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 peripherical 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 Haf-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

Frequency	MHz	175
$\beta=v/c$		0.094
$R_{aperture}$	mm	20
$\beta\lambda$	mm	161.04
R_{cavity}	mm	90
G	Ohm	28.55
E_{pk} / E_{acc} *)		4.42
B_{pk} / E_{acc} *)	mT/MV/m	10.12
*) $L_{cav} = N_{gaps} * \beta\lambda/2$, where $N_{gaps}=2$ – 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-ß 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.
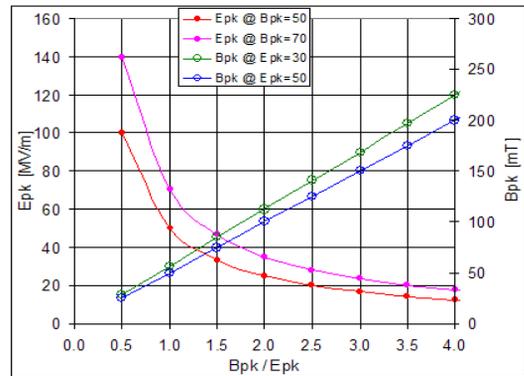

Figure 1: Peak electrical and magnetic surface fields.

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).
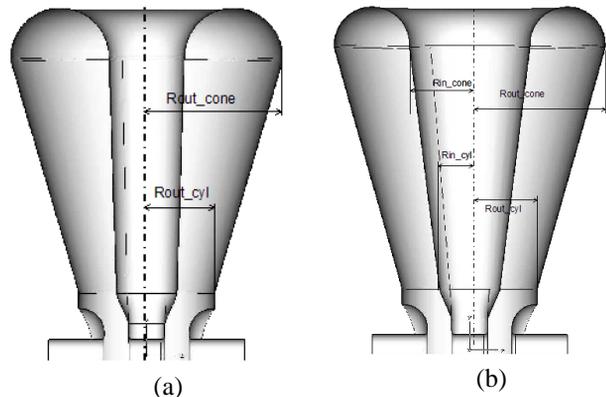

(a)   (b)

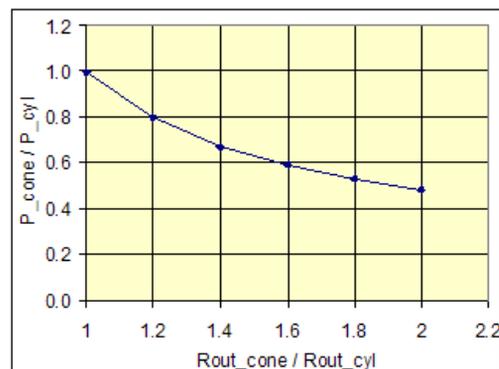Figure 2: HWR with enlarged outer (a) and central conductor (b) dome diameters.

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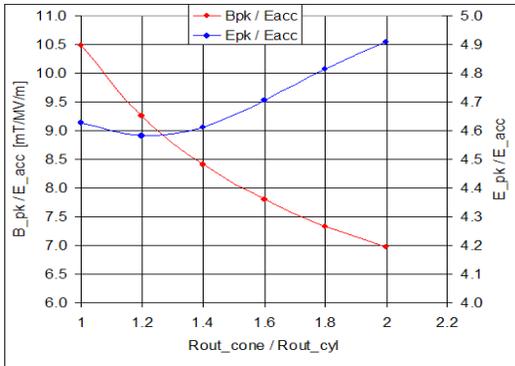
Figure 4: Peak magnetic and electrical fields in conical cavity.

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.
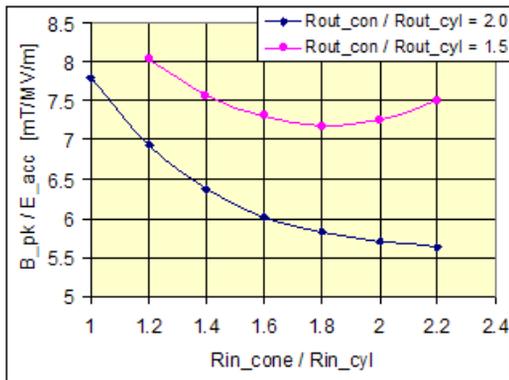

Figure 5: Peak magnetic field in conical cavity with enlarged central electrode dome diameter.

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.

