HIGH-FREQUENCY AND MECHANICAL BASIC ANALYSIS OF CONICAL HALF-WAVE RESONATOR*

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Abstract

A cylindrical Half-Wave length Resonator is a proved superconducting structure in the low energy part of accelerators. Accelerating efficiency in such resonator is limited by the peak RF magnetic field on the inner cavity surface. An enlargement of the dome cavity volume containing RF magnetic field reduces the cavity peak surface magnetic field. Additionally, this results in the power dissipation reduction. The paper reports results of cavity shape optimization and structural analyses of conical Half-Wave Resonators for β=v/c=0.11 and two resonance frequencies 325 MHz and 162.5 MHz.

INTRODUCTION

The main purpose of this work is to investigate the possibility using of Half-Wave Resonator (HWR) for β=0.11 that provides substantially lower the peak magnetic field by the same accelerating rate. Additionally, an alternative to the standard beam port deformations option for the cavity frequency adjustment should be developed.

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

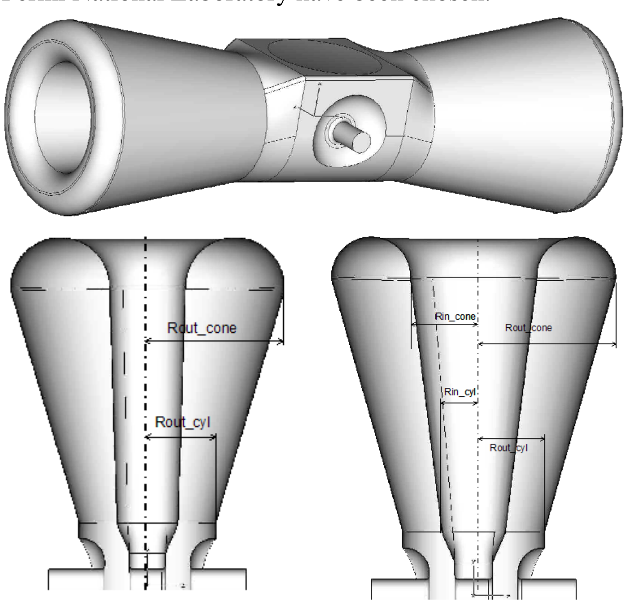

Figure 1: HWR with enlarged outer conductor dome diameter.

To reduce substantially B_{pk}/E_{acc} the conical Half-Wave Resonator (cHWR) [1] can be used.

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CAVITY RF DESIGN

162.5 MHz, β=0.11 cHWR

A straight circular IFMIF 175 MHz, β=0.094 half-wave resonator ([2]) has been used as a basis for a 162.5 MHz, β=0.11 HWR developments. The cavity geometry has been modified to get the design frequency 162.5 MHz and β=0.11 and to minimize values of peak electrical and magnetic fields on the cavity surface relative to the accelerating electrical field on the cavity axes (B_{pk}/E_{acc} and E_{pk}/E_{acc}).

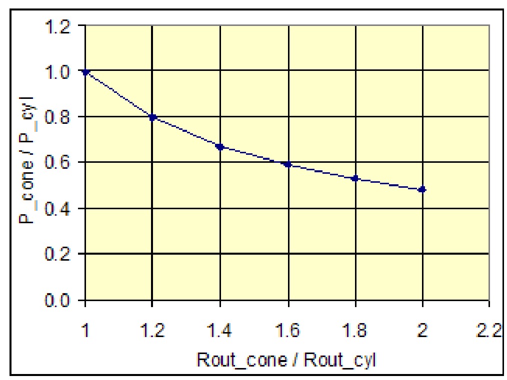

Figure 2: Power dissipation in conical HWR relative to cylindrical shape.

