CEA PRELIMINARY DESIGN OF THE CRYOMODULES FOR SARAF PHASE-II SUPERCONDUCTING LINAC

R. Cubizolles, C. Madec, N. Bazin, P. Hardy, F. Leseigneur, T. Plaisant, J. Plouin, D. Chirpaz-Cerbat, P. Bredy, R. Bruce, CEA, Saclay, France

Abstract

CEA is committed to deliver 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 40.1 MeV. The SCL consists of 4 cryomodules and 4 warm sections with diagnostics at the end of each cryomodule. The first two identical cryomodules host 6 half-wave resonator (HWR) low-beta cavities (beta = 0.091), 176 MHz, and 6 focusing superconducting solenoids. The last two identical cryomodule welcome 7 HWR high-beta cavities (beta = 0.181), 176 MHz, and 4 solenoids. The paper will presents the preliminary design of the cryomodules.

CRYOMODULE OVERVIEW

The SARAF-Phase II cryomodule design [1] is based on CEA experience with IFMIF cryomodule. Figure 1 presents the cryomodule and its components.

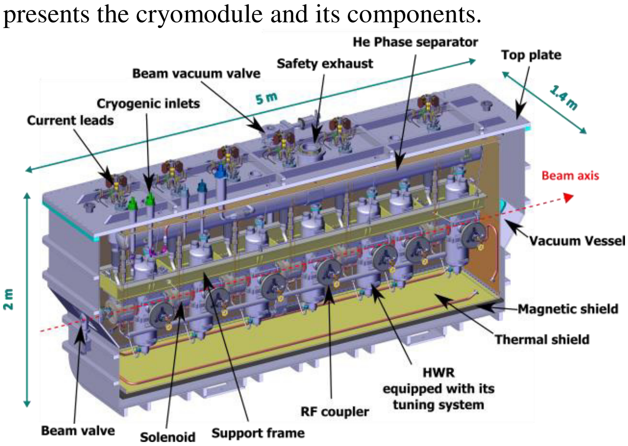

Figure 1: Overview of the low beta cryomodule with an optional cavity.

During the installation and maintenance, the cryomodules need to be moved freely in the beam corridor without disassembling any components of the accelerator line. Thus, the cavities have been placed vertically and the power coupler horizontally in order to reduce the cryomodule width.

Moreover, the cryomodules will be assembled by top loading. The cold mass will be hung on the top plate and top loaded into the vacuum vessel. Thus, interfaces are gathered on the top plate as far as possible in order to ease the assembly and conception of the cryomodule.

Beam dynamics studies have determined the number of solenoids and cavity for the two types of cryomodules and limited the length of the cavity string (cavities and solenoids) to 5 m. A free space for an optional cavity is placed between the 5th and 6th cavity of the second low-beta cryomodule. Moreover, the studies also induce a limitation on the cavity string misalignment at cold of +/- 1 mm.

Hence, due to the impact on the cavity string alignment of the support frame, top plate and vacuum vessel, these components have been designed in order to ensure the alignment specifications. Simulations and studies on the thermal and magnetic shield, phase separator, beam vacuum and assembly process were carried out, but only the studies of the components impacting the misalignment are presented in this proceeding. Following thermal and mechanical simulations were performed with the finite elements software Cast3M.

SUPPORT FRAME

Mechanical Design

In order to support the cavity string, a titanium frame for magnetic hygiene issues will be used. However, due to the heat shrinking of the support frame the cavities and solenoids cannot be directly attached on the frame [1]. Thus, C-shaped elements [2] with needle rollers are used to allow a longitudinal displacement of the cavity string independently of the support frame, and for magnetic issues, homemade C-shaped elements [3] will be used.

Then, the cavities and solenoids are fixed on an invar rod (with a heat shrink lower than titanium [1]) attached in the center of the frame to ensure their longitudinal positions.

The titanium frame is hung to the top plate by eight vertical rods and attached to the vacuum vessel by four horizontal rods made of Ti-6Al-4V, a titanium allow used for its mechanical and thermal properties. The tie rods will be heat sunk on the thermal screen at 70 K at the two third of their length to minimize the heat loads on the cold parts.

