PROGRESS ON THE SRF LINAC DEVELOPMENTS FOR THE IFMIF-LIPAC PROJECT

F. Orsini#, N. Bazin, P. Brédy, P. Carbonnier, G. Devanz, G. Disset, N. Grouas, P. Hardy, V. Hennion, H. Jenhani, J. Migne, A. Mohamed, J. Neyret, B. Renard, J. Relland, D. Roudier, CEA/IRFU, Gif-sur-Yvette, France
P. Abramian, J. Calero, J. Calvo, J.L. Gutierrez, T. Martinez, J. Munilla, I. Podadera, F. Toral, CIEMAT, Madrid, Spain

Abstract

In the framework of the International Fusion Materials Irradiation Facility (IFMIF), which consists of two high power accelerator drivers, each delivering a 125 mA deuteron beam at 40 MeV in CW, a Linear IFMIF Prototype Accelerator (LIPAc), is presently under design and realization for the first phase of the project [1]. This accelerator prototype includes a Superconducting Radio-Frequency Linac (SRF Linac), which is designed for the transportation and focalization of the deuteron beam up to 9 MeV. This SRF Linac is a large cryomodule of ~6 m long, working at 4.4 K and at the frequency of 175 MHz in continuous wave. It is mainly composed of 8 low-beta Half-Wave Resonators (HWR), 8 Solenoid Packages and 8 RF Power Couplers. This paper focuses on the recent developments and changes made on the SRF Linac design: following the abandon of the HWR frequency tuning system, initially based on a plunger located inside the central region of the resonator, a new external tuning system has been designed, implying a complete redesign of the resonator and consequently impacting the cryomodule lattice. The recent changes in the design are presented in this paper. In addition, cold tests were performed on a HWR prototype and cold tests results of the magnets prototypes are also presented.

SRF LINAC DESCRIPTION

The IFMIF-LIPAc SRF Linac is a compact cryomodule, with short lattices defined by beam dynamics constraints [2], and with a large number of components sharing cryogenics circuits. The cryomodule consists of a horizontal vacuum tank of around 6 m long, 3 m high and 2.0 m wide, which includes the following elements:

- 8 low-β HWRs with a frequency tuning system,
- 8 RF Power Couplers,
- 8 Solenoid Packages (including solenoids, H&V steerers and cryo-Beam Position Monitor),
- A cryostat (vacuum tank) with access doors,
- Supports and alignment system,
- Cryogenic, vacuum and electrical systems,
- Magnetic shielding and thermal screens.

The cryomodule under development is illustrated in Figure 1. Main parameters of this cryomodule are summarized in the following Table 1.

Corresponding author: fabienne.orsini@cea.fr

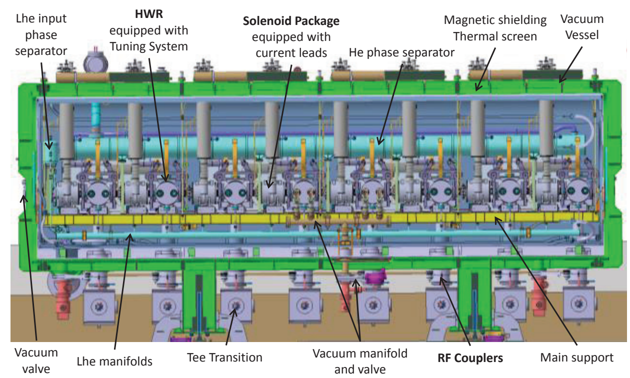

Figure 1: General layout of the IFMIF-LIPAc SRF Linac.

