R&D ON SPOKE-TYPE CRYOMODULE

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Abstract

Within the framework of the high intensity proton accelerators projects EURISOL and XADS, we have started the study of a cryomodule with spoke cavities and ancillary equipments : power coupler, focusing elements (superconducting quadrupoles), cold tuning system … The purpose is the fabrication of a whole spoke cryomodule to be tested under proton beam.

This paper describes the studies done on β=0.15 spoke cavities and gives the first layout of the cryomodule

1 INTRODUCTION

In several projects using high-intensity proton accelerators (EURISOL [1], XADS), spoke cavities are foreseen to be used as accelerating devices for the intermediate-energy section of the accelerator. In this context, a crucial point is to prove the feasibility of these structures by dedicated R&D programs.

For this purpose, we have started preliminary studies on β=0.15 spoke cavities, which have been designed for the energy range 5–18 MeV [2], and on their associated power coupler, helium tank and cold tuning system. In parallel, we are working on a preliminary design of a cryomodule, which will be composed of two fully equipped spoke cavities and two quadrupole doublets.

2 β=0.15 SPOKE CAVITY

Based on the study of the β=0.35 spoke prototype [3-4], we have designed a 352.2 MHz, 2-gap, β=0.15 spoke cavity. This cavity integrates a power coupler port (see subsection 2.3). Electromagnetic and mechanical simulations have been performed using respectively MAFIA and ACORD-CP software.

2.1 Geometry

The overall design of the cavity is quite identical than the β=0.35 prototype one (see 3D drawing in Figure 1) : the base of the spoke bar is cylindrical and the center part has a racetrack shape.

Main changes have dealt with the decrease of the beam tube diameter (from 60 to 50 mm) and the integration of the power coupler port. While decreasing the tube diameter, we have checked that it always matched our beam dynamic criteria (i.e. beam tubes aperture ≥10 times the rms beam diameter, see [2]). Moreover, this decrease led us to have almost the same RF parameters (i.e. concerning the E_{pk}/E_{acc}, B_{pk}/E_{acc} and voltage gain per cavity active length ratios). Table 1 summarizes the major dimensions of the cavity.

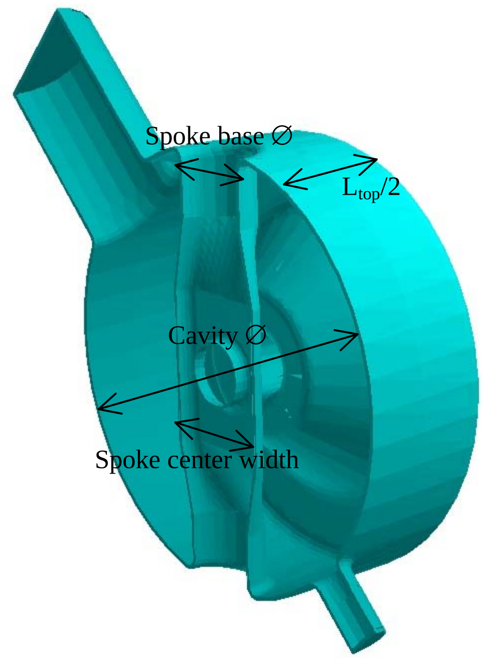

Figure 1: Cross section of the cavity.

Table 1: Dimensions of the β=0.15 spoke cavity (in mm)

Cavity diameter	354
Top cavity length	217.5
Spoke base diameter	72.5
Spoke center thickness	28
Spoke center width	98
Gap-center to gap-center length	64
Iris-to-iris length	85
Tube length (from iris to flange)	150
Power coupler port diameter	103
Beam tube aperture	50

2.2 RF parameters

We used the same numbers of mesh points (~ 4000000, 2.2 mm mesh size) for both β=0.15 and β=0.35 cavities simulations in order to have the same accuracy on the electric and magnetic fields values to compare their RF performances (see Table 2). Conventions used for the definition of the parameters are described in [4].