A welded circuitry will be used in order to actively cool down the support frame with helium to 4.45 K during the cryomodule cooling down process. Then, the cooling will be stopped during the nominal operation and its temperature will drift to a thermal equilibrium between 4.45 K and 70 K. No significant heat loads will be added on the cavities and solenoids since the thermal contacts between the support frame and the cavity string through the C-shaped elements are poor, and no heat shrinking between 4.45 K and 70 K is expected due to the thermo-mechanical properties of the materials.

As no barometric compensators are used to limit the axial stroke of the coupler bellows, the difference of pressure at the interface with the vacuum vessel induces a lateral force on the cavity coupler flange. Hence, the supporting system has to sustain the weight of the cavity string and the lateral forces from the power coupler while ensuring the cavities and solenoids alignment at cold.

ISBN 978-3-95450-182-3

Thermo-mechanical Simulations

Thermo-mechanical studies were performed to ensure the cavity string alignment by optimizing the profile of the support frame and the positions of the tie rods. The lateral deformations resulting from the coupler forces on the original profile were over the alignment requirement. Hence, the profile of the support frame has been stiffened in order to reduce the lateral deformations of the frame. Figure 2 presents the original and improved support frame profile. The deformations of two frame edges are monitored during the thermo-mechanical simulations in order to determine the cavity string misalignment.

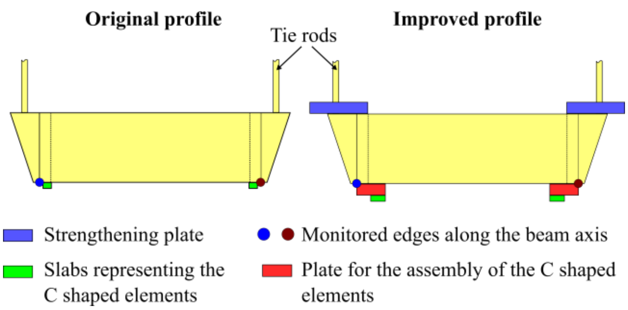

Figure 2: Original and optimized support frame profile used for the thermo-mechanical simulations.

For the simulations the extremity of the tie rods are fixed. One extremity of the tie rod is at 293 K and the other is attached to the support frame where the temperature is set at 4.45 K on the slabs representing the C-shaped elements. The tie rods are heat sunk at 70 K at the 2/3 of their length. The weight of the cavity string (estimated to 15 kN) is divided on the slabs representing the C-shaped elements, and the power coupler forces (estimated to 310 N per coupler) are applied on each cavity slabs located on the left side of the frame. Moreover, a torque is created resulting of the vertical distance (d on Figure 3) between the lateral coupler force applied on the cavity flange (point A on Figure 3) and the line define by the cavity attachment points (B1 and B2 on Figure 3). This torque can be assimilated to two opposed vertical forces with an amplitude of 155 N on the right and left slabs. Figure 3 summarizes the mechanical loads on the support frame.

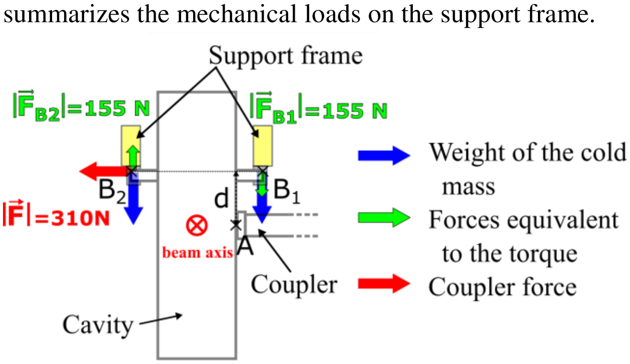

Figure 3: Mechanical loads on the support frame for the thermo-mechanical simulations.

Figure 4 presents the lateral deformations along two edges defined in Figure 2. No lateral springs are present on the C-shaped element of the right side, thus the cavity string components are in contact with the C-shaped elements and the misalignment is determined by the deformation range of the right edge. The coloured vertical lines represent the position of the strengthening bars and vertical and horizontal tie rods.

