ESS MEDIUM AND HIGH BETA CAVITY PROTOTYPES

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Abstract

In the framework of the ESS activity in progress at INFN-LASA, we are designing and developing 704.42 MHz Medium (β=0.67) and High (β=0.86) beta prototype cavities plug compatible with the ESS cryomodule design. The cells of one Medium and one High beta cavity are fabricated with high quality CBMM Large Grain Niobium (480 mm dia. Ingot, RRR=300, sliced by Heraeus) while a Medium beta cavity is done with Fine Grain material for comparison. The prototype cavities will be produced by the firm Ettore Zanon S.p.A. under the supervision of INFN - LASA group.

INTRODUCTION

In the framework of ESS project, INFN-LASA is in charge of the development and of the industrial production of the whole set of 36 superconducting elliptical cavities for the Medium beta (β=0.67) section of the Linac. These cavities have to be designed as "plug-compatible" with the already existing CEA cryomodule boundaries and the ESS interface specification documents [1, 2].In order to verify all the fabrication and treatment processes for the 36 series Medium beta (MB) cavities, INFN-LASA has started to build two Medium beta cavity prototypes with same geometry but different materials, one in Fine Grain (FG) and the other in Large Grain (LG) Niobium. Furthermore, we intend also to build a LG high beta (β=0.86) cavity. The aim of building the LG cavities is to explore both the potential technical benefits (higher thermal stability due to "phonon peak" in the thermal conductivity, lower residual resistances) and the cost benefit as well thanks to the lower price of the bare material due to a simplified fabrication process [3].

The Medium beta cavity prototypes have been designed by INFN LASA team and they are currently under fabrication and will be cold tested in LASA. Large Grain Nb material is already available also for the High beta prototype that will be fabricated soon after the two Medium beta prototypes will be ready.

In this article, we present the medium-beta cavity prototype design, fabrication status and recent upgrading of the infrastructure in LASA.

CAVITY PROTOTYPE DESIGN

The MB cavities will be fabricated using INFN design and will be plug-compatible with CEA design boundary conditions, including helium tank, fundamental coupler, flanges and tuner connections.

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RF Design

The MB prototypes has been designed using SUPERFISH 7 and the updated BuildCavity 1.4.3 codes [4, 5]. Within BuildCavity, seven key parameters are used to design the half-cells: the half-cell length L, the iris aperture Riris, the wall angle α, the wall distance from the iris plane d, the equator ellipse aspect ratio R, the iris ellipse aspect ratio r and the distance between the equator and iris ellipse centres [6]. During the cavity design, the choice of these parameters involves both the RF and mechanical performances as well as the treatment requirements, such as a wall angle large enough for chemical treatment and Ultra-Pure Water rinsing.

The RF parameters of INFN-LASA MB cavity design are shown in Table 1, where the optimum beta, β_{opt}=0.705, is referred to maximum R/Q and the comparison values are referred to a MB cavity with R_{iris}=47 mm.

Table 1: RF Parameters of INFN-LASA MB Cavity

Parameters	INFN design	ESS spec.
R_{iris} (mm)	50	≥47
Geometrical beta	0.67	0.67
Frequency (MHz)	704.42	704.42
Acc. length (m)	0.855	0.855
Cell to cell coupling k	1.55%↗ (+26%)	
π-5π/6 mode sep.(MHz)	0.70↗(+30%)	>0.45
G (Ω)	198.8	
Optimum beta, β_{opt}	0.705	0.705
Max R/Q at β_{opt} (Ω)	374↘(-6%)	
E_{acc} at β_{opt} (MV/m)	16.7	16.7
E_{peak}/E_{acc}	2.55 ↗ (+7%)	
E_{peak} (MV/m)	42.6	< 45
B_{peak}/E_{acc}(mT/MV/m)	4.95 ↗ (+3%)	
Q_0 at nominal gradient	$>5\times10^9$	$>5\times10^9$
Q_{ext}	7.8×10^5	$5.9\sim8\times10^5$

Our design goal is to have a MB cavity with a large cell-to-cell coupling factor, k, more than 1.5%, allowing for a slight modest increase on the peak fields. Figure 1 shows E_{peak}/E_{acc}, R/Q and cell-to-cell coupling k as a function of R_{iris} of the inner half-cell for our MB cavity (the other parameters, L=7.13 cm, R=1, α=7°, d=1.2 cm are fixed while the iris ratio r is always the value giving in the smallest E_{peak}, for example r=1.7 for R_{iris}=5 cm). We have chosen R_{iris}=5 cm to achieve k > 1.5%. Comparing to R_{iris}=4.7 cm, we have a significant increase on k (+26%) with a modest reduction on R/Q (-7%) and a modest increase on E_{peak}/E_{acc} (+6%).

