DESIGN AND INDUSTRIAL FABRICATION OF β=0.35 SPOKE-TYPE CAVITY

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Abstract

The design of the first β=0.35 spoke-type cavity was recently achieved, leading us to proceed with its industrial fabrication by the French company CERCA at Romans.

This paper describes the geometric and mechanical optimizations of this cavity prototype and especially the fabrication process.

1 INTRODUCTION

Since 2001, we have started in the IPN (Institut de Physique Nucléaire) the study of spoke-type cavities for high-intensity proton accelerators projects : EURISOL [1] (EURopean Isotope Separation On-Line) and XADS [2] (eXperimental Accelerator Driven System). Beam dynamic simulations [3] led us to chose both β=0.15 and β=0.35, 2-gap, 352.2 MHz spoke cavities to cover the energy range : 5 MeV (i.e. RFQ output energy) to 80 MeV (i.e. β=0.47 elliptical cavities input energy).

Integration of such cavities into the intermediate energy part of proton Linacs [4-6] (typically between 5 and 100 MeV) instead of classic warm devices represents an exciting challenge with regard to many providing advantages :

- efficiency (almost 100% RF power into the beam),
- reliability (large beam tubes aperture for higher safety margin for structures activation),
- flexibility (independent RF power sources).

2 SPOKE DESIGN

The optimization of the cavity shape has been done in order to minimize the E_{pk}/E_{acc} and B_{pk}/E_{acc} ratios (i.e. the electric and magnetic peak surface fields over the accelerating electric field) while taking into account the feasibility of the spoke fabrication [7]. Calculations have been performed using MAFIA software [8].

2.1 Main parameters

Before doing the electromagnetic cavity optimization, basic parameters have been chosen in order to match XADS general requirements :

- 352.2 MHz frequency (i.e. IPHI-RFQ frequency)
- β=0.35 (transition with the 704.4 MHz, β=0.47 elliptical cavities)
- 2-gap (higher energy acceptance as compared to multi-gap structures)
- Beam tubes aperture=6 cm (≥10 times the rms beam diameter)

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2.2 Dimensions

Optimizations led to the final shape shown in Figure 1. Main caracteristics are :

- Spoke bar length=1/3 wall-to-wall distance
- A cylindrical spoke base (minimum B_{pk}/E_{acc} value)
- A racetrack spoke center (maximum transit time factor)

Table 1 summarizes the major dimensions of the cavity.

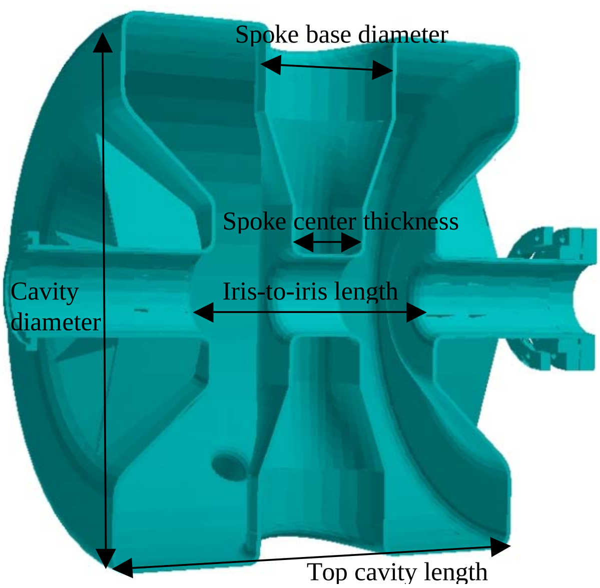

Figure 1 : Cross-section of the spoke cavity.

Table 1: Major dimensions (in mm)

Cavity diameter	408
Top cavity length	354
Spoke base diameter	118
Spoke center thickness	67
Spoke center width	147
Gap-center to gap-center length	150
Iris-to-iris length	200
Tube length (from iris to flange)	150
Beam tube aperture	60

One can note that we used the following conventions :

- Iris-to-iris length=2/3βλ
- Gap-center to gap-center length=βλ/2

2.3 RF parameters

Results of the MAFIA calculations are shown in Table 2. We used approximatively 4000000 mesh points (corresponding to a 2.2 mm mesh size).

The accelerating electric field E_{acc} is scaled with respect to the iris-to-iris length. The quality factor has been calculated assuming a residual resistance of 10 nΩ. The r/Q_0 value was defined as follows : $r/Q_0=V_{acc}{}^2/\omega P_{dissipated}$.

