CONICAL HALF-WAVE RESONATOR INVESTIGATIONS

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Abstract
In the low energy part of accelerators the magnets usually alternate accelerating cavities. For these particle energies Half-Wave Resonators are considered. Such layout allows enlargement of the peripheral cavity volume containing RF magnetic field. This results in decreasing the cavity peak surface magnetic field $B_{pk}/E_{acc}$ by the factor of two. Additionally, an enlarged dome volume allows an installation of magnetic tuner for cavity frequency adjustment without affection of $B_{pk}/E_{acc}$.

The paper reports the results of superconducting Half-Wave Resonator shape developments. A magnetic plunger for cavity frequency tune is investigated. Different cavity shape modifications are suitable also for close situated cavities. The results are applicable for SC RF Quarter-Wave Resonators.

CAVITY RF DESIGN

Conical Half-wave Resonator

The goal of the cavity electrodynamics design is to optimise the cavity geometry 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 $E_{pk}/E_{acc}$).

Table 1: Some parameters of IFMIF half-wave resonator

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>MHz 175</td>
</tr>
<tr>
<td>$\beta=v/c$</td>
<td>0.094</td>
</tr>
<tr>
<td>$R_{aperture}$</td>
<td>mm 20</td>
</tr>
<tr>
<td>$\beta\lambda$</td>
<td>mm 161.04</td>
</tr>
<tr>
<td>$R_{cavity}$</td>
<td>mm 90</td>
</tr>
<tr>
<td>$G$</td>
<td>Ohm 28.55</td>
</tr>
<tr>
<td>$E_{pk}/E_{acc}$</td>
<td>4.42</td>
</tr>
<tr>
<td>$B_{pk}/E_{acc}$</td>
<td>mT/MV/m 10.12</td>
</tr>
</tbody>
</table>

*) $I_{cav} = N_{gaps} \times \beta\lambda/2$, where $N_{gaps}$ is the number of gaps

The dependence of peak magnetic and electrical fields in cavity via their ratio $B_{pk}/E_{pk}$ with a certain their values are shown on Fig. 1. Here we considered two peak values for both fields that correspond to the range of more probable project values for low-β accelerator part (for $B_{pk} = 50$ mT and 70 mT, for $E_{pk} = 30$ MV/m and 50 MV/m). The limitation on cavity accelerating efficiency is defined by $B_{pk}$ for the ratio $B_{pk}/E_{pk}$ larger than 1.5 and from $E_{pk}$ with this ratio lower than 1.5. In most cases of low-beta resonators $B_{pk}/E_{pk}$ is about 2.5. It means, with the decrease of $B_{pk}/E_{acc}$ the cavity accelerating efficiency can be increased.

To improve RF parameters of half-wave cavity a conical shape resonator (cHWR) [1] can be used. A “standard” straight circular IFMIF half-wave resonator has been used as a model for a comparative investigation ([2] and Table 1). Since SC magnets alternate cavities in cryomodule there is a space for cavity dome volume enlargement.

Figure 1: Peak electrical and magnetic surface fields.

The first step was increasing the cavity outer conductor diameter in the dome region up to two times bigger (up to 360 mm). The rest of the cavity was kept unchanged (Fig.2a).

Figure 2: HWR with enlarged outer (a) and central conductor (b) dome diameters.

Figure 3: Power dissipation in conical HWR relative to cylindrical shape.
The resonator magnetic field volume enlargement is equivalent to the bigger cavity inductance, which results in the enhancement of cavity shunt impedance and reduction of power losses (Fig. 3). It also decreases resonance frequency. To correct the shift of the resonance frequency the cavity length becomes shorter to get the project frequency value. The larger magnetic field volume means also the smaller surface current flow density that results in the substantial $B_{pk}$ reduction with only minor $E_{pk}/E_{acc}$ enhancement (Fig. 4).

Figure 4: Peak magnetic and electrical fields in conical cavity.

The next step was to increase the diameter of the cavity inner (central) conductor (Fig. 2b). Two different diameters of outer conductors – 1.5 and 2.0 times bigger than IFMIF HWR have been investigated.

Figure 5: Peak magnetic field in conical cavity with enlarged central electrode dome diameter.

For these particular cavities the tilted cHWR (Fig. 6) was considered. The same investigations like for the straight cHWR have been provided. The results for power dissipation are very similar. There is a small difference in the field results caused by non-symmetrical field distributions (Fig.7, red points on plots are related to the straight cHWR).