Table 1: Summary of Main SRF Linac Parameters

Parameters	Target Value	Units
β value of the HWR	0.094	
Accelerating field E_{acc}	4.5	MV/m
Unloaded Quality factor Q_0 for R_s=20 nΩ	1.4×10^9	
Beam aperture HWR / Solenoid Package	40 / 50	mm
Freq. range of HWR tuning syst	± 30	kHz
Max. transmitted RF power by coupler (CW)	200	kW
External quality factor Q_{ex}	6.3×10^4	
Transmission Lines for HWR	coax 6" 1/8	
Magnetic field B_z on axis max.	6	T
∫ B.dl on axis	≥ 1	T.m
Field at cavity flange	≤ 20	mT
CBPM position accuracy	0.25	mm
CBPM phase accuracy	2	deg
Total Static heat losses @ 4.4 K	28+11	W+l/h
Total Dynamic heat losses @ 4.4 K	55+8	W+l/h

LOW-BETA HWR DEVELOPMENT

HWR Prototype Validation Test

Two HWR prototypes were initially realized with a plunger system for the frequency tuning. Due to technical difficulties appearing during the first cold tests results on both prototypes [3] and due to the tight time schedule of the LIPAc, the project decided to abandon the plunger tuning system. An HWR prototype was therefore modified: plunger was removed, and the plunger port of

ISBN 978-3-95450-122-9

the resonator was sealed by welding a Niobium disk, as illustrated on Figure 2.

Figure 2: HWR prototype after modification (without helium tank).

After a standard surface preparation (chemical treatment and high pressure rinsing), the modified prototype was tested in vertical cryostat at 4.2 K. The results obtained were satisfactory, as illustrated on Figure 3. Q_0 was above specifications and measured at 2×10^9 @ 1 MV/m. Quenches appeared at 8 MV/m, well above the nominal accelerating field of 4.5 MV/m. Dissipated RF power in the cavity walls is limited to 4 W at nominal accelerating field. Multipactor barriers were also observed at very low field from ~10 kV/m up to 200 kV/m, but were easy to overpass. Field emission appeared at 5.4 MV/m during this test and can be explained by a non-optimal replacement of a feedthrough during HWR preparation in clean room.

From these results, the HWR prototype was qualified with margin and HWR RF design was therefore validated.

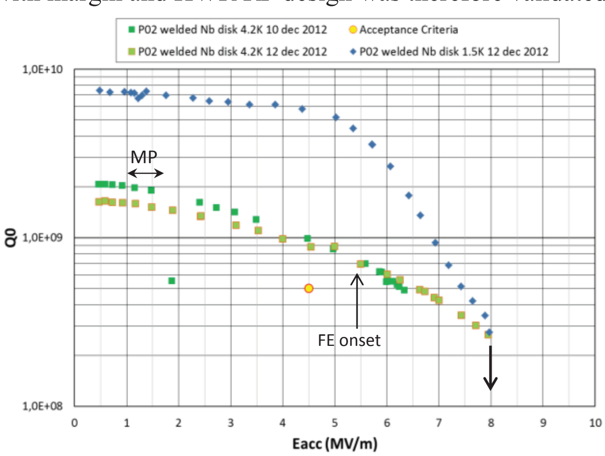

Figure 3: Cold tests results of HWR prototype: Q_0 vs E_{acc}.

HWR and External Frequency Tuner Design

The new frequency tuning system of HWR is based on an external solution, where beam noses of the HWR are compressed by a mechanical system. This design had to fulfill few constraints:

- Reduce the HWR stiffness, while still being compliant with Japanese pressure vessel code.
- Location of interface for tuning efficiency.
- Lever arms have to be rigid enough compared to the HWR rigidity.
- Deform the HWR only at 4.4 K; tuning system has to be released at room temperature.
- Increase the lattice length of the cryomodule for the integration of the lever arm around the HWR.

Figure 4 illustrates the new HWR geometry and tuner design (the internal RF design of the resonator is unchanged). According to calculations, a deformation of the two noses of 0.68 mm is sufficient for a detuning of 88 kHz (the frequency sensitivity along beam axis is -129 kHz/mm). The cavity wall thickness is 3 mm thick. The tuning force to apply is 8000 N per nose for a 0.3 mm displacement. Mechanical stress on the HWR, submitted to helium pressure and tuning force at 4.4 K, is found acceptable and below 150 MPa.

