

STUDY AND REALIZATION OF THE FIRST SUPERCONDUCTING HALF WAVE RESONATOR FOR THE SRF LINAC OF THE IFMIF PROJECT

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Abstract

In the framework of the International Fusion Materials Irradiation Facility (IFMIF), which consists of two high power CW accelerator drivers, each delivering a 125 mA deuteron beam at 40 MeV, an accelerator prototype (EVEDA) is presently under design for the first phase of the project [1]. A superconducting option has been chosen for the 9 MeV RF Linac, based on a cryomodule composed of 8 low-beta Half-Wave Resonators (HWR), 8 Solenoid Packages and 8 RF couplers. This paper will focus on the HWR sub-system: the RF, thermo mechanical design, and the realization of the first prototype of HWR will be presented. The resonator tuning frequency is controlled by an innovating tuning system, located in the central region of the cavity. The different options for tuning will be discussed and the final thermo mechanical design will be detailed. A dedicated testbench for the tuning system under development is presented.

INTRODUCTION

The main purpose of the IFMIF-EVEDA project is to validate all the technical options for the construction of the accelerator prototype, with a full scale of one of the future IFMIF accelerator, from the injector to the first cryomodule of the SRF Linac. The main requirements for the accelerator prototype are as follow:

- Energy of D+ beam on target: 9 MeV
- RF Frequency: 175 MHz
- Beam intensity on target: 125 mA
- Output rms long. emittance: $< 0.55 \pi$.mm.mrad, and $< 0.35 \pi$.mm.mrad in transverse.

The general layout of the accelerator prototype is illustrated in Figure 1. The objectives of the EVEDA phase consist to design, realize, validate and commission the first on fourth cryomodule of the IFMIF accelerator. This 1st cryomodule is the most difficult one, essentially due to the short drift lengths between components and small interfaces between sub-systems, in order to design a cryomodule as compact as possible to fulfil the beam dynamics requirements in the case of intense beam [2].

The goals of the SRF Linac are to transport and accelerate the deuteron beam of nominal intensity, in continuous wave (CW), with energy from 5 MeV up to 9 MeV at the output of the linac. Good performances in

terms of transverse and longitudinal emittances are necessary to fit with the 300 mm diameter aperture at the Beam Dump entrance [3], and the footprint for IFMIF: 200 mm \times 50 mm, without beam loss (< 1 W/m).

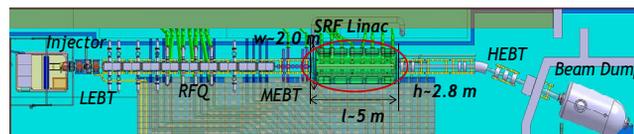


Figure 1: General layout of the accelerator prototype in the vault at the Rokkasho site.

SRF LINAC DESCRIPTION

The SRF Linac is a complex system, due to the huge number of components sharing cryogenics circuits. The cryomodule consists of a horizontal vacuum tank of around 5 m long, ~ 2.8 m height and ~ 2.0 m diameter, which includes the following elements:

- A cryostat (vacuum tank) with access traps,
- 8 low- β HWRs with a freq. tuning system [7],
- 8 RF couplers [4],
- 8 Solenoid Packages [5] (including solenoids, H&V steerers and Beam Position Monitors),
- Supports and alignment system,
- Cryogenic, vacuum and electrical systems,
- Magnetic and thermal shield.

The cryomodule under development [6] is illustrated in Figure 2. Main parameters of this linac are summarized in the following Table 1.

Table 1: Summary of SRF Linac Parameters

Parameters	Target Value	Units
β value of the HWR	0.094	
Accelerating field E_a	4.5	MV/m
Unloaded Quality factor Q_0 for $R_s=20$ n Ω	1.4×10^9	
Beam aperture HWR / Solenoid Package	40 / 50	mm
Freq. range of HWR tuning syst	± 50	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

$\int B \cdot dl$ on axis	≈ 1	T.m
Field at cavity flange	≤ 20	mT
BPM position accuracy	0.25	mm
BPM phase accuracy	2	deg
Total Static/Dynamic Heat losses	18 / 120	W

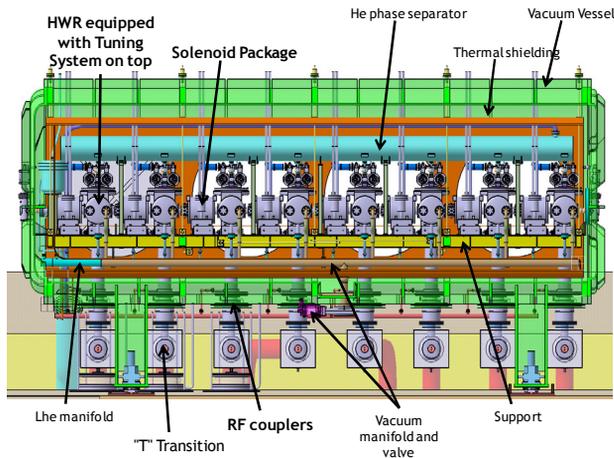


Figure 2: General layout of the SRF Linac.