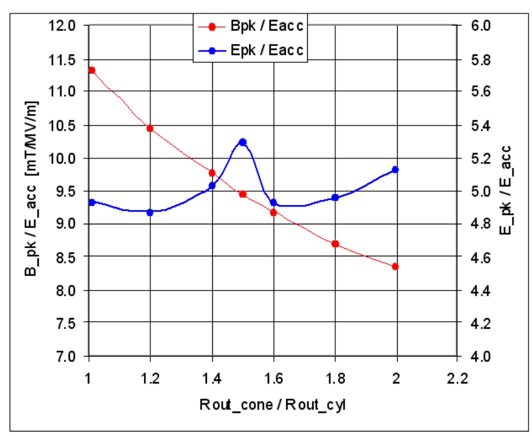

Figure 3: Peak magnetic and electrical fields in conical cavity.

At the cavity dome region there is a space for the peripherical cavity volume enlargement containing RF magnetic field 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 [3].

The results of conical resonator geometry optimisations are shown on Figs. 2-4. The complete conical half-wave resonator RF design results in B_{pk}/E_{acc} reduction by about 40%.

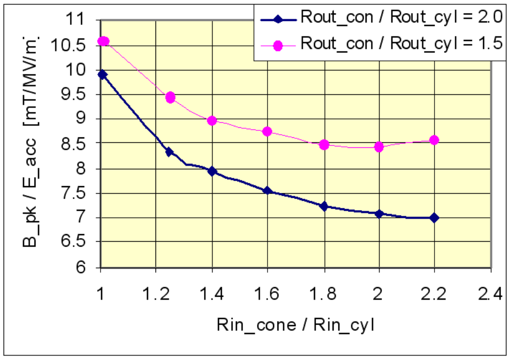

Figure 4: Peak magnetic field in conical cavity with enlarged central electrode dome diameter.

The central part of the cavity is designed non-symmetrical with outer conductor plane surface. This plane plate can be deformed to provide the resonance frequency adjustment (Fig. 5). The frequency tune sensitivity is about –97 kHz/mm at 5 mm wall deformation.

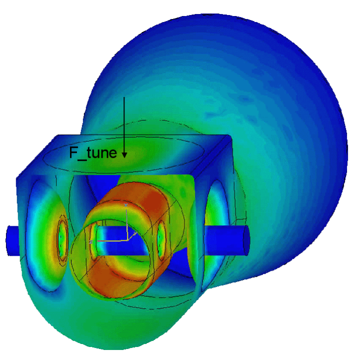

Figure 5: cHWR simulation tune model.

325 MHz, β=0.11 cHWR

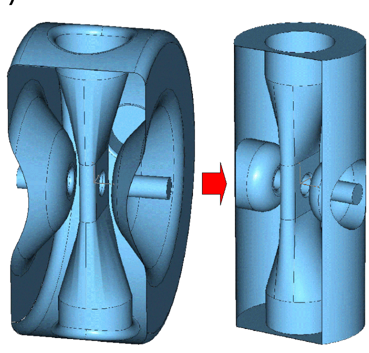

Figure 6: SSR0 geometry transformation into HWR.

A spoke cavity SSR0 design of FNAL Project X [4] was the base for the development of cHWR for the resonance frequency 325 MHz and β=0.11 (Fig. 6). Geometry of HWR central electrode (spoke of SSR0), HWR longitudinal (along beam path – z) dimension are kept the same. HWR vertical dimension is the same as SSR0 radius. The cone beam port geometry replaced by simple straight cylindrical with the size of the cone small radius. HWR has no rounding by central electrode outer conductor joint and by dome. The dome geometry is kept straight since this place is considered as a tune plate. With a new beam port design compare to SSR0 the whole cavity geometry was checked again to prove its optimal dimensions.

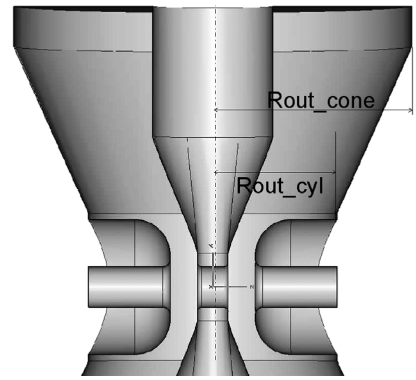

Figure 7: cHWR RF simulation model.