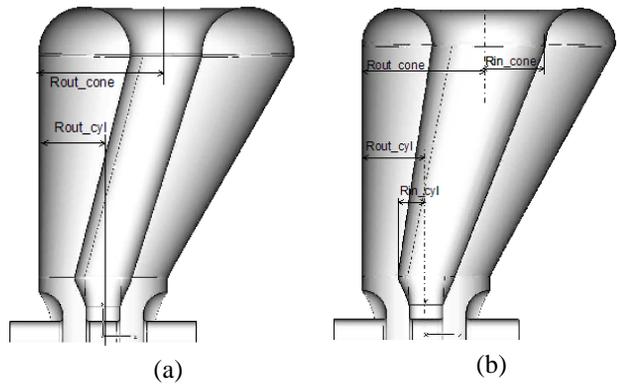(a)   (b)

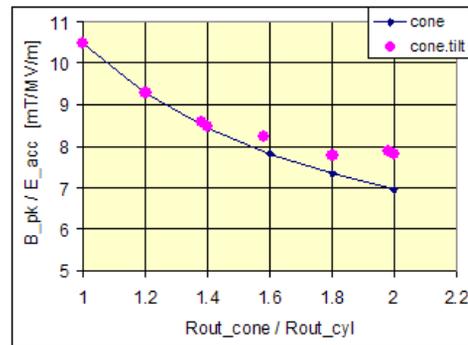Figure 6: Tilted cHWR geometry.

Figure 7: Tilted cHWR parameters.

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).
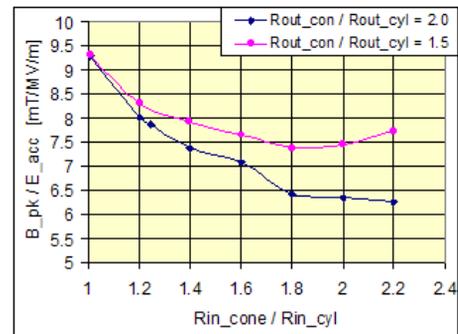

Figure 8: Tilted cHWR geometry and peak surface magnetic field.

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.
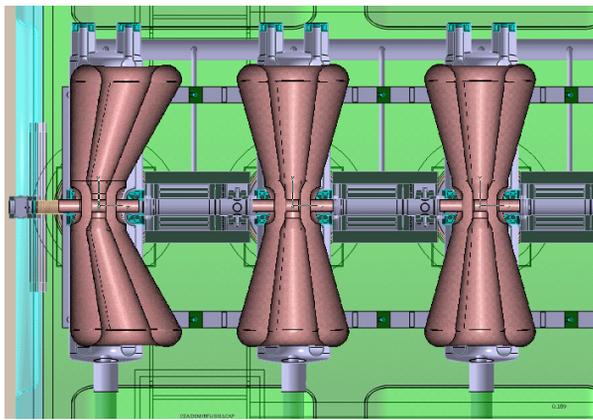
Figure 9: cHWR positions in cryomodule.

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.
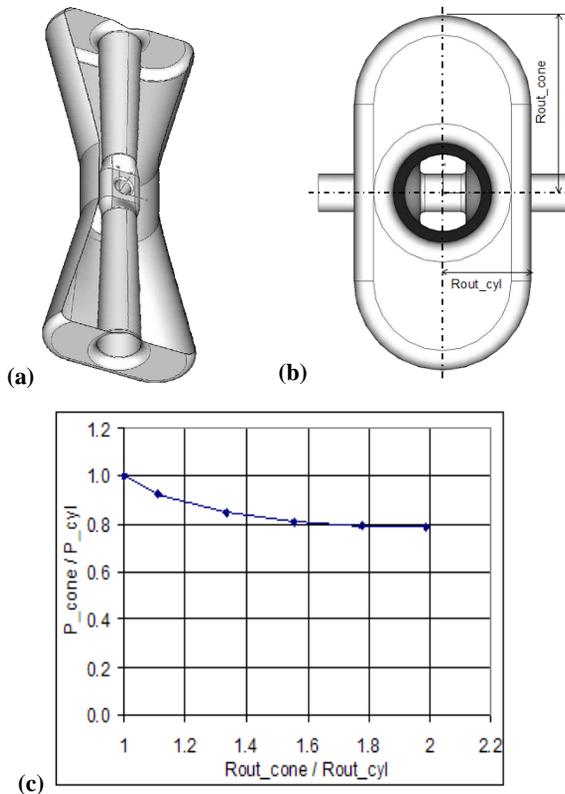

(a)   (b)

(c)

Figure 10: Racetrack HWR geometry and relative power dissipation by cavity shape modification.

