FNAL PROJECT X CONICAL HALF-WAVE RESONATOR DESIGN*

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Abstract

A high-intensity proton accelerator complex proposed at Fermi National Accelerator Laboratory (Project X) should provide beam for a variety of physics projects. The superconducting resonators of different types will be used as accelerating structures. Here we describe the design of conical Half-Wave Resonator that is considered as an option for a first accelerating cavity for beta=v/c=0.11 with the resonance frequency 162.5 MHz.

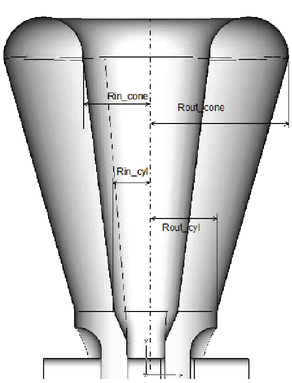
A careful study of the fields in the cavity has been carried out in order to optimize the electromagnetic parameters of the structure (peak fields, quality factor and dissipation power). Intensive investigations were provided of the liquid helium vessel design to minimize cavity frequency shifts from the external loads. Different tuning schemes have been studied to secure a frequency tuning range to cope with fabrication tolerances.

The paper reports results of numerical simulations of the cavity shape optimization and structural analyses.

The detailed developments of the structure using numerical coupled analyses allowed minimizing the level of expected microphonics in the cavity.

INTRODUCTION

The main purpose of this work is to provide the conceptual design of Half-Wave Resonator (HWR) that produces a substantially lower peak magnetic field for the same accelerating rate. Additionally, as an alternative to the standard beam port deformations, an option for the cavity frequency adjustment has been developed. The cavity structural design should secure the lowest possible resonance frequency dependence on external loads.



D_aperture = 33 mm

Rout_cyl = 90 mm

Rout_cone = 180 mm

Rin_cyl = 40 mm

Rin_cone = 80 mm

Cavity height = 895 mm

Figure 1: HWR with enlarged outer conductor dome diameter.

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Several resonator design parameters based upon the requirements of the Project X low-β part of accelerator at Fermi National Laboratory have been chosen.

CAVITY RF DESIGN

The cavity geometry has been optimized to get the design frequency 162.5 MHz and β=0.11 and to minimize the peak electric and magnetic fields on the cavity surface relative to the accelerating electrical field on the cavity axis (B_{pk}/E_{acc} and E_{pk}/E_{acc}). To reduce substantially B_{pk}/E_{acc} the conical Half-Wave Resonator (cHWR) is considered. The cavity dome region containing RF magnetic field was enlarged to get the conical cavity shape (Fig. 1). This results in decreasing the cavity peak surface magnetic field B_{pk}/E_{acc} . For the cHWR geometry optimisation we used the same procedure discussed elsewhere [1].
Nevertheless, we didn't aim the ultimate RF design but mainly provided it as a justification of using idea of conical HWR. That's why the cavity model is not perfect allowing corners at the places of the cavity different part joints in electric field regions, which results in slightly higher surface peak field definitions. Also we didn't put any additional effort trying to optimise the mesh using mainly "automesh" option in simulations. The final resonator shape should also take into account the whole cryomodule design and fabrication preferences.

Table 1: Conical HWR Parameters.

frequency	MHz	162.42
β = v/c		0.11
βλ	mm	202.94
G	Ohm	40.78
R/Q	Ohm	118
E_{pk}/E_{acc} *)		5.02
B_{pk}/E_{acc} *)	mT/MV/m	6.64
B_{pk} / E_{pk}	mT/MV/m	1.32
*) $L_{eff} = N_{gaps}$ * βλ/2, where N_{gaps}=2 – number of gaps		

Fig. 1 and Table 1 present the geometry and some parameters of the simulated conical HWR.

CAVITY STRUCTURAL DESIGN

The conceptual design of the liquid helium vessel is investigated to reach the lowest possible resonance frequency shift from the external pressure on cavity walls.

To understand the behaviour of helium vessel structure we provided the simulations of pure cylindrical (Fig. 2) and with non-symmetrical central tuning part of cHWR.

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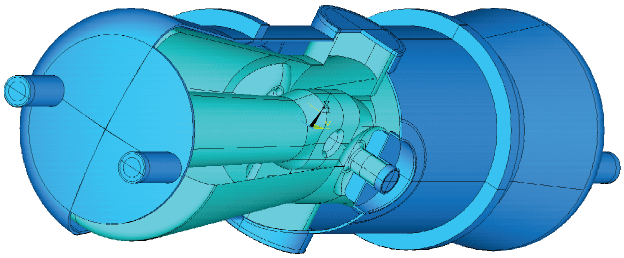

Figure 2: Simulation model of pure cHWR with helium vessel.