Figure 6: Tilted cHWR geometry.

The larger central electrode dome diameter results in the reduction of magnetic field volume that returns the cavity frequency back to required value. The same happens with power dissipation.

Since the surface for the cavity current flowing along the central electrode in the dome region becomes bigger, the current density lows down. This results in the further $B_{pk}/E_{acc}$ reduction (Fig. 5).There is no much space for the first and last cavities in the cryomodule for dome volume developments.

Figure 7: Tilted cHWR parameters.

Figure 8: Tilted cHWR geometry and peak surface magnetic field.

The same cavity would be valid for two in series HWR installation between SC magnets. The central electrode cone diameter enlargement works in the way like by straight cHWR (Fig. 8). Fig.9 shows a possible position of conical resonators in the cryomodule.

Figure 9: Possible position of conical resonators in the cryomodule.
Racetrack Half-wave Resonator

For the higher energy part of an accelerator where cavities are installed without space between them the conical cavities cannot be used otherwise the whole accelerator length will be increased. In this case racetrack shape cavities (rHWR) are proposed.

First, the case with the same shape of the central electrode has been investigated. Stretching dome shape in one direction results in magnetic field volume enlargement. The cavity frequency decreases but since the cavity shunt impedance grows up, dissipated power losses are reduced. During this study for simple comparisons the same nominations like in the case with conical HWR developments have been kept.

Since the dome enlargement has been made only in one direction a peak magnetic surface field is defined by the shorter racetrack size and stays the same like in the original round HWR (Fig.11).

For a modification of the central electrode geometry an elliptic shape has been used (Fig.12). Here again, the shorter ellipsis axes (Rin_cyl) have been kept of the size of the original cavity and the bigger axes was increased up to two times of Rin_cyl.

An enhancement of the surface of the central electrode close to the dome results in decrease of surface current density. Bpk/Eacc has been reduced from 10.5 down to 8 mT/MV/m. There is clear optimum for the central electrode shape modification (Fig.13).
CAVITY TUNE

The cylindrical plunger installed at the cavity dome was investigated [2]. This plunger by insertion in the cavity disturbs the magnetic field volume and changes inductance of the cavity. Since the cavity magnetic field occupies much bigger volume in comparison with disturbed one, the frequency change caused by the “magnetic” plunger is low or it requires large plunger insertion. Our simulations result in few kHz per mm of the insertion depending on plunger length. Another negative aspect of the inductive tuner is the large enhancement of the peak magnetic field value. The peak magnetic field region with the use of the inductive plunger is moved from the surface of the central electrode to the plunger.

![Figure 14: cHWR with inductive tuner geometry.](image)

The conical HWR makes magnetic plunger more effective. The bigger cavity dome volume allows using the bigger plunger that will result in the larger frequency shift.

The results of cHWR simulation with inductive plunger (Fig. 14) are presented on Fig. 15. Here on all plots, the blue lines correspond to vacuum port diameter rbport=16 mm and b-plunger radius rbplun=0.7*rbplport=11.2 mm. The red lines for rbplport=24 mm and rbplun=0.7*rbplport=16.8 mm. The bigger plunger (rbplun=16.8 mm) with a depth penetration in the cavity of ybplun=80 mm results in nearly 200 kHz frequency shift with highest tune sensitivity more than 2.5 kHz/mm.

![Figure 15: Tune sensitivity of cHWR.](image)

Because of the bigger distance between plunger and central electrode there is no affection on Bpk/Eacc has been detected (Fig. 16).

An enlargement of the central electrode cone diameter in the dome region results in the closer electrode position to the plunger, which in its turn results in the Bpk position shifting to the plunger and growing in a value (Fig. 17).

![Figure 13: rHWR magnetic field distribution (a) and peak surface magnetic field (b).](image)
An enhancement of $B_{pk}/E_{acc}$ with plunger insertion eliminates an advantage of bigger central electrode diameter in terms of $B_{pk}/E_{acc}$ minimisation. The resulted cavity frequency shift is not much bigger than in the previous case (about 250 kHz) with a maximal tune sensitivity of slightly less than 4 kHz/mm (Fig. 18).

An installation of the inductive plunger in racetrack HWR does not change a value of the peak magnetic field. The resulted cavity frequency shift with 60-70 mm plunger penetration in the cavity is about 150 kHz with a maximal tune sensitivity of around 2.5 kHz/mm (Fig. 19).

REFERENCES
