DESIGN OF THE LOW-BETA, QUARTER-WAVE RESONATOR AND ITS CRYOMODULE FOR THE SPIRAL 2 PROJECT

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Abstract

The SPIRAL 2 project, to be built in GANIL, consists of a 40 MeV linear accelerator for 5 mA of deuterons and a target-source complex for the production of exotic isotopes. The accelerator is also optimised to accelerate q/A = 1/3 ions up to 14.4 MeV/u. The three stages of the linac are a RFQ (up to 0.75 MeV/A), a low beta (0.07) and a high beta (0.12) sections consisting of quarter-wave, 88 MHz superconducting resonators. This paper focuses on the low beta cavity and its cryomodule. The cavity nominal accelerating gradient is 6.5 MV/m in operation. RF properties of the cavities are dealt with, as well as the mechanical ones: helium pressure effects, tunability, vibrations. The cryomodule is designed so as to save longitudinal space and therefore is partly assembled in clean room.

DEFINITIONS

In all this paper, the accelerating field E_{acc} is defined as $E_{acc}= Vacc/(\beta_{opt}\lambda)$, where $V_{acc}= \int |E_z(z)e^{i\omega z/\beta c}dz|$. The z axis is the beam propagation axis and the y axis the vertical one.

CAVITY RF OPTIMISATION

RF calculations were performed using Ansoft HFSS v8.5 and Vector Fields SOPRANO v8.7. The nominal accelerating field is high, therefore the main purpose of the optimisation is to reduce the peak fields over accelerating field ratios at least below 10 mT/(MV/m) and 40 (MV/m)/(MV/m) for the magnetic and electric fields respectively (the operating field is 6.5 MV/m).

Cavity shape

The peak magnetic field is located at the top of the conical stem and is directly related to its radius. Using a conical stem allows to lower the magnetic field at the top while keeping a relatively thin stem at the drift tube level. The peak electric field is located on the central drift tube (figure 1) and is related to the radius of curvature of the drift tube and to the distance between the drift tube and the cavity wall.

A special attention is given to the shape of the cavity so as to ease all chemical treatments and rinsing operations: the top is rounded and the bottom is removable, to help fluids evacuation.

Beam axis position is kept low enough to minimize the B_x field component, but high enough to limit the value of the magnetic field in the bottom gasket, which cannot be cooled efficiently. Beam dynamics calculations [2] proved it not necessary to shape the drift tubes in order to lower the B_x and E_y field components. RF calculations indicate that this shaping would be very efficient.

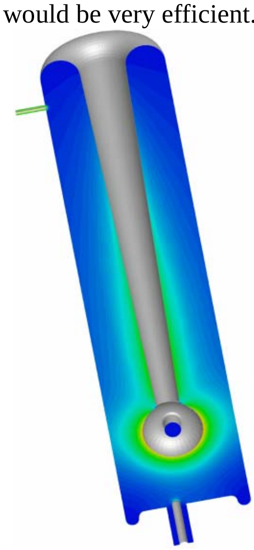

Figure 1: 88 MHz, β=0.07 cavity shape. Field shown is |E| at nominal coupling.

The resonance frequency is adjusted using the height of the cavity. The final dimensions of the cavity are about 960 mm high for an internal diameter of 230 mm.

The main RF parameters of the cavity are presented in table 1.

Table 1: Main Specifications

Resonance frequency	87.931 MHz
Optimal β	0.070
E_{peak}/E_{acc}	5.00
B_{peak}/E_{acc}	8.75 mT/(MV/m)
R_s/Q	632 Ω
Quality factor Q_0	$2.2\ 10^9$
Cavity losses (@ E_{acc}=6,5 MV/m)	1.75 W
Gasket losses (@ E_{acc}=6,5 MV/m)	26 mW

Power coupling

The coaxial RF power coupler is connected to the bottom cap in vertical position. There are several advantages to do so: it avoids adding a helium tank feedthrough, and as the magnetic field in this region is weak it is the most suited area to avoid coupler heating.

Radial position and coaxial diameter of the coupler have been optimised with a $6.6\ 10^5$nominal Q_{ext} for deuterons. The 50 Ω coupler final diameter is 36 mm and the position offset is 20 mm away from the cavity axis. The coupler penetration inside the cavity is 10 mm.

Multipactor computations using MUPAC [3] showed no multipacting barrier whatsoever in the 0 to 20 kW range (travelling wave mode).