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Table 2: RF parameters of both spoke cavities

	β=0.15	β=0.35
Quality factor Q_0 @ 4K	1.4 10^9	1.9 10^9
r/Q_0 (Ω)	101	220
Geometrical factor G (Ω)	72	101
E_{pk}/E_{acc}	3.56	3.06
B_{pk}/E_{acc} (mT/MV/m)	7.59	8.28
E_{acc} @ E_{pk}=25 MV/m (MV/m)	7.02	8.18
Maximum voltage (MV)	0.60	1.64
Optimum beta	0.194	0.363

2.3 Power coupler

Preliminary study has been done to set the outer diameter of the port as well as the antenna diameter by performing analytical calculations of multipacting. Scaling laws gives the power levels of the first 1-point multipacting barriers for a given impedance and frequency [5]. Results for several outer diameters of a 352.2 MHz-coupler are shown in Table 3.

Table 3 : Power levels (in kW) for 50 Ω (in blue) and 75 Ω (in black) impedances

Order	∅50		∅70		∅90		∅100	
1	24	36	91	137	249	373	379	569
2	16	25	63	94	172	258	262	393
3	9	14	36	54	99	148	151	226
4	6	8	21	32	58	88	89	134
5	3	5	13	20	36	54	55	83
6	2	3	9	13	24	36	36	55
7	2	2	6	9	17	25	26	39
8	1	2	5	7	13	20	20	23

The power coupler is designed for a 10-mA proton beam. The beam power needed in the intermediate section of the Linac is between 4 kW (first β=0.15 cavities) and 14 kW (last β=0.35 cavities). Power levels, where multipacting phenomena could appear until 28 kW (twice the maximum nominal power), are underlined in yellow in Table 3. It clearly appears that bigger are the port and the impedance, lower the multipactor risks are. Moreover, it seems better to choose 75 Ω instead of 50 Ω for a better thermalization.

So, we hold the following caracteristics for both β=0.15 and β=0.35 cavities :

- Impedance : 75 Ω
- Outer diameter : 103 mm (idem LEP coupler)
- Antenna diameter: 29 mm

2.4 Mechanical study

Simulations were performed for vacuum loads of 1 and 2 bars (see results in Table 4). As for the β=0.35 prototype, stiffening supports are needed to be near the yield strength limit (σ=50 MPa @ 300 K).

Table 4: Structural analysis @ 2 bars (both flanges fixed).

	No support	8 supports
Peak Von Mises stresses (MPa)	290	54
Peak displacements (mm)	0.65	0.09

3 CRYOMODULE CONCEPT

Preliminary study of a test-cryomodule has been realized. It will be composed of 2 fully equipped spoke cavities (cavities, helium tank, power coupler, cold tuning system ...) with 2 SC quadrupole doublets, inspired from the "superferric" quadrupoles developed in Legnaro [6]. It should allow us to chose between several assembling and thermalization options.

3.1 General layout

The overall dimensions of the cryomodule are around 2.4 meters long and 1 meter diameter. The general layout of the module is presented in Figure 2.

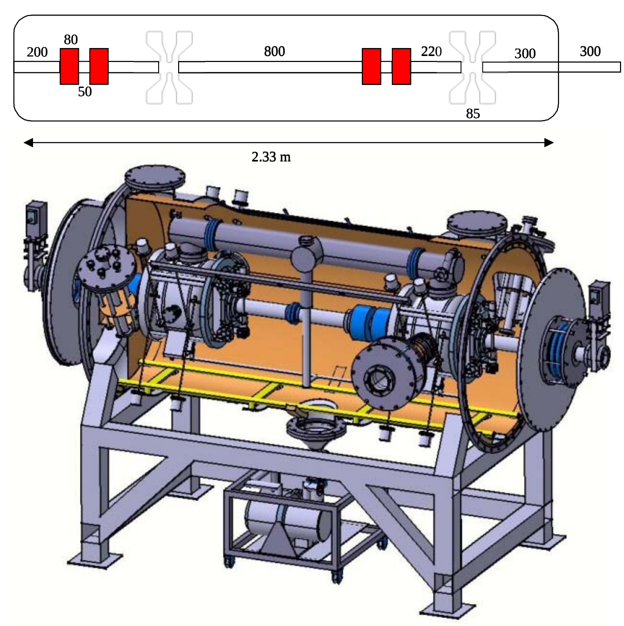

Figure 2 : Cryomodule general layout, and 3D design using CATIA V5 CAD software

Cavities are hold by 8 epoxy supports (alignment operations are performed from outside). Cavities and quadrupoles are cooled down into a boiling helium bath (4 K, 1 atm). The fluids feed-box and the pumping system of the vacuum vessel take place outside the cryomodule (respectively above and under). In contrast, due to the reliability requirements and the consequence on the focusing design [2], large space is available between both cavities and may be used to insert, the cavities vacuum system and diagnostic instruments. For economical reasons, stainless-steel flanges and helium tanks are foreseen.