The total effect of external pressure application on all cavity and liquid helium vessel walls results in nearly complete compensation of the frequency shifts caused by cavity and vessel wall deformations (df/dp is close to zero, Fig. 3). The dependence of df/dp on resonator wall thickness is about 0.9 Hz/mbar/mm.

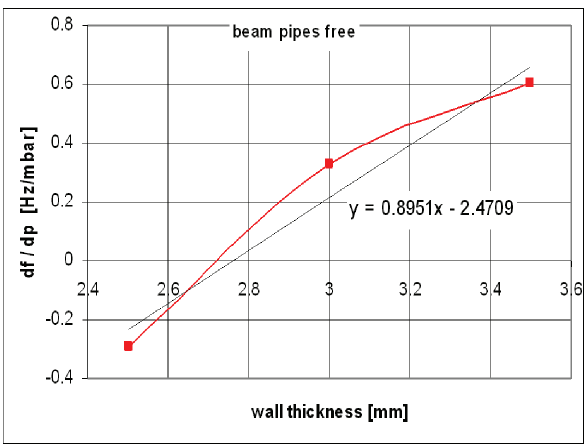

Figure 3: cHWR with helium vessel simulation results.

The helium vessel model was fixed by means of special rings simulating the structure supports in the cryomodule. The simulations were provided for two extreme conditions (fixed and free) of the beam ports and coupler ports since their stiffness a priori is unknown. Fig. 4 presents calculation results for df/dp for different constraint conditions of coupler ports with beam port stiffness variation.

The "standard" tune procedure with beam port deformations results in tune sensitivity up to 130 kHz/mm.

To use effectively the outer conductor wall for cavity tuning deformations, the central part of cHWR is made asymmetric with a planar surface on one side (Fig. 5). This planar surface is used for deformations. To achieve a higher tuning sensitivity this plane surface is deformed inwards of the cavity outer conductor diameter for 10 mm.

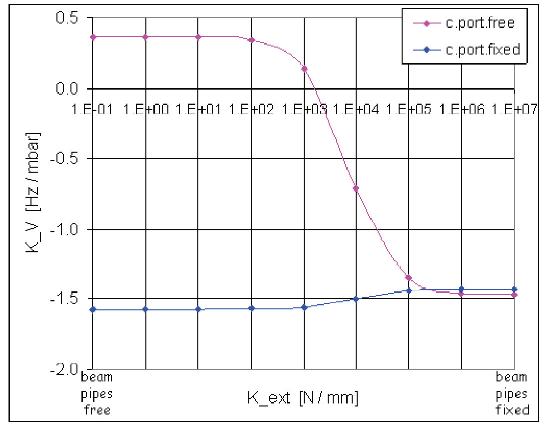

Figure 4: cHWR under external pressure with helium vessel.

The simulations of different schemes of helium vessel constraints were provided to predict the structure behaviour under external loads in the cryomodule. The helium vessel model was fixed by means of the external rings. Also the coupler ports were supposed fixed. The simulations were provided for two extreme conditions (fixed and free) of the beam ports and the tuner. The calculation results of df/dp for different constraint conditions of beam pipes with the tuner stiffness variation are presented in Fig. 6.

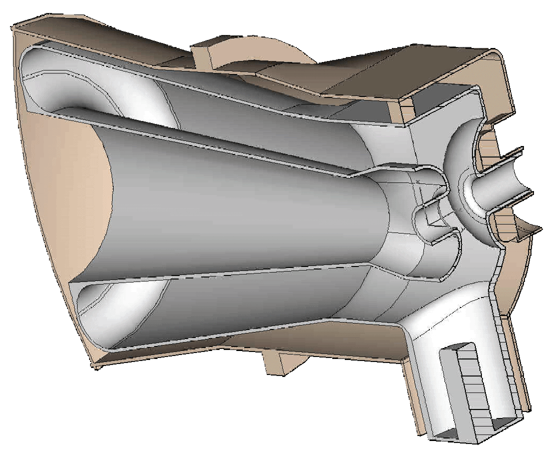

Figure 5: cHWR simulation model.

For complete compensation of external pressure (to reach df/dp=0) the tuner should be pre-stressed (tuning force should be directed outwards) with the tuning force of about 50 N for the cavity wall thickness 3 mm (Fig. 7).

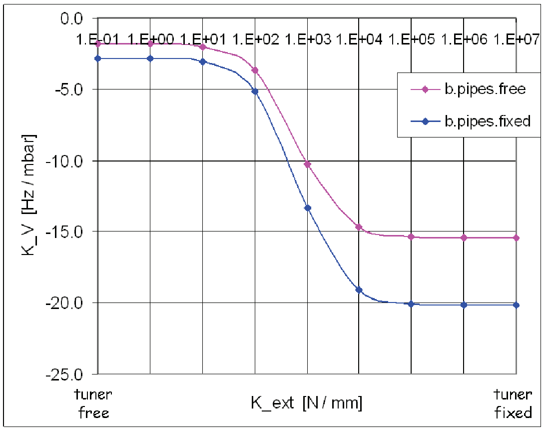

Figure 6: cHWR under different external pressure and beam port constraints.