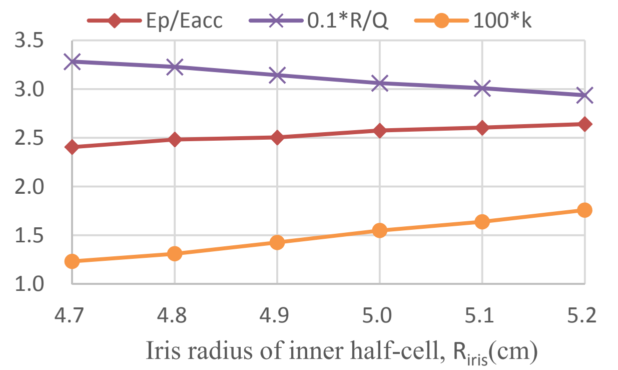

Figure 1: E_{peak}/E_{acc}, R/Q and cell-to-cell coupling k as a function of the inner half-cell iris radius (β=0.67, L=71.3 mm, R=1, α=7°, d=12 mm and r minimizing E_{peak}).

An advantage of the large cell iris, R_{iris}=5 cm, is the increase of the 5π/6 and π -mode separation by 30% to 0.7 MHz. Moreover, the larger coupling k offers also a better coupling of HOMs to the outer cells, a favourable condition for their damping. The fundamental modes for INFN-LASA MB cavity design are shown in Figure 2.

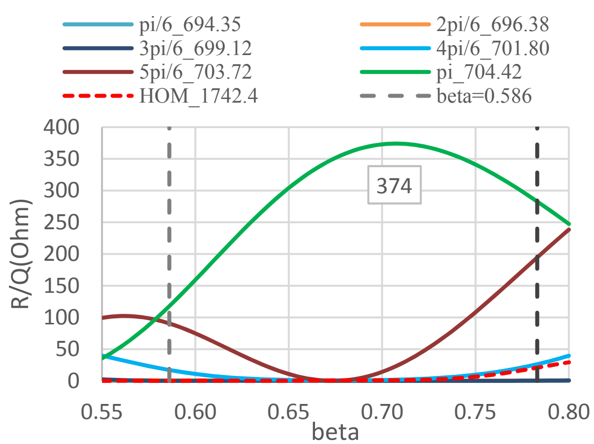

Figure 2: R/Q versus beta for the fundamental modes and the HOM mode at 1742.4 MHz in INFN-LASA MB cavity (mode frequencies in MHz).

Both end cells are designed with a slight larger equator diameter than the inner cells to get field flatness with the large beam pipes. This allows an almost spherical equator dome, useful to limit multipacting, without reducing the side wall angle.

The end cell on the Main Coupler side, in particular, plays an important role in the coupling power to the cavity. Since the main coupler (MC) is a basic interface to the cryomodule, the geometry of MC part is fixed and the external Q (Q_{ext}) has to be kept in the ESS specified range, 5.9 ~ 8 10^5. Therefore, the end cell is optimized to have the proper Q_{ext} by choosing a proper wall distance from the iris plane d. The beam pipes have the same size as the original CEA prototype so that the main mechanical and ancillary interfaces such as the tank connection, fundamental and pickup couplers, flanges and bellows are fully compatible.

Given the CEA power coupler geometry [7], we have used ANSYS HFSS to calculate Q_{ext} with our MB cavity design using the method developed by P. Balleyguier [8]. Simulation shows that, for INFN-LASA designed MB cavity, with CEA coupler, the Qext is 7.8x10^5 within ESS specification.

We have also studied the Higher-Order Modes (HOMs) to identify dangerous modes near the machine lines (MLs), namely harmonics of 352.21 MHz for ESS Linac, because the HOM induced power largely depends on their distance from the MLs [9, 10].

