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 $\beta = v/c = 0.11$ 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 $\beta = 0.11$ 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-$\beta$ part of accelerator at Fermi National Laboratory have been chosen.

CAVITY RF DESIGN

$162.5 \text{ MHz, } \beta = 0.11 \text{ cHWR}$

A straight circular IFMIF 175 MHz, $\beta = 0.094$ half-wave resonator ([2]) has been used as a basis for a 162.5 MHz, $\beta = 0.11$ HWR developments. The cavity geometry has been modified to get the design frequency 162.5 MHz and $\beta = 0.11$ 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 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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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 $-97 \text{ kHz/mm}$ at 5 mm wall deformation.

Figure 5: cHWR simulation tune 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 7: cHWR RF simulation model.

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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.
CAVITY COUPLED ANALYSIS

162.5 MHz, $\beta=0.11$ 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.

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 its turn increases frequency (positive sign of $df/dp$). The results are opposite to the cavity wall pressure application.

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).

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).
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).

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

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.

All main simulation results are summarized in Table 1.

<table>
<thead>
<tr>
<th>parameter</th>
<th>hwr</th>
<th>ifmif</th>
<th>chwr 2.0</th>
<th>chwr 1.5</th>
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<td>162.5</td>
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<td>0.11</td>
<td>0.11</td>
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<td>$R_{\text{aperture}}$ mm</td>
<td>20</td>
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<td>$\beta \lambda$ mm</td>
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<td>202.94</td>
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<td>1.57</td>
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<tr>
<td>tune kHz/mm</td>
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<td>-73.6</td>
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<td>$L_{\text{cav}} = N_{\text{gaps}} \times \beta \lambda / 2$, where $N_{\text{gaps}}=2$ – number of gaps</td>
<td>-1.39</td>
<td>-1.2</td>
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</tbody>
</table>

*) $L_{\text{cav}}$ = cavity length along beam path

### 325 MHz, $\beta=0.11$ 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.
The deformation of dome plate can be used for cavity tune like it was investigated in [5].

### CONCLUSIONS

#### 162.5 MHz, $\beta=0.11$ 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.

### REFERENCES