DESIGN OF THE LOW- β HWR PROTOTYPE AND FREQUENCY TUNING SYSTEM

RF Design of HWR

The goal of the cavity electro-dynamics design is to optimize the cavity geometry to minimize peak values of electrical and magnetic fields on the cavity surface, relative to the accelerating electrical field on the cavity axes (B_{pk}/E_{acc} and E_{pk}/E_{acc}). The structural design has also to minimize the resonant frequency dependence on the external pressure fluctuations. The general basics of this design are to avoid using plane surfaces. Since the optimization of the cavity structural design has already been presented in details in another paper [7], only final results are summarized here.

Table 2: Summary of HWR Parameters

Parameters	Target Value	Units
$R_{aperture}$	20	mm
$\beta\lambda$	161.04	mm
R_{cavity}	90	mm
G	28.55	Ohm
E_{pk}/E_{acc}^*	4.42	
B_{pk}/E_{acc}^*	10.12	mT/MV/m
$E_{pk}@E_{acc}=4.5$ MV/m	19.87	MV/m
$B_{pk}@E_{acc}=4.5$ MV/m	45.56	mT
Cooldown frequency shift	250	kHz
BCP frequency shift	40	kHz/100 μ m
df/dp	0.04	Hz/mbar

*) $L_{cav} = N_{gaps} \times \beta\lambda/2$, where $N_{gaps}=2$ —number of gaps

Tuning System

Few solutions were studied for the frequency tuning of this cavity. The standard effective way to tune HWR is to apply the tuning force on the beam ports for deformations to change the accelerating gap capacitance. Unfortunately, the disadvantages of such method are the change of E_{pk}/E_{acc} (not large), the relatively high stresses and the requirement on the additional space for the tuner structure between the cavities. This method requires also an application of a high tune force since the beam port structure has rather high rigidity.

Cavity tuning by outer conductor wall deformation in the central part of the cavity has been also investigated. By asymmetric tune force application, because of the coupler port in opposite side, there was also displacement of beam port, which changes accelerating gap capacitance. Moreover, the limited space for tune area defined the stresses on cavity wall above elastic deformations. Considering all these disadvantages of these methods, another solution was chosen: capacitive tuner in central region.

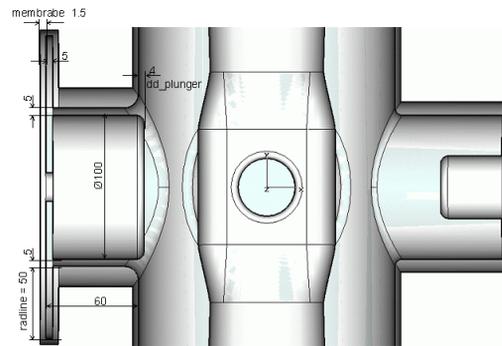


Figure 3: Layout of the capacitive plunger.

The capacitive tuner is installed in the electric field region perpendicular to the beam axis. This tuner changes the capacitance between wall and the central electrode. To avoid an enhancement of E_{pk}/E_{acc} , the capacitive gap is kept low (4 mm plunger penetration in the cavity volume). To achieve the required tune sensitivity (50 kHz/mm), the plunger diameter has been made 100 mm. The plunger is connected to a flexible membrane (1.5 mm thick) via a 5 mm long stem. The tuning force is applied to the tuner stem. The membrane will be deformed in the range of ± 1 mm.

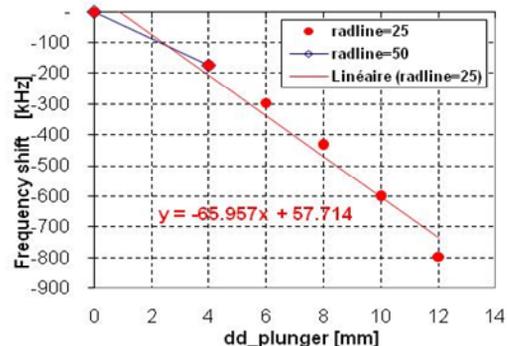


Figure 4: Frequency tuning sensitivity after optimization.

