DESIGN OF THE HWR CAVITIES FOR SARAF

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Abstract

CEA is committed to delivering a Medium Energy Beam Transfer line and a superconducting linac (SCL) for SARAF accelerator in order to accelerate 5mA beam of either protons from 1.3 MeV to 35 MeV or deuterons from 2.6 MeV to 40 MeV. The SCL consists in 4 cryomodules. The first two identical cryomodules host 6 half-wave resonator (HWR) low beta cavities (β = 0.09) at 176 MHz. The last two identical cryomodules will host 7 HWR high-beta cavities (β = 0.18) at 176 MHz. Low-beta and high beta cavities have been optimized to limit electric and magnetic peak fields in the cavity, and to minimize the dissipated power. Manufacturing constraints and helium cooling were taken into consideration to minimize the risk during manufacturing and operation. Preliminary mechanical studies of the cavity, the tuning system, as well as the couplers and pick-up antennas were carried out.

INTRODUCTION

CEA is building a new accelerator facility for SARAF Phase II [1]. A key element of the project is the superconducting LINAC (SC LINAC) at 40 MeV (deuterons) or 35 MeV (protons). The beam dynamics defined the accelerating voltage, 1.0 and 2.3 MV, the β_{opt}, 0.09 and 0.18, and the flange-to-flange length for RF cavities, 280 mm and 410 mm respectively. This papers covers the resonator development for HWR cavities.

RF DESIGN

The frequency was defined to 176.000 MHz in nominal operations. The optimal β, β_{opt}, of the cavities is defined by the β that *maximizes* the R/Q ratio at 176.000 MHz. The target values are *0.091 and 0.181* ± 0.001. The accelerating fields is defined at β_{opt}. The low and high beta cavity must reach accelerating gradients of *6.5* and *7.5* MV/m respectively. Based on the literature [2] and previous CEA projects [3,4], at the accelerating gradients, we considered 70 mT and 35 MV/m as reasonable peak magnetic and electric field respectively. The power losses on the cavity walls must be as low as possible in LHe at 4.45 K.

Figure 1 shows the resonators. The most critical parts for peak electric field are the beam ports and the central drift tube. The most critical parts for peak magnetic field are the HPR ports on top and bottom, and the shape of the inner conductors. The peak magnetic field can appear either on the fillet between the HPR ports and the extremity tori, or on the inner conductor, depending on the shape of the inner conductor. For the low beta cavity, a tubular shape proved to give the best result: the peak magnetic field appear on the inner conductor. For the high beta cavity, an optimal conical shape was found. The dissipated power is mainly located on the inner conductors, where magnetic flux is the higher.

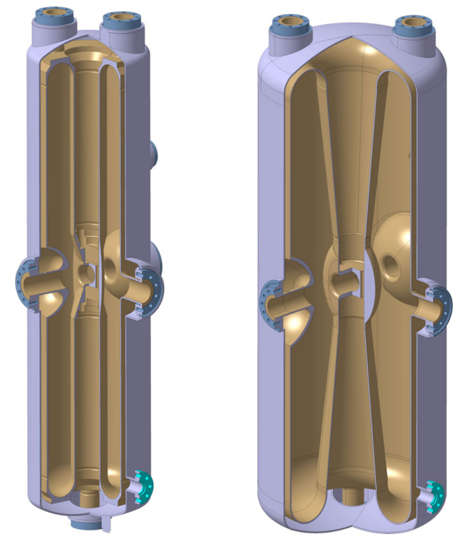

Figure 1: On the left: ¾ of the low beta cavity. On the right: ¾ of the high beta cavity.

The field maps for the low beta cavity is presented in Figure 2. Figure 3 shows the peak electric field on the beam ports and drift tube. The simulations were carried out with Ansys ED. Results for the low and high beta cavities are detailed in Table 1. RF power loss was computed for a niobium surface resistivity of 40 $n\Omega$ at 4.45 K [5].

Table 1: Parameters of the Low and High Beta Cavities

	Low β cav.	**High β cav.**
β_{opt}	0.091	0.181
Required E_{acc} (MV/m)	6.5	7.5
Epk_{max} *(MV/m)*	32.1	33.2
Bpk_{max} *(mT)*	60.9	60.5
Diss. Power@40nΩ (W)	6.16	14.4
R/Q @ β_{opt} (Ω)	189	280
Stored Energy (J)	4.9	14.4

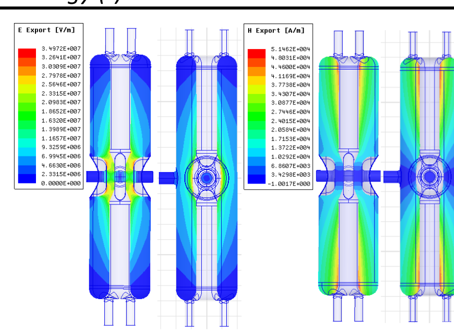

Figure 2: Electric field (left) and magnetic field (right) in the low-beta cavity.