The side tune procedure results in tune sensitivity up to 80 kHz/mm with acceptable stresses 350 MPa/mm. There is nearly no dependence on coupler port stiffness.

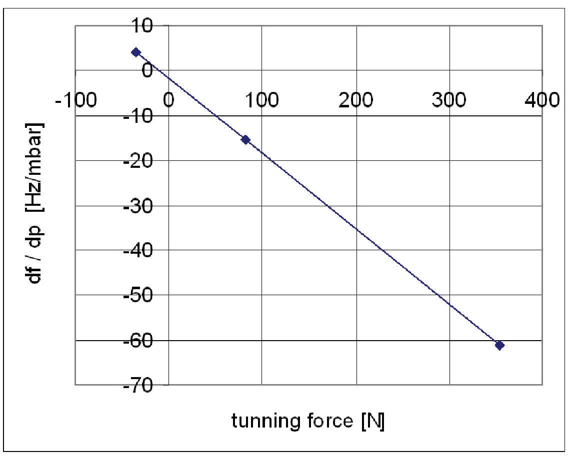

Figure 7: cHWR tuning sensitivity.

To enable of the possibility of further df/dp adjustment the installation of a bellow combined with an additional tuner ring was investigated (Fig. 8). The bellow is simulated as a slot in the vessel tuning plate. The tuner ring is installed around the bellow (tuner ring radius is bigger than bellow radius) connecting cavity and helium vessel tuning plates. The tuner ring installation provides compensation of the cavity tuning wall external pressure deformation. The best compensation conditions define an optimum value of the tuner ring radius. The calculation results of df/dp for different constraint conditions of beam pipes with tuner stiffness variations detect a weak dependence on the tuner stiffness – for two extreme cases of tuner constraints the frequency shift from helium external pressure is within +/- 3 Hz/mbar (Fig. 9). The dependence on the cavity wall thickness is about 0.9 Hz/mbar/mm.

CONCLUSIONS

The Half-Wave Resonator conceptual design is provided. The conical option of HWR allows reducing the peak value of magnetic field (B_{pk}/E_{acc}). Because of its big length the cavity volume enlargement in cHWR is made far from the beam path and does not affect an overall accelerator length.

The cavity helium vessel structure can be designed to reach complete compensation of microphonics within fabrication tolerances. The side option of the cavity tuner can be effectively implemented and permits saving the space along the beam path.

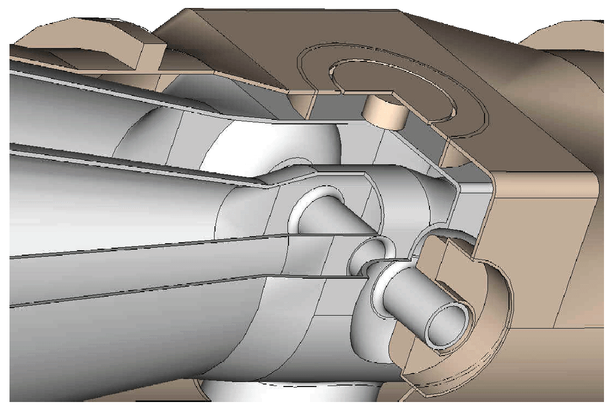

Figure 8: cHWR simulation model with bellow slot.

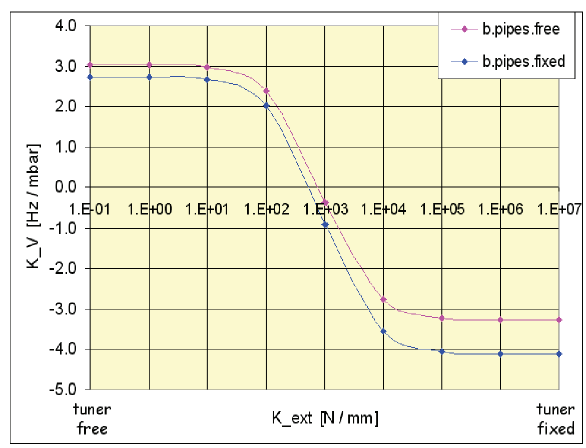

Figure 9: cHWR simulation model with bellow slot.

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[2] E. Zaplatin, A. Kanareykin, "High-Frequency and Mechanical Basic Analisis of Conical Half-Wave Resonator", SRF11, Chicago, USA, 2011.

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