Simulations of multipactor probability, its intensity and zones for each separate surface in the cavity, and in the plunger region, have been performed [7]. To eliminate residual multipactor, all gaps in the tuner housing were optimized. Figure 3 illustrates the capacitive plunger design after optimization. Figure 4 shows the frequency shift versus the length of penetration of the plunger inside the cavity volume. The calculated frequency sensitivity is > 50 kHz/mm.

Thermo Mechanical Design

The cavity is made in pure niobium, fixed in a titanium vessel, and is cooled with liquid helium at 4.4 K. The cavity and helium vessel are directly welded to the cavity flanges in niobium-titanium. The distance between cavity wall and helium vessel is around 2 cm. The helium inlet and outlet have a diameter of 24 and 40 mm respectively, and are placed at the opposite sides of the vessel to facilitate the helium flow around the cavity. Figure 6 illustrates the final design of the cavity prototype.

Several calculations have been carried out to check the cavity and helium vessel design according to the mechanical constraints. Maximum stress caused by the helium pressure at 2.5 bar (nominal pressure being 1.25 bar) is around 65 MPa for the niobium cavity, which is acceptable compared to the niobium elastic limit estimated around 400 MPa at 4.4 K. The stress on the titanium vessel is around 80 MPa for an elastic limit of 400 MPa at 300 K and this limit is much higher at cold temperature.

The tuning system has been also studied in details with the required displacement of the center of the membrane of ± 1 mm. The stress level obtained is about 125 MPa, which is satisfactory compared to the niobium-titanium elastic limit. This result is illustrated in Figure 5.

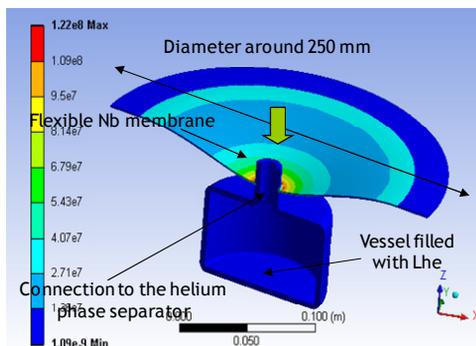


Figure 5: Mechanical stress in the plunger ‘membrane’.

Manufacturing of Prototypes of HWRs and Tuning System

The cavity feasibility has been discussed in details with manufacturers in order to optimize the detailed drawings.

All niobium sub-assemblies and niobium-titanium flanges are high vacuum electron beam welded. The realization of two prototypes is now well in progress and the cavity delivery is expected for summer 2010.

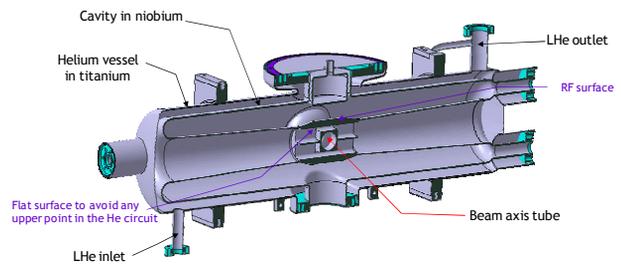


Figure 6: Final drawing of the HWR prototype.

The whole tuner structure is dismantlable from the cavity body. The plunger is moved by an actuator system constituted by a controlled step motor, an infinite screw and a mechanical arm. This system is fixed to the cavity flange and allows displacement of membrane downwards and upwards, with a precision of at least 200 Hz. This tuning system will be realized in the coming months and a dedicated testbench is needed for its mechanical and thermal validation at cold temperature (see Figure 7).

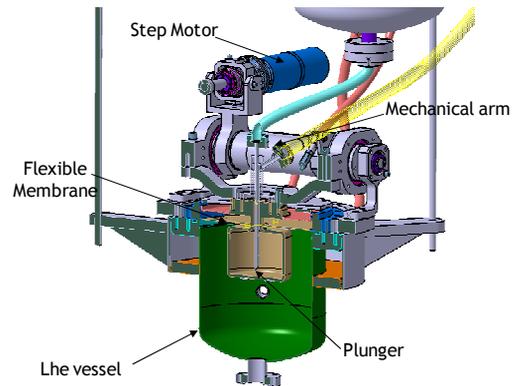


Figure 7: Scheme of the dedicated testbench for the HWR frequency tuning system.

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