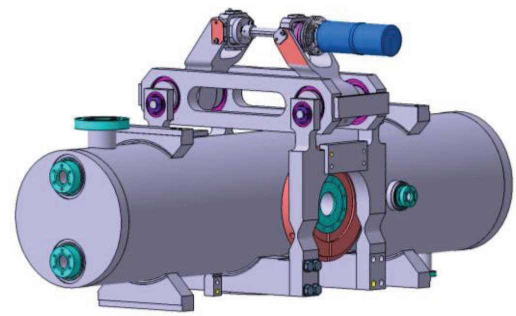

Figure 4: Mechanical design of the low-beta HWR, tuned by beam noses compression.

RF POWER COUPLERS STATUS

The RF Power Couplers are designed to be able to withstand RF power up to 200 kW at 175 MHz in CW travelling wave mode (and 200 kW in pulsed full reflection mode for the tests). The Power Coupler has a 50 Ω coaxial geometry with coaxial ceramic disk. The design, specifications and preliminary tests on a representative Coupler' mock-up (RF window and Tee transition) have already been presented in [4].

Since the mock-up validation tests, two RF couplers prototypes have been realized. Figure 5 illustrates the preparation and leak test performed on one prototype in clean room (ISO 5). Cleaning and assembly procedures have been developed and validated. The next step consists to condition the couplers prototypes with high RF power on a dedicated testbench [8].

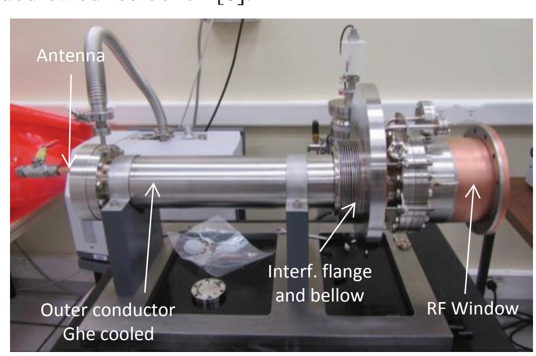

Figure 5: RF Coupler prototype assembled for leak tests in clean room.

ISBN 978-3-95450-122-9

SOLENOID PACKAGES STATUS

Each Solenoid Package is 400 mm long with an aperture diameter of 50 mm. The integrated on-axis field is ≥ 1 T.m for the solenoid, with a nominal current of 210 A. In order to decrease the fringe field at the HWR entrance, an active shielding is used. It consists of a concentric external solenoid connected in series with the inner one, with current in opposite sense. It decreases the fringe field, but at the same time weakens the actual field created by the internal solenoid. The design and specifications of the Solenoid Package have been already presented in [5]. The Figure 6 illustrates the detailed design of this package.

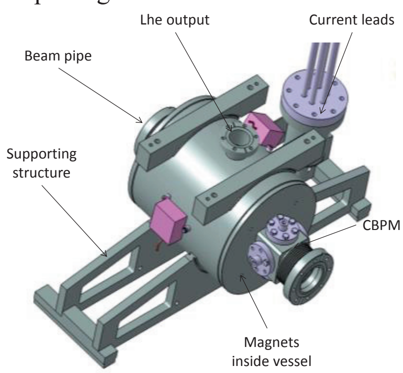

Figure 6: Detailed design of the Solenoid Packages.

A prototype with final magnets configuration has been built. Magnetic field profile along solenoid axis was measured at room temperature with Hall sensor at a reduced current of 102 mA. Results were within the specifications and were presented in [5]. In addition, the magnets were tested at 4.2 K in vertical cryostat (at first in vertical position) up to the nominal power. No mechanical damages were observed after few thermal cycling and quench. In order to reproduce real operation conditions, another cold test was performed with the inner & outer coils in horizontal position, powered up to quench value at a critical current of 262 A. The helium vapour was evacuated correctly and the cooling channels inside the vessel were checked to be efficient enough.