3.2 Cryomodule assembly

Thanks to the short length of this cryomodule, two assembly options are possible. The first one is to mount the whole cryomodule in a clean room (LEP2 cryomodules assembly has been taken as a reference). For this purpose, apertures are foreseen into the vacuum vessel. The other option could be to perform assembly of the cavities-quadrupoles-drift tubes-and-couplers system in clean room only. It would be set on two trolleys (which can be dismantled), then, fully equipped with the associated tanks and cryogenic supply manifolds and, at last, slide into the cryomodule (see Figure 3).

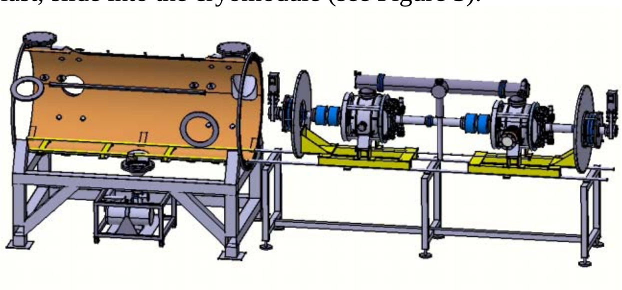

Figure 3 : Assembly of the cryomodule

Concerning the thermal shielding, two options are also considered. The first one is to put an aluminum or copper shield cooled with a liquid nitrogen circuit at 80 K. The other one is more suitable for cryomodule assembly inside a clean room. It consists in performing the shielding of the different elements (cavity, quadrupole …) with multi-layer insulation blankets once the cryomodule is getting out of the clean room.

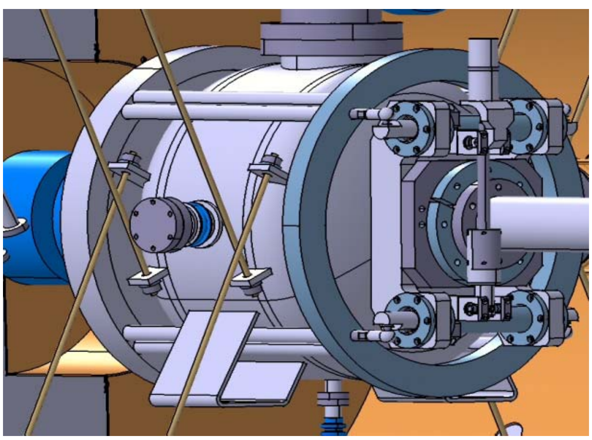

Figure 4 : The cold tuning system (CTS)

3.3 Cold tuning system (CTS)

The CTS is similar to those designed for SOLEIL synchrotron cavities and 700 MHz elliptical cavities for proton [7]. Due to the position of the power coupler on the spoke cavities body, the helium tank can not be used as a rigid structure during the tuning process. Thus, tuning efforts are applied on both sides of the cavity by means of Titanium compression rods fixed on a rigid flange at the opposite side of the CTS (see Figure 4).

4 CONCLUSION

The study of the β=0.15 spoke cavity is nearly achieved, and a preliminary version of a full cryomodule is proposed. The fabrication of such a module could allow testing different technological solutions, especially for the assembling and the choice of the thermal shielding.

Moreover, one great advantage of this cryomodule relies on the fact that it can be quite easily tested under beam. Simulations [2] show that such a module can be installed for example behind the IPHI injector facility [8], without the need of any specific matching section. With such an experiment, it should be possible to check the technological choices adopted, and to start a campaign for testing the reliability of all the components (cryogenic system, vacuum, 18 kW power sources). This point is of crucial importance in the context of the XADS project, which aims to design an accelerator where the failure of most of the components can be accepted.

5 REFERENCES

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