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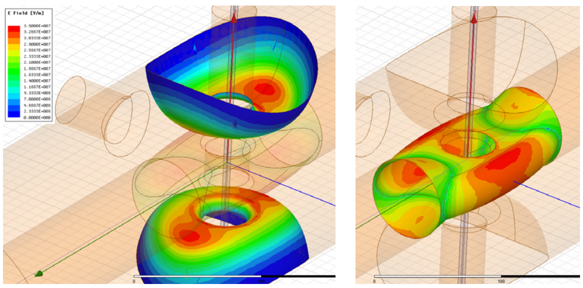

Figure 3: Electric field on the beam ports (up) and on the drift tube (down).

MECHANICAL DESIGN

Cavity and Helium Tank

In order to reduce the risk in forming and welding, we chose to build the beam ports and drift tubes in bulk niobium. This improves significantly the rigidity of the beam ports, giving far better performances to the frequency tuner system, and makes the manufacturing of these parts far easier.

The cavities will be placed vertically in the cryomodules in accordance with Figure 1. Thus, helium has to cross the drift tubes. For this reason, they are designed, taking into consideration the helium cooling. For both low and high beta cavities, two drills cross the drift tubes, to form 10 mm tubes that will allow helium to flow to the bottom part. We expect no thermal dissipation on the drift tube itself.

The HPR (High-Pressure Rinsing) ports showed to be the most critical parts with regard to pressure constraints. Indeed, the pressure deforms significantly the extremities of the tank helium, and the constraint is partly reported on the HPR ports. Therefore, we decided to build the transition between the HPR ports and the cavities in bulk niobium as well (see Figure 4).

The final mechanical simulations are shown in Figure 5 for a 2 bar pressure in the helium tank. According to the yielding stress of niobium at room temperature (40 MPa), the cavities can accept a maximal pressure in the helium tank of 2 bars without risk of yielding. No risk of shrinkage is observed at the same pressure, even with major defects.

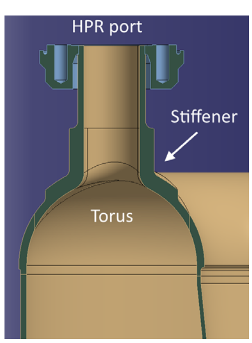

Figure 4: Bulk niobium stiffener on HPR port.

At low temperature, the yielding stress of niobium reaches 120 MPa. Simulations were computed with an external 2 bar pressure and a fixed displacement of the beam port. The tuning range target is 0-100 kHz. Knowing the sensitivity of the frequency to the tuner displacement (see Table 2), the required displacement is estimated: 0.19 mm and 0.5 mm for low and high beta respectively. These results are summarized in Table 2.

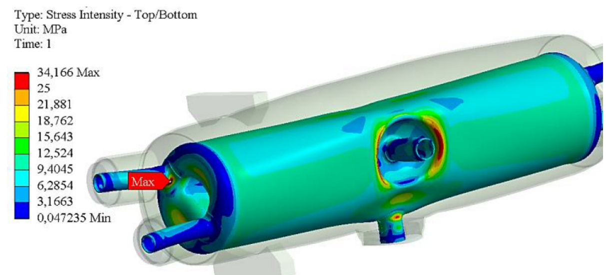

Figure 5: Stress intensity on the low beta cavity under 2 bars. The maximal stress appears on the stiffener.

Frequency Tuner System

The proposed frequency tuner system is drawn in Figure 6. It consists in compressing the beam ports as described in the previous part. The compression leading to the displacement is induced by a step motor with a worm drive that brings lever arms closer. Simulations show no risk of yielding for these displacements, nor for the cavity, neither for the tuning system.

Table 2: Mechanical Properties of the Cavities (BP: Beam port)

	Low β	High β
Acceptable Pressure (bar)	2.0	2.0
Pressure Sens. (Hz/mbar)	8.7	2.0
BP sensitivity (kHz/mm)	520	200
Required BP Displacmt (mm)	0.19	0.50
Tuning Range (kHz)	0-100	0-100

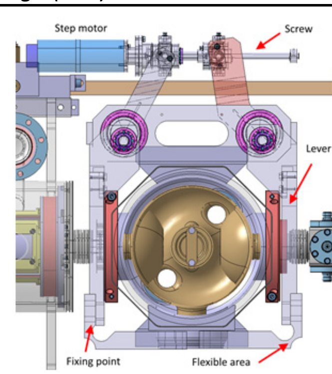

Figure 6: Cut of the proposed frequency tuning system.

