PERFORMANCES OF THE TWO FIRST SINGLE SPOKE PROTOTYPES FOR THE MYRRHA PROJECT

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Abstract

The MYRRHA project aims at the construction of an accelerator driven system (ADS) at MOL (Belgium) for irradiation and transmutation experiment purposes [1]. The facility will feature a superconducting LINAC able to produce a proton flux of 2.4 MW (600 MeV - 4 mA). The first section of the superconducting LINAC will be composed of 352 MHz (beta = 0.37) Single Spoke Resonators (SSR) housed in short cryomodules operating at 2K.

After a brief presentation of the cryomodule design, this paper will aim at presenting the RF performances of the SSR tested in vertical cryostat in the framework of European MYRTE project (MYRRHA Research and Transmutation Endeavour) [2] and at comparing experimental results (Lorentz forces, pressure sensitivity, multipacting barriers …) to simulated values.

INTRODUCTION

In the continuation of MAX project (MYRRHA Accelerator eXperiment) [3], MYRTE project is aiming at pursuing the R&D on the MYRRHA research facility. In both projects, a task is dedicated to the R&D of a Spoke cryomodule: a detailed engineering design of the full cryogenic module has been performed and two prototypes of the Single Spoke Resonator (SSR) have been built within MAX project [4]. MYRTE project aims now at assessing the RF performances of the two prototypes at the operating temperature (2K) to validate the mechanical and RF design. In addition, dedicated R&D is being done to improve the intrinsic quality factor (Q_0) by applying heat treatments (low temperature baking, hydrogen degassing ...) on cavities already equipped with their helium jacket (Titanium). This paper will present the baseline results of the two prototypes that have been tested in vertical cryostat. The first heat treatments have not been yet performed, but are foreseen for the end of this year.

SPOKE CRYOMODULE DESIGN

The Cryomodule and Ancillaries

As depicted in Fig. 1, the cryomodule is housing two superconducting SSR made of bulk Niobium with a beta of 0.37 and an operating frequency of 352 MHz. Because of very high reliability requirements, that makes MYRRHA project so specific [5], the cavities could be operated at two different regimes. The first one, the nominal regime, is requiring an accelerating gradient of 6.4 MV/m. The second one, called the fault-recovery regime, activated in case of failure of a neighbour cavity, is requiring an accelerating gradient of 8.4 MV/m. In both regimes, the cavity power dissipations have to be kept below 10W.

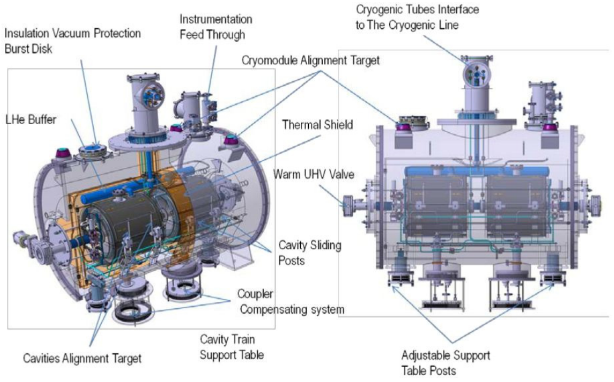

Figure 1: SSR cryomodule for MYRRHA.

The cavities will be powered by a power coupler with a single warm window designed to transfer 20 kW RF power in CW. A prototype has been developed and successfully tested within the EURISOL project [6].

The frequency regulation will be achieved with a cold tuning system by deformation very similar to the ESS design [7]. Some modifications will be done to implement a fast detuning capability to fulfil the fault-recovery requirements.

The magnetic shield is for instance designed to be actively cooled with 4.2K liquid helium. It will be composed of two 1-mm-thick layers of Cryoperm® directly installed around the helium tank to ensure an optimal shielding of the residual magnetic field as it was done for Spiral2 type-B cryomodules [8].

The Single Spoke Cavity

The RF design was achieved following the experience feedback from previous Spoke developments [9][10]. RF parameters are optimized to operate the cavity at very conservative electromagnetic field (E_{peak}<40 MV/m and B_{peak}<80 mT) and to decrease manufacturing difficulties. Table 1 below summarizes the RF parameters of the cavity.

The mechanical designs of the cavity and its helium tank (see Fig. 2), made of titanium, were optimized to limit frequency shifts due to microphonics, pressure variations and Lorentz forces without compromising reliability and manufacturing simplicity (see Table 1). Main parameters can be found in [4].

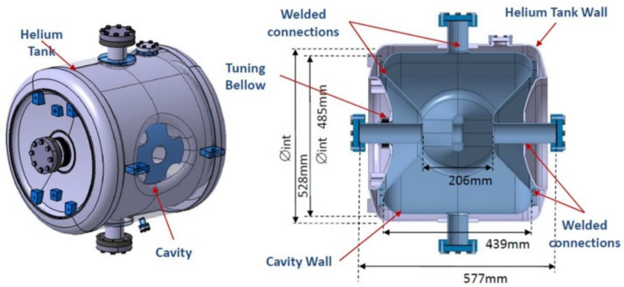

Figure 2: Drawings of the SSR with its helium jacket (tank).