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CAVITY MECHANICAL OPTIMISATION

Mechanical computations were performed using CEA *CASTEM* [4] and EDS *IDEAS* codes. When combined RF and mechanical computations were necessary (e.g. for helium pressure sensibility and tuning system calculations), deformed meshes have been generated using the mechanical codes and then transferred using the *IDEAS* "universal" format into the *SOPRANO* RF code. This method allows solving full 3D mechanics/RF coupled problems. An alternative method using a reference RF computation as a basis for Slater perturbation method computations was applied in the *CASTEM* mechanical code on deformed meshes.

The cavity is made of bulk niobium. The wall thickness is optimised with respect to helium pressure and tuning sensibilities as indicated below. These studies result in a 4 mm niobium thickness.

Bottom shape

A strong requirement is the use of a stainless steel helium tank, which implies the use of a stainless steel flange for the removable bottom cap.

The bottom cap shape is optimised to take into account several conflicting factors:

- to resist a 2.5 bars pressure (qualification tests);
- to keep the gasket in a low magnetic field area;
- to keep the power coupler in an optimal position to minimize its penetration in the cavity;
- to resist a thermal shock during cooldown and brazing operations (niobium and stainless steel thermal shrinking coefficients are very different).

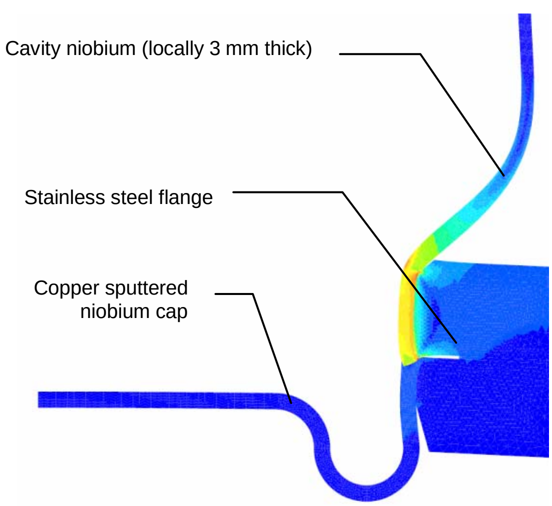

Figure 2: Von Mises stress and deformation distributions in the bottom plate after a thermal shock at 70K.

The result is the S shape bottom presented on figure 2. This shape is the best compromise between mechanics and RF aspects. Thermal shocks on this flange geometry using a plastic deformation model have been computed and checked against a similar flange configuration taken from the SOLEIL HOM couplers which has been built and tested.

The material chosen for the bottom is niobium-sputtered copper, for thermal considerations mainly.

Helium pressure sensibility

The cavity sensitivity to helium pressure variations has been checked. The goal was to keep the frequency shift below 10% of the bandwidth, which means a sensitivity of -13 Hz/mbar maximum if the pressure stability is 1 mbar or better.

The pressure effects can be divided into two contributions: first the vertical displacement and deformation of the stem and toroidal top assembly into the cavity, and second the horizontal displacement and deformation of the half drift tubes into the cavity. The first component is the main one (about 80%) if one considers a bare cavity.

Therefore, various mechanical stiffeners have been studied, the best of which (see figure 3) decreases the pressure sensitivity as low as -1.0 Hz/mbar if necessary.

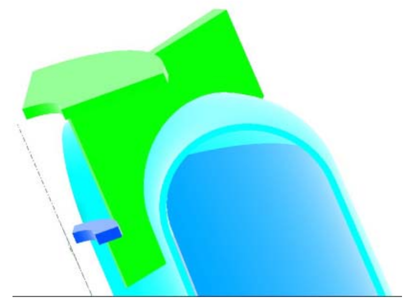

Figure 3: Strengthening structure for helium pressure frequency shift minimization.

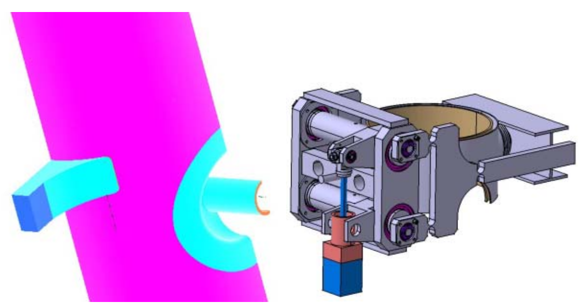

Figure 4: Tuning system. Left: shape of the applicator on the cavity. Right: Overview of the tuning system installed on the cavity.

Tuning system

Considering the very small room available, it has been decided not to tune the cavity using the beam tubes. The cavity is thus tuned by deforming its shape in the direction perpendicular to the beam axis (see figure 4). An optimal height of the pod has been found by numerical simulation. The shape of the tuner has also been optimised in order to decrease stress while keeping the tuning sensibility as high as possible. It has also been shown that the tuning range is better (for a maximum admissible stress) if the cavity is 4 mm thick than if it is 3 mm thick. Nevertheless, if a lower part of the cavity body (between the bottom flange and the drift tubes) is kept thinner (3 mm), the tuning range is even enhanced

(25%), because the resulting flexibility helps reducing stress.