POWER COUPLERS

The RF power requirements are 5 kW and 11 kW for low and high betas. The couplers were designed for a maximal RF power of 20 kW. The external diameter of the power coupler will be 36.8 mm (compatible with CF40 flanges), to be connected to a standard EIA 1 5/8“

(37.8 mm). It will be divided into two parts: a coaxial line from the cryomodule flange to the cavity flange (about 200 mm long), and a second coaxial line, outside of the cryomodule, with the warm ceramic window, diagnostics, and a thermalized forced air flow (about 100 mm long).

The antenna will be built in bulk copper, to minimize the RF power and optimize the thermal conductivity. The external wall of the coupler will be a single copper coated stainless steel wall, cooled by a thermal intercept at 60 K, at 100 mm from the cavity flange. The coupler is designed to optimize the RF matching at 176 MHz.

To compensate the thermal displacement of the cavity flange with respect to the cryomodule flange, the bellow will be chosen by the manufacturer.

PICK-UP ANTENNA

The pick-up antenna will be a loop, located in one of the HPR ports. A 3D model of the pick-up antenna is presented in Figure 7. The HPR ports have a 30-mm diameter. For the low beta cavity, and for a target output power of 1 W, the dissipated power on the pick-up is only 0.8 mW (RRR = 20). The maximum magnetic field reaches 16 A/m on the flange, i.e. 20 µT. Even considering a flange in stainless steel (with a surface resistance of 23 $m\Omega$), the dissipated power on the flange should not exceed 0.25 mW. Results are similar for the high beta cavities.

In practical, a target output power of 100 mW could be enough, depending of the LLRF requirements. In this case, the total RF power losses on the pick-up antenna could be lower than 0.1 mW.

The accurate bending of the copper wire and the weld of the extremity to the flange are the challenges for this pick-up.

VACUUM PUMPING

Simulations, using Molflow software, were done to evaluate the pressure profile along the beam axis at room temperature, before cooling down to cryogenic temperature.

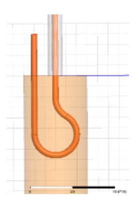

Figure 7: Simple diagram of the pick-up antenna in the HPR port.

The vacuum in the cavities will be ensured by pumping through the HPR ports and on warm sections (between cryomodules). The pressure in the 2nd cryomodule is presented in Figure 8. For comparison, simulations were carried out with a pumping through 2 HPR ports instead of 1: no improvement was observed. Figure 9 shows the simulation results on the beam axis with pumping through 1 and 2 HPR ports in the full SC LINAC. The lowest pressure is observed close to the warm vacuum pump between cryomodules (less than 1.0.10^{-7} mbar). The highest pressure is found at the output of the SC LINAC, right below the requirements (1.0.10^{-6} mbar).

Once at cryogenic temperature, pumping will not be ensured by HPR port, but only from warm sections. Simulations at cryogenic temperature have not been done yet.

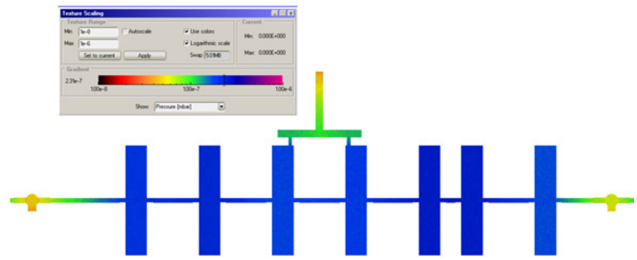

Figure 8: Pressure in the 2nd cryomodule. Vacuum is pumped between modules and in the 3rd and 4th cavities.

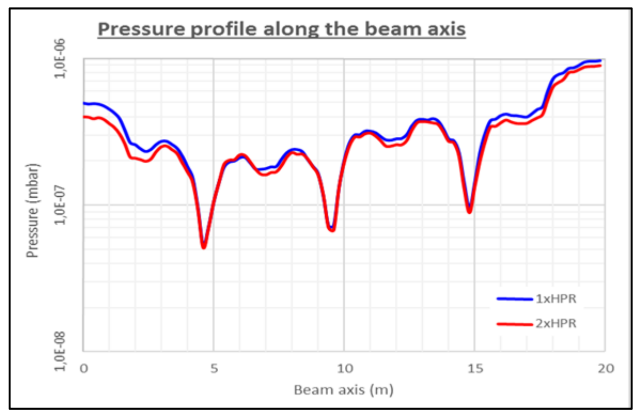

Figure 9: Pressure in the full LINAC with pumping by 1 or 2 HPR ports.

CONCLUSION

Developments on the equipped superconducting resonators are in progress at CEA for the SARAF phase II Linac. Final designs of the components will be validated in June 2016. We will then launch the call for tender for prototype manufacturing.

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