To improve B_{pk}/E_{acc} ratio the cavity outer conductor diameter in the dome region was increased up to 1.6 times (Fig. 7). The rest of the cavity was kept unchanged. The results are shown on Figs.8-9.

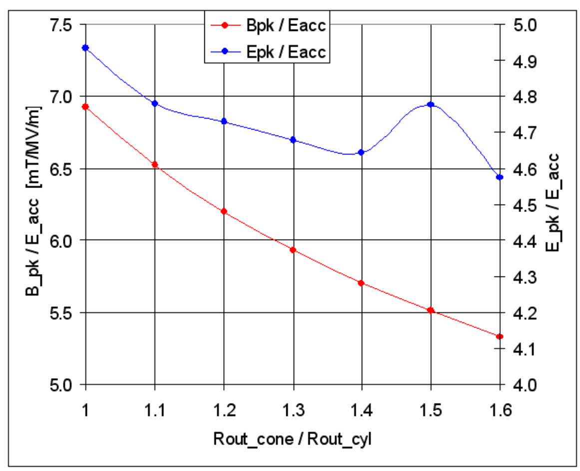

Figure 8: Peak magnetic and electrical fields in cHWR.

The conducted investigation (Figs. 8-9) was provided for cone ratio up to 1.6 (cone big diameter 1.6 times bigger than HWR outer cylinder diameter). But resonance frequency of 1.6-cavity with an original HWR length (208.27 mm) is about 295 MHz. To get the required frequency the cavity length should be reduced by 30 mm (about 1 MHz/mm). In this case the whole RF optimization is slightly violated. Also, the cavity vertical size becomes so small that it results in larger cavity dimension along beam path, which affects the overall length of accelerator.

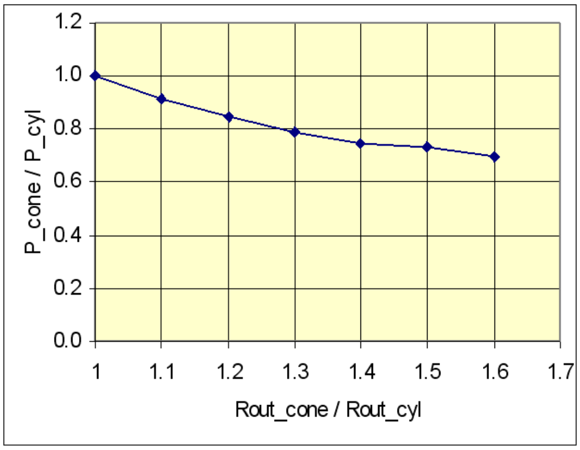

Figure 9: cHWR power dissipation change.

CAVITY COUPLED ANALYSIS

162.5 MHz, β=0.11 cHWR

The conceptual design of the liquid helium vessel (Fig.10) 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 with separated pressure applied on cavity and vessel walls.

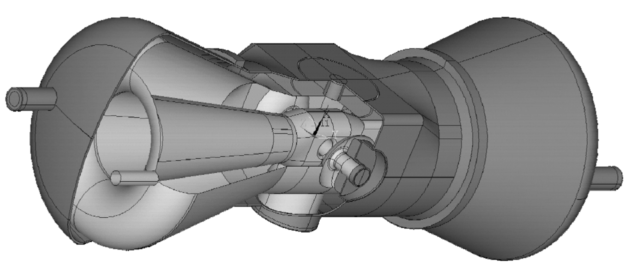

Figure 10: cHWR with helium vessel.

The pressure applied only on cavity walls directed inwards the cavity volume results in the total cavity deformation that leads to the capacitance enhancement, which in its turn results in the frequency reduction (negative sign of df/dp) (Fig.11).

The pressure applied only on liquid helium vessel walls directed outwards the liquid helium vessel volume results in the biggest deformation located at tune plate region. An effect results in cavity capacitance reduction that in it's turn increases frequency (positive sign of df/dp). The results are opposite to the cavity wall pressure application.