The final tuning range of the system is ±24.2 kHz for a 400 MPa Von Mises stress (which is considered to be the niobium maximum admissible stress at 4 K).

Microphonics

Modal computations showed that microphonics are a potential cause of trouble. The lower mode resonance frequency is around 60 Hz and this frequency cannot be raised significantly whichever stiffener is used. Thus, if the vertical cryostat tests show it is necessary, a mechanical damper will be installed inside the stem [5].

CRYOMODULE OVERVIEW

Each cryomodule contains a single cavity. This choice eases conception, maintenance and alignment tasks.

The beam (cavity) vacuum and the isolation vacuum are separated.

The cryomodule is box-shaped, with one door on each side for easy access. This helps the clean room assembly, the assembly of the very short beam tubes extremities, of the tuning system, etc. The 70 K thermal screen has the same box shape, and is made of three separated, bolted parts.

Clean room assembly includes the cavity, power coupler, beam tube extremities and bellows, end valves and positioning of all these elements inside the opened cryomodule.

Special care has been taken to keep the distance between cavities as low as possible, as required by beam dynamics. To do so, the bellows and beam tube between 4 and 300 K have been kept as short as afforded by the cryogenic system, the number of welding has been reduced, and flanges geometry adapted to gain space.

The thermal load on the 70 K screen is around 20 W (1 W through the beam tube). From 70 K to 4 K the load is around 15 W. The thermal load at 4 K through the RF power coupler is around 1 W.

The operating temperature is 4.5 K. The helium tank is made of stainless steel.

The tuning system's stepping motor will be either kept in the cryomodule or put outside. The gear box will be kept inside the cryomodule in both cases.

Provision is made for the positioning of a vibration damping device in the conical stem if the need arises.

Alignment of the cavity in the cryomodule will be performed using Ta6V rods. There are ten such rods, four horizontally placed at the top of the helium tank and four at the bottom, and the two others vertically. The horizontal rods are crossed by pairs so that the cavity doesn't rotate; together with the symmetric position of the horizontal rods it avoids any movement of the cavity inside the cryomodule during cooldown. The vertical rods are placed in such a manner that the thermal shrinking of the cavity's niobium and helium tank's stainless steel are compensated by the rod's one during cooldown, to ensure that the position of the beam axis is not modified. External references of the cavity position will allow the alignment of one cryomodule with respect to the others.

Elements not in contact with liquid helium, like the bottom cap and the coupler port, are connected to a small liquid helium reservoir located beneath the cavity through copper breads.

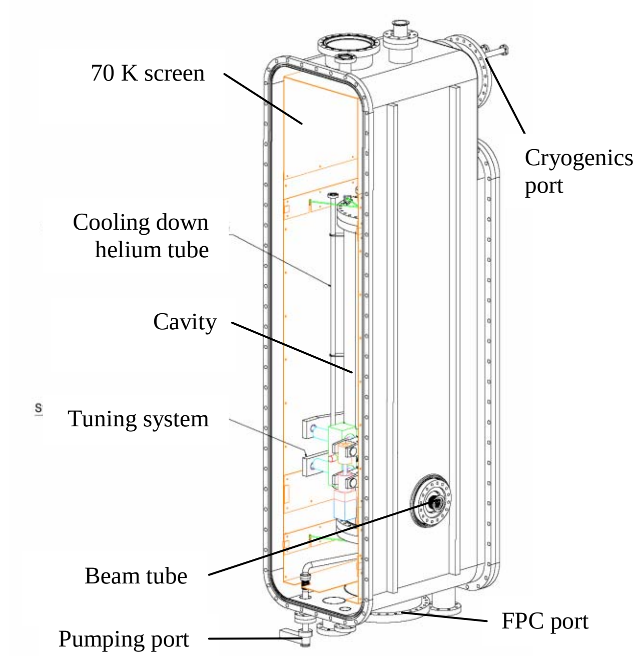

Figure 5: Cryomodule general scheme.

PERSPECTIVES

A prototype of the cavity is presently being built. This prototype is only very slightly different from the final cavity: the niobium thickness is only 3 mm, and the bottom plate is flat and made of niobium-titanium alloy. No helium tank is included, as it will be tested in a vertical cryostat.

This cavity should be ready for testing during the autumn of 2004.

It is envisioned to build a pre-series cryomodule during 2005.

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