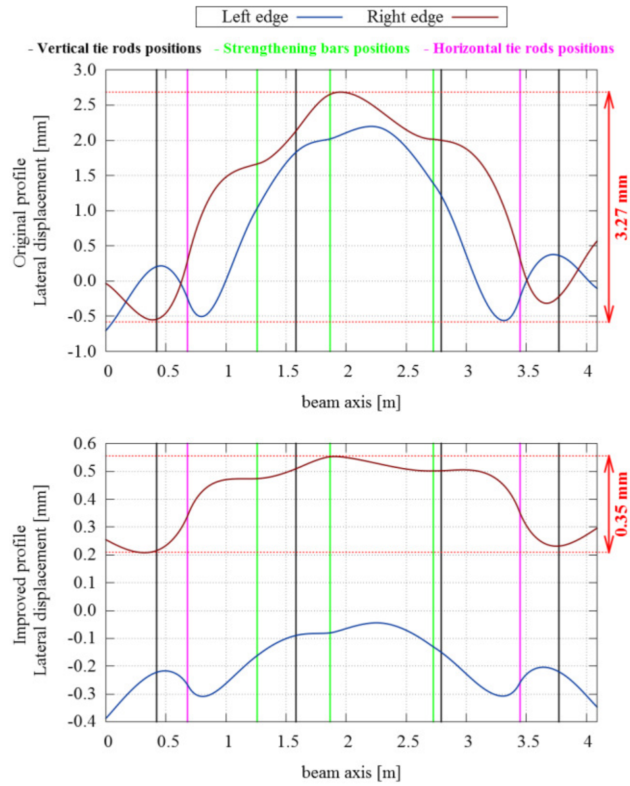

Figure 4: Lateral displacement along the monitored edges for the original (Top) and the improved profile (Bottom).

The addition of the strengthening plates divided the lateral displacement range by a factor 10 (from 3.27 mm to 0.35 mm). Elsewhere, the vertical displacement is mainly due to the heat shrinking of the vertical tie rods of 1.1 mm and the stiffness of the frame limits the deformations range to 0.15 mm.

Hence, as the heat shrinking of the vertical tie rods can be anticipated during the cavity string assembly, the total misalignment of the cavity string due to the support frame deformations is +/- 0.19 mm for the low beta cryomodule and +/- 0.16 mm for the high beta cryomodule.

TOP PLATE

As the support frame is connected to the top plate, the top plate deformations have a direct impact on the cavity string. An eccentric positions of the vertical tie rods of the support frame could imply a lateral displacement of the cavity string when the top plate is under vacuum.

Simulations of the top plate has been performed in order to determine an efficient mechanical design. The deformations on the vertical tie rods attachment points were monitored, and strengthening bars were placed in order to minimize the deformations of the top plate submitted to 0.1 MPa difference of pressure. For the simulations the external part of the top plate is fixed, and in addition of the pressure, the weight of the cold mass estimated to two tons is applied on the eight vertical tie rods attachment points.

Preliminary calculations using analytic formulas were carried out before mechanical simulations in order to determine the thickness of the top plate and the material used. The choice of stainless steel 304L and a thickness of 40 mm appears to be a good compromise between stiffness and weight.

The optimization were performed with different type of strengthening bars and rectangular bars with a width of 40 mm and a height of 80 mm were chosen for their stiffness and manufacturing properties. Four lateral and two longitudinal strengthening bars suffice to reduce the deformations under the requirement, and Figure 5 depicted the top plate deformation for the optimized design.

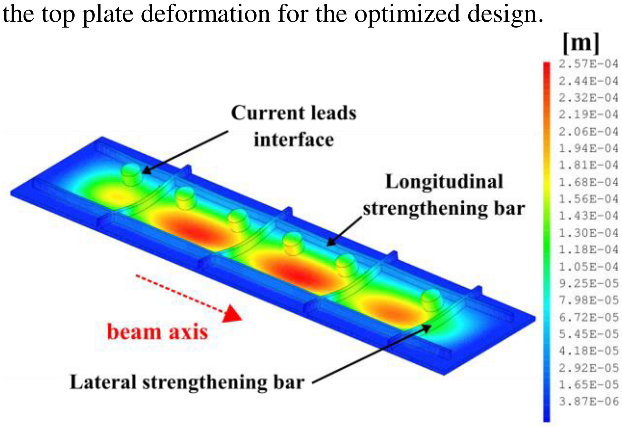

Figure 5: Vertical deformations of the optimized top plate.

