injector.

REFERENCES

[1] MYRRHA, http://myrrha.sckcen.be

[2] D. Vandeplassche *et al.*, MAX deliverable D1.5 "MAX Project Final Report", http://ipnwww.in2p3.fr/MAX/images/stories/freedownloads/MAX_Deliverable_1.5_final_free_download.pdf, Aug. 2014

[3] F. Bouly *et al.*, in *Proc. IPAC'17*, Copenhagen, Denmark, May 2017, paper TUOBA2, pp. 1226–1229.

[4] H. Podlech *et al.*, in *Proc. IPAC'17* Copenhagen, Denmark, May 2017, paper TUPVA071, pp. 2243–2245.

[5] J. Brison, "A New Compact Solid State Amplifier Design for Particle Accelerators: The MYRRHA Genesis", presented at IPAC'18, Vancouver, Canada, May 2018, paper THPAL006, this conference.

[6] D. Mäder *et al.*, "Status and Development of the MYRRHA Injector", presented at IPAC'18, Vancouver, Canada, May 2018, paper MOPML017, this conference.

[7] D. Longuevergne *et al.*, in *Proc. LINAC'16* East Lansing, MI, USA, September 2016, paper THPLR030, pp. 916–919.

[8] H. Saugnac *et al.*, in *Proc. LINAC'14*, Geneva, Switzerland, 2014, paper TUPP082, pp. 613–615.

[9] R. Modic *et al.*, "MYRRHA Control System Development", presented at IPAC'18, Vancouver, Canada, May 2018, paper THPML075, this conference.

[10] Pantechnik SA, http://www.pantechnik.com

[11] NTG Neue Technologien GmbH, http://www.ntg.de

[12] Bevatech GmbH, http://www.bevatech.com

[13] Accelerators and Cryogenic Systems (ACS), http://www.acsfrance.com