Table 1: Optimized RF/Mechanical Parameters of SSR

Parameters	Value	Unit
Optimal beta (β)	0.37	
Geometrical factor (G)	109	Ω
Shunt impedance (r/Q)	217	Ω
Accelerating length (L_{acc})*	0.315	m
E_{pk}/E_{acc}	4.3	
B_{pk}/E_{acc}	7.3	mT/MV/m
Power dissipation at 6.4 MV/m	9.4	W
Sensitivity to pressure		
Lorentz factor	23-31	Hz/mbar
	-4.7 - -7.7	Hz/(MV/m)^2

*βλ definition

MULTIPACTING SIMULATIONS

Unfortunately, multipacting simulations have not been carried out during the design phase of the cavities but after fabrication. Cavity design has thus not been optimized to limit multipacting risks.

Simulations have been done with a code developed at IPNO named MUSICC3D [11]. Complex 3D geometries including several materials can be simulated. Electromagnetic field distributions have to be imported from any RF simulation code using a tetrahedral mesh (eg., HFSS, CST).

Simulations done on the MYRRHA SSR show several multipacting barriers between 5 and 20 MV/m. These correspond to first order 2 points multipacting as depicted in Fig. 3.

Additional simulations are under completion to take into account coupling antenna during vertical test.

EXPERIMENTAL RESULTS

Problem During Manufacturing

After completion of cavity manufacturing, it has been noticed that one or several welds have been forgotten on both cavities (see Fig. 4). These welds, between the cavity and the helium tank, were meant to stiffen the cavity.

Additional calculations showed that these missing welds would only affect the frequency sensitivity. Stresses during cavity preparation procedure and cold tests would not deform plastically the cavity. The cavities have thus been accepted as is to respect MYRTE project deliverables.

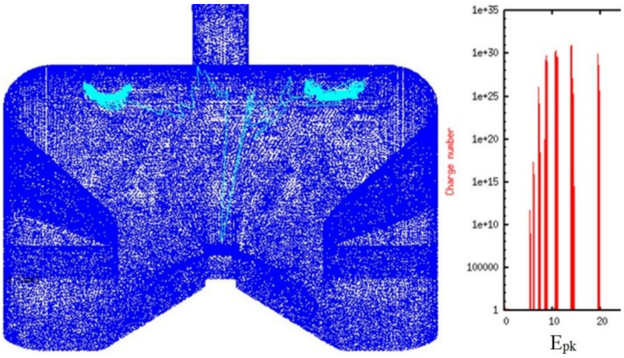

Figure 3: (left): multipacting trajectories. (right): Values of peak electric fields (E_{pk}=4.3×E_{acc}) for which multipacting resonances are calculated. The charge number on vertical axis represents the "strength" of the barrier.

Figure 4: Pictures taken with an endoscope. On top image, no welds are visible contrary to bottom image.

Cavity Surface Preparation

Both cavities have been prepared at IPNO facilities. After ultrasonic degreasing, the cavity undergoes a deep BCP (Buffered Chemical Polishing) etching of about 150µm. The acid bath temperature is kept below 18°C and the cavity is cooled down by water flowing in the helium tank. A second BCP of at least 25µm is following with fresh acid. The cavity is then rinsed at high pressure with ultra pure water and dried in an ISO-4 clean room at least during 48 hours. This represents the baseline preparation before starting specific heat treatments as planed in MYRTE project.

Vertical Test Results

Both prototypes have been tested in vertical cryostat at temperatures between 4.2K and 2K as shown in Fig. 5. As both configurations can be tested in IPNO vertical cryostat, the cavities have been tested either fully immersed in liquid helium (dunk test, all ports of helium jacket have been left opened) or in cryomodule configuration, in which liquid helium is flowing only in the helium tank.

Both prototypes show a very good Q_0 of 2E10 at low field at 2K in both configurations corresponding to a residual resistance of about 3.5nΩ (R_{BCS} = 1.6nΩ at 352MHz at 2K). The Q_0 decreases continuously and similarly for both cavities with accelerating gradient (see red square and purple circles curves in Fig. 5). The power dissipated at the nominal gradient is nevertheless below 3W well below specifications and below 5W at the fault-recovery gradient. The maximal gradient achieved by the first prototype (Amelia) is of 12.4 MV/m due to repetitive quench. For the second prototype (Virginia), a gradient of 20 MV/m (corresponding to B_{pk}=146mT and E_{pk}=86MV/m) has been reached without quenching. Unfortunately, due to the significant RF power of 200W dissipated at this gradient, we didn't go any further to reach the real limit of the cavity.