For this design the misalignments of the cavity string are respectively +/- 0.08 mm and +/- 0.14 mm for the low and high-beta top plate.

VACUUM VESSEL

As the horizontal tie rods of the support frame have to be kept under tension when the cryomodule is under vacuum in order to ensure the cavity string alignment, the maximal deformations on the attachment points on the vacuum vessel are limited to 1.0 mm. Spring washers will be used in order to allow such deformations, resulting in additional cavity string lateral displacement of 0.1 mm due to the power coupler forces. Moreover, because of the maximal stroke of the coupler bellows, the vacuum vessel deformations on the coupler interfaces are limited to 2.0 mm.

As for the support frame and top plate, the number of stiffeners and their positions were optimized in order to limit the deformations from a difference of pressure of 0.1 MPa. The chosen material for the vacuum vessel is 304L for its mechanical properties and its manufacturing advantages. For the mechanical simulations, the top plate with the optimized strengthening bars was used.

Figure 6 presents the deformations for the final results of the optimisation for the low beta vacuum vessel with an optional cavity. The displacement on the horizontal tie rods attachment points and coupler interface are respectively under 1.0 mm and under 1.5 mm.

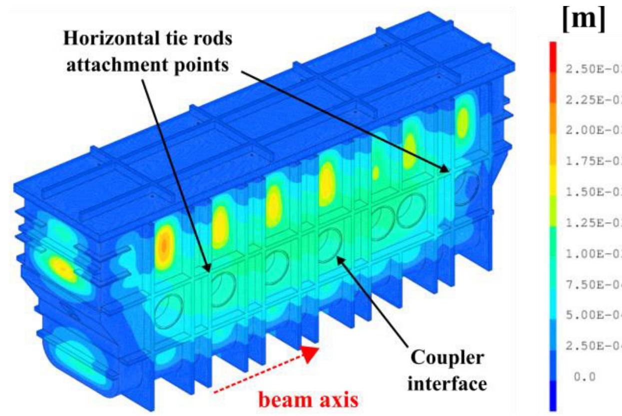

Figure 6: Total deformation of the low-beta vacuum vessel.

The cavity string misalignments due to the deformations are +/- 0.08 mm for the low-beta optimized vessel and simulations are still in progress for the high-beta vessel.

ALIGNMENT BUDGET

Considering a misalignment of +/- 0.3 mm from the manufacturing defects of the cavity string components and the alignment process errors, the misalignment from the devices in interface with cavities and solenoids is limited to +/- 0.70 mm. Hence, the total misalignment can be estimated by cumulate the misalignment provided by the studied components, and Table 1 summarizes the misalignment calculated for each components simulations.

Table 1: Misalignment from the Cryomodule Components

	Misalignment	
Components	**Low-beta**	**High-beta**
Support frame	+/- 0.19 mm	+/- 0.16 mm
Top plate	+/- 0.08 mm	+/- 0.14 mm
Vacuum vessel	+/- 0.08 mm	tbd
Conception and alignment process	+/- 0.3 mm	+/- 0.3 mm
Cumulated misalignment	**+/- 0.65 mm**	**<+/- 0.60 mm**

The misalignment of the low-beta cryomodule is under value of +/- 1 mm. The high-beta cavity string misalignment will be calculated before October 2017, date of the Critical Design Report.

REFERENCES

[1] C. Madec and al., Design of the superconducting linac for SARAF, Whistler, BC, Canada, SRF 2015.

[2] C. Pagani, Advance in cryomodule design and new approaches, Berlin, Germany, SRF 1999.

[3] N. Bazin, Magnetic aspect of the IFMIF cryomodule, Tsukuba, Japan: TTC meeting, December 2014.

ISBN 978-3-95450-182-3