The racetrack HWR is a modification of round HWR with racetrack dome shape in the direction perpendicular to the beam path (Fig.10). The shorter size of racetrack was kept the same as the round cavity diameter ($Dout=2*Rout\_cyl$) and longer part is varied like in conical cavity case up to two times ($Rout\_cone=Dout$).

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).
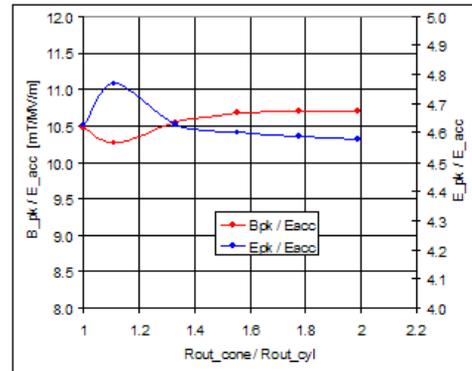

Figure 11: rHWR magnetic field distribution.

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.
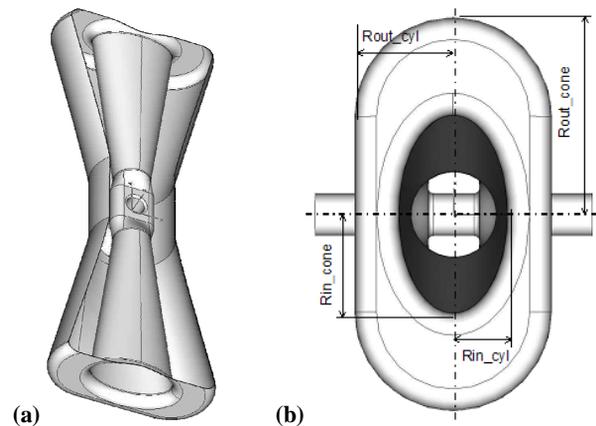

(a)   (b)

Figure 12: rHWR geometry with enlarged central electrode dome shape.

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.
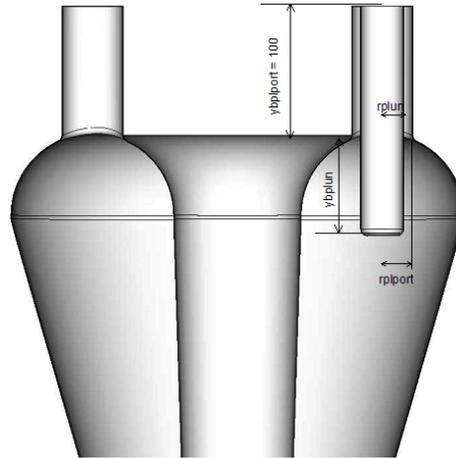

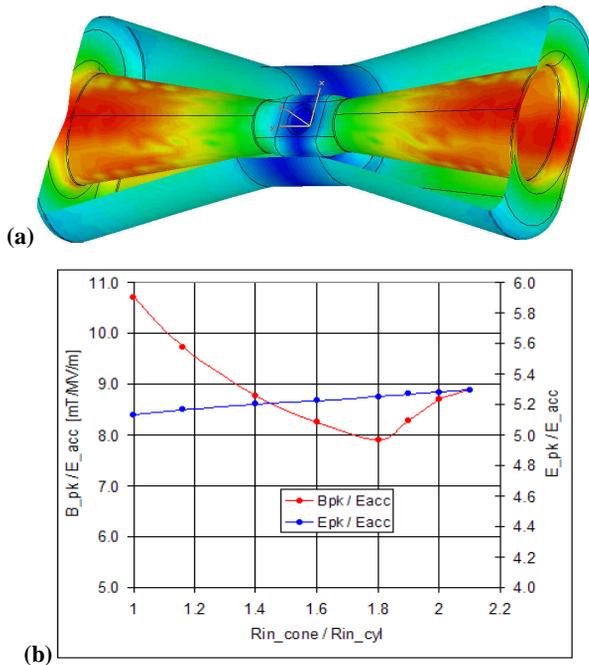Figure 14: cHWR with inductive tuner geometry.

Figure 13: rHWR magnetic field distribution (a) and peak surface magnetic field (b).