Virginia prototype has been tested two times. The first test was done with the cavity fully immersed (dunk test, red squares) and the second in cryomodule configuration (green squares). The cavity has been in between warmed up at room temperature and left under vacuum with no additional BCP or high pressure rinsing. As a result, the Q_0 at low field remains the same but a stronger Q-slope is noticeable with a very similar behaviour to a cavity affected by Q-disease. The same effect has been observed on ESS Double-Spoke Resonators (DSR) [12]. Hydrogen degassing at 650°C will be done to prevent any hydride precipitation from degrading cavity performances.

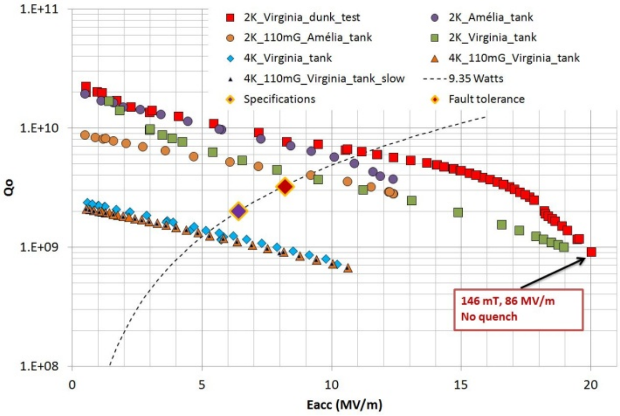

Figure 5: Summary of all Q_0 curves measured on both prototypes (Virginia and Amelia) in different configurations.

The cryostat is magnetically shielded to ensure a residual field below 20mG. The horizontal component is screened with mu-metal sheets rolled around the vacuum vessel whereas the vertical component is adjusted with three coils. The cavities can thus be exposed to different magnetic field configurations, from an optimal configuration minimizing the residual field and up to a vertical field of about 110mG. Magnetic field sensitivity of cavities can be evaluated. This test has been done for both cavities, at 2K for Amelia (purple and orange circles) and at 4.2K for Virginia (blue diamonds and orange triangles) showing respectively sensitivities of 0.6nΩ/µT and 0.45nΩ/µT. The sensitivity appears to be independent of the cooling speed through transition as the Qo curves after a fast cool-down (10.2 K/min) or a slow cool down (1.25 K/min) are perfectly superimposed (see orange and black triangles curves in fig. 5) even though the magnetic field change measured on top of the cavity is three times higher during a fast cool-down (see Fig. 6). The magnetic field shift should be proportional to the field trapped in the material through transition. A similar behaviour was observed on Spiral2 resonators as described in [13].

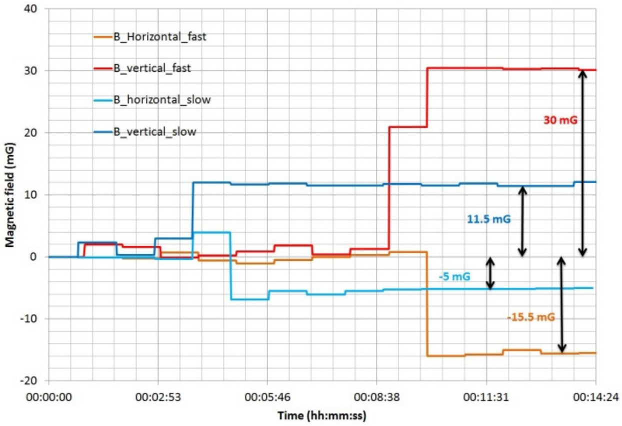

Figure 6: Magnetic field measured on top of the cavity on the vertical and horizontal axis during superconducting transition for two different cooling speeds.

Lorentz force detuning and pressure sensitivity have been evaluated at 2K for both cavities as shown in table 2. Because of the missing welds, pressure sensitivities of both cavities are well above calculated values making these cavities not usable for beam operations. The Lorentz factor is however not degraded.

Table 2: Measured Sensitivities of the SSR

Cavity/configuration	Pressure sensitivity Hz/mbar	Lorentz factor Hz/(MV/m)^2
Amelia/dunk	-251	-8.4
Amelia/tank	-180	-9.8
Virginia/dunk	-236	-8.2
Virginia/tank	-155	-7.3

CONCLUSION

Due to missing welds between the cavity and the helium tank, the two prototypes show a very high sensitivity to pressure. Frequency regulation and reliability tests foreseen in the future on the cryomodule prototype will not be relevant. Two new cavities have to be fabricated.

On the other hand, both prototypes show very good RF performances well above specifications with a basic surface preparation (BCP+HPR). As observed, hydrogen degassing will be mandatory to fully recover from Q-disease after a room temperature thermal cycle.

Heat treatment at 650°C of the cavity equipped with its helium tank will be performed by the end of this year in the new furnace recently commissioned at IPNO.

ACKNOWLEDGMENT

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