Table 2: RF parameters

Quality factor Q_0 @ 4K	$1.9\ 10^9$
r/Q_0 (Ω)	220
Geometrical factor G (Ω)	101
E_{pk}/E_{acc}	3.06
B_{pk}/E_{acc} (mT/MV/m)	8.28
E_{acc} @ E_{pk}=25 MV/m (MV/m)	8.18
Maximum voltage (MV)	1.64
Optimum beta	0.363

3 MECHANICAL STUDY

Based on the designed spoke cavity using MAFIA, we have done a structural analysis [7]. Calculations have been performed with ACORD_CP software [9]. Material properties of Niobium used were :

- Density=8560 kg/m^3,
- Young's modulus=107000 MPa,
- Poisson ratio=0.359.

3.1 Calculations under vacuum load

Numerical runs were performed with the cavity subjected to an external pressure of 1 and 2 Bars (boundaries conditions : both beam tubes end fixed). As illustrated in Figure 2, the cavity has been stiffened by adding 8 Niobium supports on both end walls (thickness : 3 mm as the whole cavity).

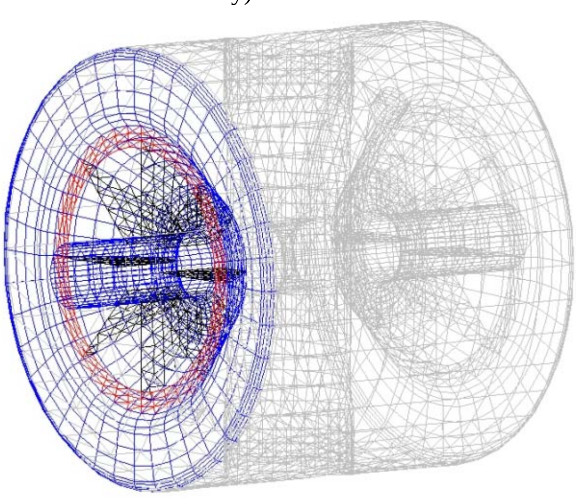

Figure 2 : Spoke cavity with the stiffeners (in black) and the ring (in red).

Due to the fabrication process (see Section 3), a 2 mm thick Niobium ring was also added on the top part of the stiffeners.

Results of the calculations are summarized in Table 3.

Table 3: Von Mises stress and displacements @ 1 Bar

Peak Von Mises stress (MPa)	35.5
Peak displacements (mm)	0.06

The maximum constraints are localized on the stiffeners base (i.e. at the beam tube junction) as illustrated on Figure 3. It seems not to represent a problem for the tuning or the rigidity of the cavity. One can note that constraints on the other parts of the cavity (i.e. the reentrant part and the beam tube) stay below 20 MPa.

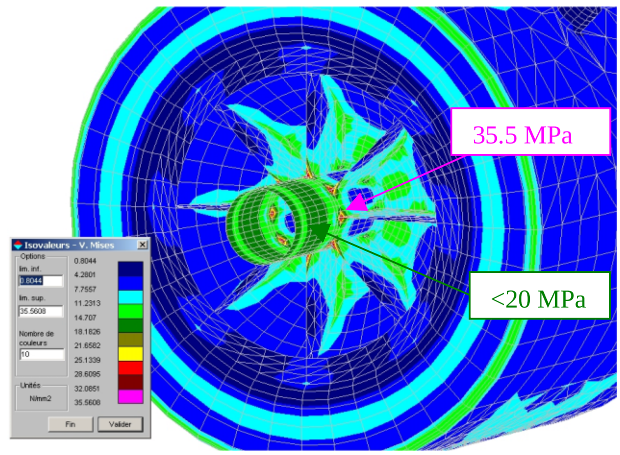

Figure 3 : Von Mises stresses @ 1 Bar. Peak stress in pink.

3.2 Tuning and mechanical vibrations

The yield strength limit (i.e. σ=50 MPa @ 300 K) was reached for a maximum displacement of each end wall of 0.4 mm. The corresponding frequency shift expected is between 300 kHz and 400 kHz. It gives us the frequency range to tune the cavity.

Calculations of the mechanical vibrations modes were performed by fixing both beam tubes end (see Table 4).

Table 4: First mechanical vibrations modes (in Hz)

Mode 1	97
Mode 2	149
Mode 3	287
Mode 4	303
Mode 5	336

The two first modes seem not to be dangerous (mode 1 : torsion around the beam axis & mode 2 : oscillation along the beam axis). They should not cause a frequency change. Other modes are longitudinal modes with a deformation of the cavity.

4 FABRICATION

Within the framework of the collaboration between FRAMATOME-ANP [10] and the CNRS [11], IPN and CERCA have started a tight collaboration to build our first spoke cavity prototype. This French company, ISO 9000 certified, is well-known for its ability in fabricating cavities [12].

The prototype is under construction and expected to be delivered at the end of June 2002. For the fabrication we used 3 mm thick Niobium sheets (RRR>250) coming from Tokyo Denkai Co, Ltd.

All the cylinders (i.e. the beam and coupler tubes, the spoke bar and the body) are fabricated by roll-welding. Each weld is made with an electron beam welding machine under high vacuum ($<10^{-5}$ mbar).