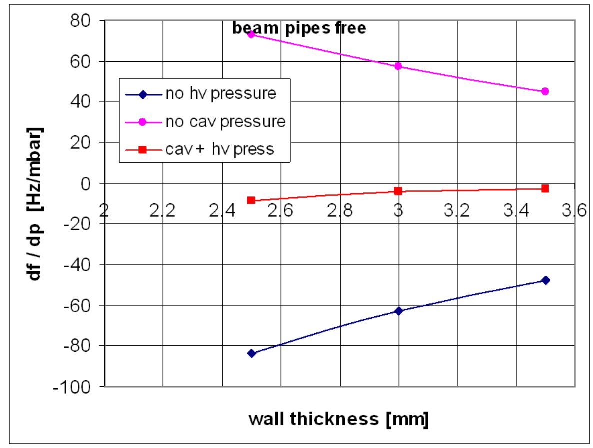

Figure 11: cHWR with helium vessel simulation results.

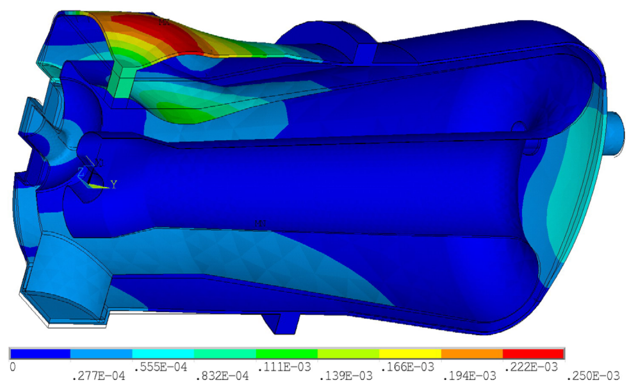

Figure 12: cHWR under external pressure with helium vessel.

The summary effect of external pressure application on all cavity and liquid helium vessel walls results in small cavity capacitance enhancement (negative df/dp) (Figs. 11-12).

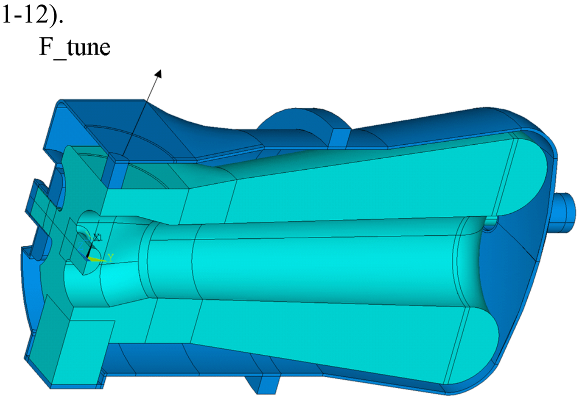

Figure 13: cHWR tune simulation model.

For complete compensation of external pressure application (to reach df/dp=0) the tuner should be pre-stressed (tune force should be directed outwards) with tune force of about 126.5 N for cavity the wall thickness 3 mm (Fig. 13-14).

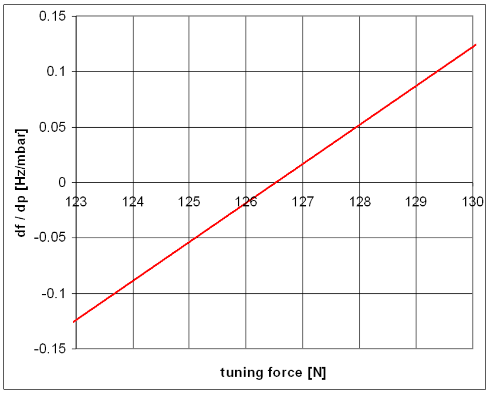

Figure 14: cHWR tune simulation results.

There is an optimum bellow radius when the pressure at cavity walls (directed inward of cavity) and pressure at he vessel (directed outward of cavity) in the tune plate region define df/dp=0 (Fig. 15-16).