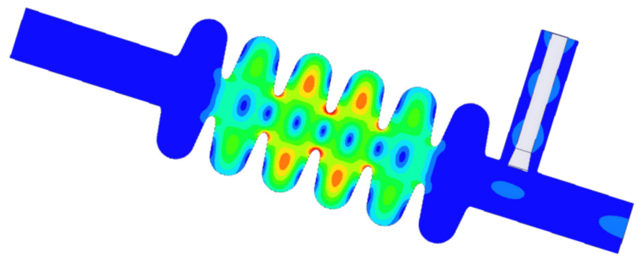

Figure 3: 1742.4 MHz monopole electric field distribution (electric boundary conditions applied on MC and beam pipe ends).

SUPERFISH and HFSS have been used to calculate the HOMs up to the cut-off frequency (2295 MHz for TM01) of the cryomodule end tubes (radius at 50 mm). In INFN-LASA MB cavity, there is only one monopole mode, at 1742.4 MHz, located within 20 MHz from MLs, which appears properly a quasi-trapped mode as shown in Figure 3. Thanks to the large inner-cell iris of our MB cavity design, the trapped modes can be better coupled to the end cells, hence to the beam pipes and coupler. In particular, this mode has the Q_{ext}=9.6×10^4, and the maximum R/Q at 21 Ohm in the cavity beta range as also shown in Figure 2.

Concerning implications of possible manufacturing errors on HOMs, a study by A. Farricker etc. [11] shows that the mode at 1742.4 MHz is more sensitive, about -19 MHz/mm, to the horizontal-axis A of equatorial ellipse than to any other parameters used to design a half-cell. Considering the foreseen construction tolerances, this mode can be considered harmless.

Mechanical Design

For the mechanical design analysis, we have used ANSYS [12]. The cavity wall thickness of 4.5 mm is chosen for the INFN-LASA MB cavity, by considering the pressure and tuning loads as well as the cavity sensitivity to Lorentz force detuning (LFD). The mechanical parameters for INFN-LASA MB cavity design are listed in Table 2.

For a cavity with the FG Nb material, the affordable stress of elastic deformation should be less than 50 MPa. The simulation shows that the maximun elastic displacement on INFN-LASA MB cavity is 2.60 mm. With water filled in cavity (typical during treatment at the vendor), the maximum length displacement is less than 0.3 mm and the maximum von-Mises Stress less than 16

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MPa, which means that the stress and strain are not a concern during handling of the cavity filled with water.

Table 2: Mechanical Parameters for INFN-LASA Medium-Beta Cavity Design

Cavity wall thickness (mm)	4.5
Stiffening ring radius (mm)	70
Internal volume (l)	69
Cavity internal surface (m^2)	1.81
Stiffness (kN/mm)	1.72
Tuning sensitivity K_T (kHz/mm)	170
Vacuum sensitivity K_V for K_{ext} ~ 21 kN/mm (Hz/mbar)	32
LFD coefficient K_L for K_{ext} ~ 21 kN/mm (Hz/(MV/m)^2)	-1.80

FABRICATION STATUS

Two INFN-LASA designed MB prototypes cavities are under construction at Ettore Zanon S.p.A. Both LG and FG materials are already in house, and the LG disks have already been chemical and heat treated. So far, the deep drawing tests on inner and end half-cells with LG and copper have been done and the results are fully successful. Figure 4 shows the inner and end HC shapes just after deep drawing. In the upper part of the picture, the HC shape is visually and successfully compared to the reference dime, the complete 3D measurement of the HC is ongoing. The deep drawing on all the disks for both cavities prototypes will be finished soon.

The cavities will be fully chemically treated and prepared for RF measurement by Zanon and are expected to be delivered to LASA by August, ready to be Vertical Cold tested in September 2016.

Figure 4: Deep drawing tests for INFN-LASA prototype cavities (up: inner Half Cell in LG Nb; down: end HC in Copper).

LASA INFRASTRACTURE UPGRADING

In order to handle and test the ESS MB prototypes, the LASA infrastructures have been upgraded since last year. Most equipment, developed in the E-XFEL project framework, are already available. A dedicated new vertical insert and a heavily renewed High Pressure Rinsing (HPR) system are under construction as well as all the handling tool. The tuning machine is an upgrade of the device used for TRASCO cavities, adapted for the new cavity geometries and has been already installed at Zanon facility.

CONCLUSION

INFN Milano LASA will in-kind contribute to the ESS by delivering 36 medium-beta elliptical cavities. In this context, we have designed a new MB cavity that is fully plug-compatible with the interface of CEA existing design and ESS specification documents. Two medium-beta cavity prototypes are under construction, with successful half cells deep drawing tests done. The first cold test is foreseen in September 2016.

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