The flanges are carved directly into Niobium rod (this allows us to anneal the cavity without caring for diffusion problems into the furnace). Then, they are welded to the beam tubes.

The walls are made by spinning and the iris hole is done by extrusion. The stiffeners are welded on the beam tubes (8 grooves are made on the tubes to set precisely the supports). Then, the stiffeners-beam tubes set is welded on the wall (see Figure 4). At last, the stiffeners are welded by spot on the re-entrant part of the wall (note that a ring is added on the top part of the stiffeners, as shown in Figure 2)

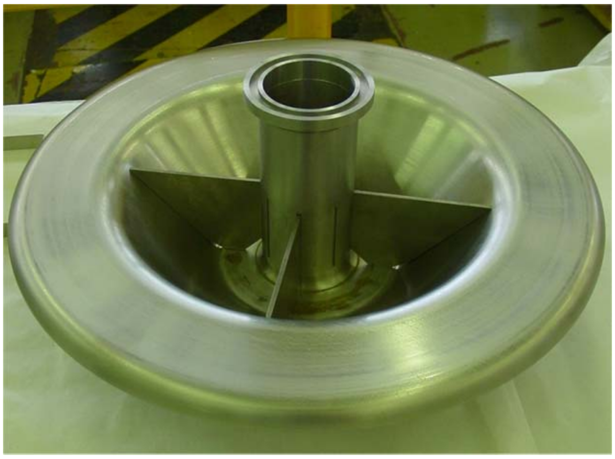

Figure 4 : Wall with stiffeners

The spoke bar is realized by squeezing the central part using a forging press (see Figure 5).

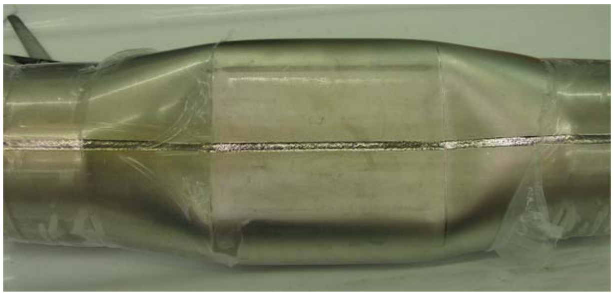

Figure 5 : Spoke bar after forming

After doing the beam hole, a rim-like tube is welded on the center.

Finally, these pieces are welded on the cavity body.

Before each welding, pieces are cleaned (BCP, high pressure rinsing and drying under ultra-pure nitrogen). Dimensional controls are realized on each stage of the fabrication process to control a possible buckling due to the welding.

5 CONCLUSION

The β=0.35 spoke cavity fabrication is under progress. Its delivery is expected for the end of June 2002. Then, we have planned to test it in a new vertical cryostat this summer. This first prototype will allow us to validate the design (with respect to electromagnetic and mechanical properties) but also the fabrication process.

In parallel, we have started the study of β=0.15 spoke cavity with a power coupler and its helium tank [13]. In near future, they should be integrated in a fully equipped cryomodule which might be tested on line with the IPHI injector [14].

6 ACKNOWLEDGMENTS

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7 REFERENCES

[1] http://itumagill.fzk.de/ADS/TWG/TWG ROADMAP - Part I.pdf
[2] http://www.ganil.fr/eurisol/
[3] J-L. Biarrotte et al., "High intensity proton SC Linac using spoke cavities", these proceedings.
[4] K.W. Shepard et al., "SC driver Linac for a rare isotope facility'', RFSC 99, Santa Fe, November 1999. http://laacg1.lanl.gov/rfsc99/WEA/wea002.pdf
[5] R.W. Garnett et al., "Conceptual design of a low-β SC proton Linac'', PAC 2001, Chicago, June 2001. http://pacwebserver.fnal.gov/papers/Thursday/PM_Poster/RPPH030.pdf
[6] J.P. Kelley et al., "ADTF spoke cavity cryomodule concept'', CEC/ICMC 2001, Madison, July 2001.
[7] G. Olry et al., "Study of a spoke cavity for low-beta applications", SRF2001, Tsukuba, September 2001.
[8] MAFIA Version 4.24, CST GmbH, Darmstadt, Germany.
[9] ACORD_CP Version 3.0.10
[10] http://www.framatome-anp.com/index.html
[11] http://www.cnrs.fr
[12] J. Kuzminski et al., "Industrial fabrication of medium-beta scrf cavities for a high-intensity proton Linac", LINAC2000, Monterey, August 2000.
[13] G. Olry et al., "R&D on Spoke-type cryomodule", these proceedings.
[14] P-Y. Beauvais & al., "Status report on the Saclay high-intensity proton injector project (IPHI)", EPAC 2000, Vienna, June 2000.