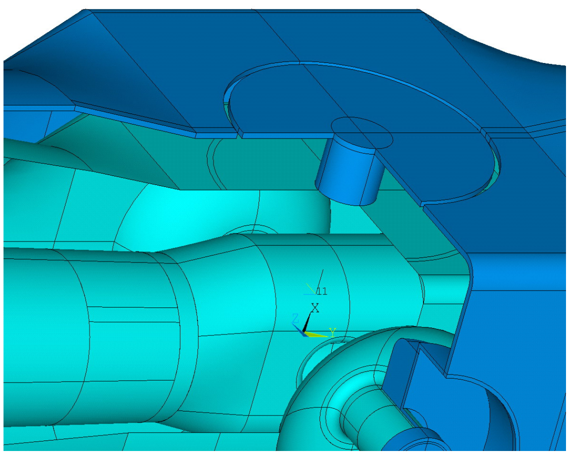

Figure 15: cHWR simulation model with bellow slot.

By optimal value R_bellow=71 mm frequency shift dependence on external pressure with cavity wall thickness deviation is df/dp/(0.1mm)=0.56 Hz/mbar/0.1mm for 1 bar and df/dp/(0.1mm)=1.32 Hz/mbar/0.1mm for 2.5 bar.

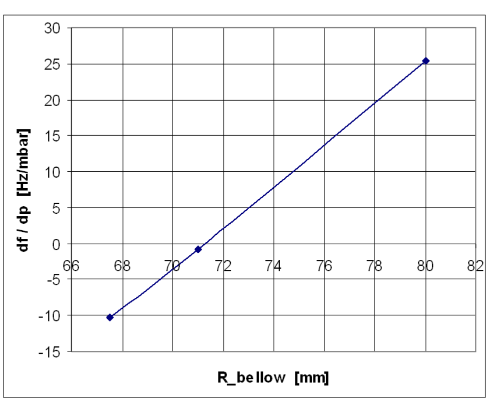

Figure 16: cHWR bellow radius optimization.

The beam port constrains change an optimal conditions equivalent to 0.2 mm wall thickness range (Fig. 17).

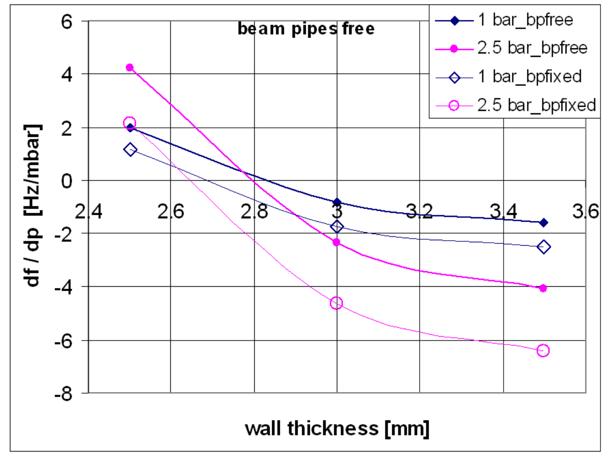

Figure 17: cHWR under different external pressure and beam port constrains.

All main simulation results are summarized in Table 1.

Table 1: Some parameters of conical half-wave resonator.

		hwr ifmif	chwr 2.0	chwr 1.5
frequency	MHz	175	162.5	162.5
$\beta = v/c$		0.094	0.11	0.11
R_aperture	mm	20	15	15
$\beta\lambda$	mm	161.04	202.94	202.94
R_cavity	mm	90	90	90
G	Ohm	28.55	36.76	29.32
R/Q	Ohm	107	114	101
E_{pk} / E_{acc} *)		4.42	5.32	5.37
B_{pk} / E_{acc} *)	mT/MV/m	10.12	7.08	8.44
B_{pk} / E_{pk}	mT/MV/m	2.29	1.33	1.57
tune	kHz/mm	-66	-73.6	-73.6
K_L	$Hz/(MV/m)^2$	-1.39		-1.2
*) $L_{cav} = N_{gaps} * \beta\lambda/2$, where N_{gaps}=2 – number of gaps				
**) cavity length along beam path				

325 MHz, β=0.11 cHWR

The same simulation procedure with separated pressure on walls to evaluate and optimise vessel structure has been used. Because of its small dimensions the structure is mechanically very stable but inherits high resonance frequency shift sensitivity on resonator deformations.
Fig.18 shows the conceptual design of the cavity together with helium vessel.