CRYOMODULE DESIGN

The cryomodule design has been updated in order to take into account the changes applied on the design of HWR equipped with its frequency tuning system. The lattice HWR-Solenoid Package- has been lengthened by +100 mm. The cryomodule was therefore extended to 5866 mm (~+1 m). If the cryomodule concept remains identical to the initial one [6], new mechanical calculations were necessary on the vacuum tank, the main helium phase separator and the main frame structure, to take into account the non-negligible extension of the cryomodule total length. Figure 7 illustrates the mechanical deformation of the vacuum tank under vacuum, cold mass load and submitted to external atmospheric pressure. The maximum deformation observed is around 0.7 mm on the access doors, which is an acceptable value.

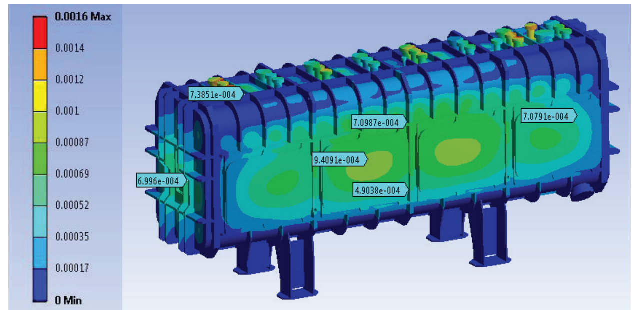

Figure 7: Mechanical deformation of the vacuum tank under operation conditions.

The main frame is also redesign to minimize deformation as low as possible in order to keep the cold mass alignment after pumping. Because all components are positioned and fixed on an invar rod, their displacement during thermal shrinking is therefore minimized to 1.2 mm on the components of both extremities.

The beam line vacuum system was also optimized and simplified [7], in order to ease the cleaning and assembly of pieces during the future assembly of cold mass in clean room.

SUMMARY AND PERSPECTIVES

HWR and magnets prototypes have been tested in nominal conditions and performances were validated. HWR geometry has been redesigned to comply with the external frequency tuning system. The production of these components for the series should be launched rapidly.

RF couplers prototypes are ready for RF conditioning, which should start soon. Detailed drawings for all other cryomodule components are under progress, and realization is planned to start by the end the year.

REFERENCES

[1] A. Mosnier et al., "The Accelerator Prototype of the IFMIF/EVEDA Project," IPAC'10, Kyoto, May 2010, MOPEC056, p.588 (2010).
[2] N. Chauvin et al., "Start-to-End Beam Dynamics Simulations for the Prototype Accelerator of the IFMIF/EVEDA Project," IPAC'11, San Sebastian, September 2011, MOPS026, p.655 (2011).
[3] F. Orsini et al., "Preliminary results of the IFMIF cavity prototypes tests in vertical cryostat and cryomodule development," SRF'11, Chicago, July 2011, THIOB02, p. 667 (2011).
[4] H. Jenhani et al., "Input Power Coupler for the IFMIF SRF LINAC," IPAC'12, New Orleans, May 2012, WEPPC001, p. 2200 (2012).
[5] S. Sanz et al., "Fabrication and testing of the first Magnet Package Prototype for the SRF Linac of LIPAc," IPAC'11, San Sebastian, September 2011, WEPO030, p. 2463(2011).
[6] N. Grouas et al., "Mechanical and Cryogenic System Design of the first Cryomodule for the IFMIF Project," IPAC'10, Kyoto, May 2010, MOPEC054, p. 582 (2010).
[7] N. Bazin et al., "Vacuum Study of the Cavity String for the IFMIF Cryomodule," THPFI003, this proceedings.
[8] D. Regidor et al., "IFMIF-EVEDA SRF Linac Couplers Test Bench," WEPWO043, this proceedings.