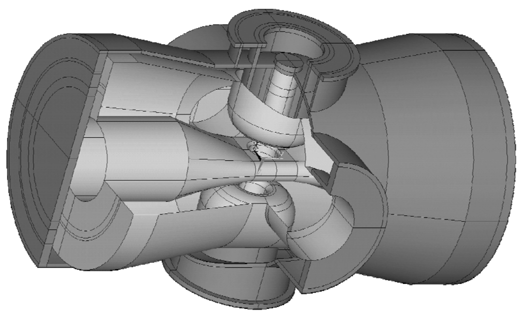

Figure 18: cHWR with helium vessel simulation model.

The results of these structure simulations (Fig. 19) show the range of df/dp in terms of beam port stiffening (from completely free to completely fixed). Also, 2.5 bar pressure calculations indicate the range of df/dp for the worse case of the working conditions.

Table 2: Some parameters of conical half-wave resonator.

		ssr0 fnal	chwr 1.6	chwr 1.25
frequency	MHz	325	295	325
$\beta = v/c$		0.114	0.11	0.11
R_aperture	mm	15	15	15
$\beta\lambda$	mm	105.16	101.47	101.47
R_cavity	mm	91 **)	91	91
G	Ohm	50	56.35	53.66
R/Q	Ohm	108	121.8	114.5
E_{pk}/E_{acc} *)		5.63	4.58	4.71
B_{pk}/E_{acc} *)	mT/MV/m	6.92	5.33	6.07
B_{pk}/E_{pk}	mT/MV/m	1.23	1.17	1.23
tune	kHz/mm		702	771
K_L	$Hz/(MV/m)^2$			-6.78
*) $L_{cav} = N_{gaps} * \beta\lambda/2$, where $N_{gaps}=2$ – number of gaps				
**) cavity length along beam path				

The deformation of dome plate can be used for cavity tune like it was investigated in [5].

CONCLUSIONS

162.5 MHz, β=0.11 cHWR

The conical cavity can be effectively used in the range of resonance frequency of 150-175 MHz to reduce 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 mechanical properties of cHWR are the same as by HWR and substantially better than by single spoke cavity. The cavity helium vessel structure can be designed to reach complete compensation of microphonics within fabrication tolerances.

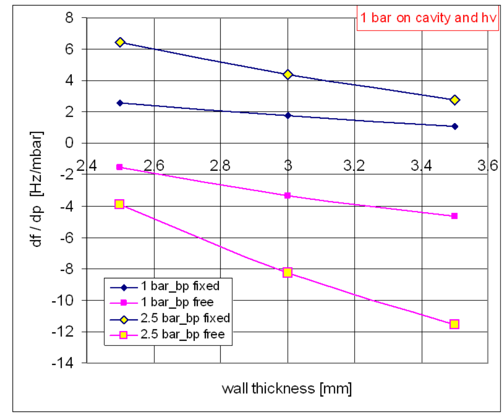

Figure 19: cHWR at different external pressure and beam pipe constrains.

325 MHz, β=0.11 cHWR

In the range of around 350 MHz for the resonant frequencies, half-wave resonator and single spoke cavity do not differ much in RF parameters for any beta values. The ratio of B_{pk}/E_{pk} =1.2 for the single spoke cavity indicates that the limitations of cavity accelerating efficiency is defined by both electric and magnetic fields simultaneously for the most project peak field values [3]. Since there is no accurate comparative investigation on the cost or complexity of cavity fabrications the resonator type choice is based on the own Laboratory experience.

The cavity inductance is growing with enlargement of magnetic field volume in cHWR. Since the cavity capacitance is defined mainly by accelerating gap geometry the length of cHWR should be reduced to target the required resonance frequency. To reach the noticeable reduction of B_{pk}/E_{acc} and power dissipation the cavity dome diameter should be substantially increased and height reduced. This results in cHWR geometry with increased overall length of the resonator to compare with straight cylindrical HWR.

REFERENCES

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