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 rbplport=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.
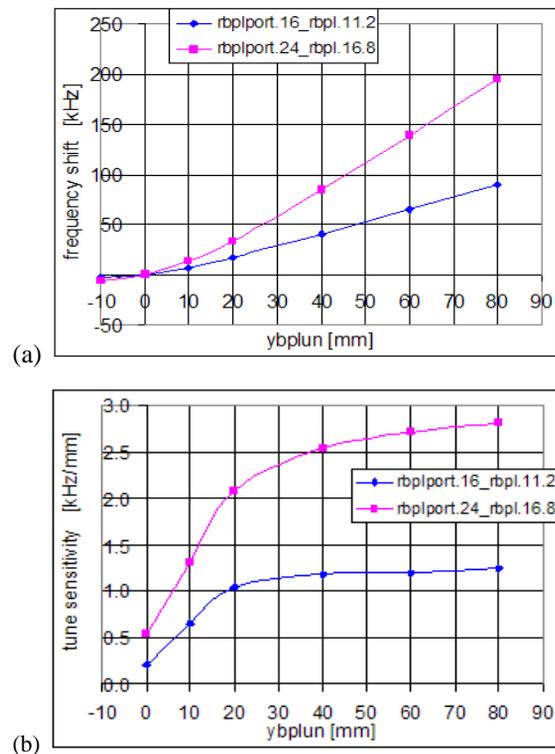

Figure 15: Tune sensitivity of cHWR.

Because of the bigger distance between plunger and central electrode there is no affection on B_{pk}/E_{acc} 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 B_{pk} position shifting to the plunger and growing in a value (Fig. 17).
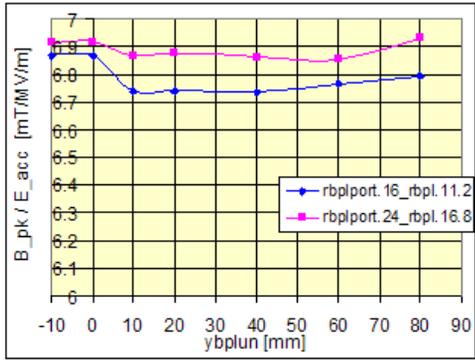
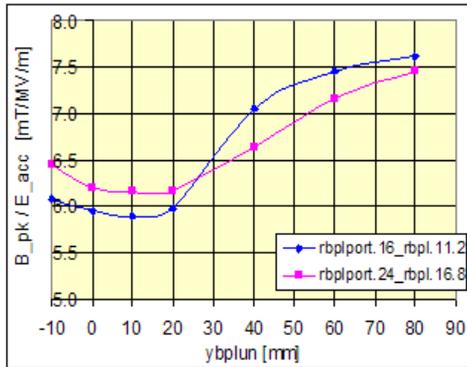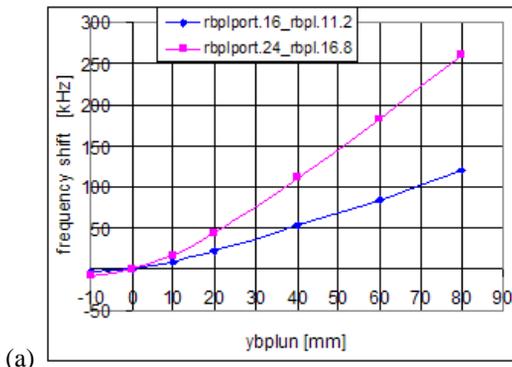Figure 16: B_{pk}/E_{acc} in cHWR with inductive plunger.
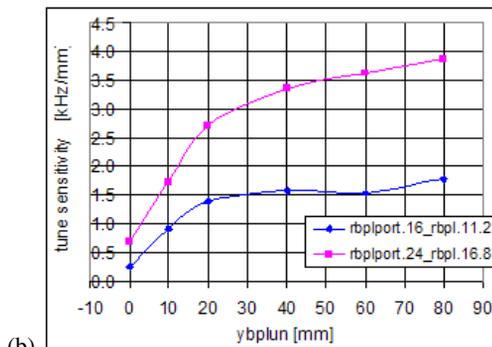

Figure 17: cHWR with inductive tuner geometry.

(a)

(b)

Figure 18: Tune sensitivity of cHWR with enlarged central electrode cone diameter.

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).
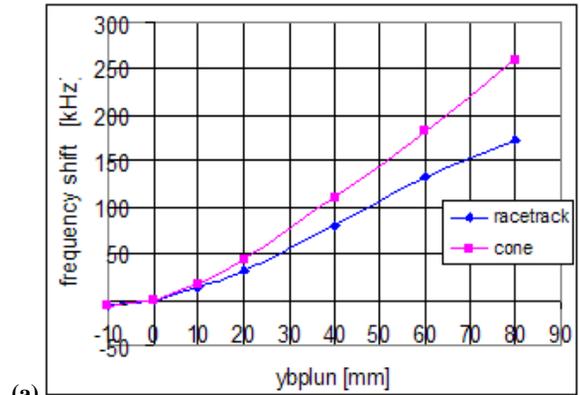
(a)
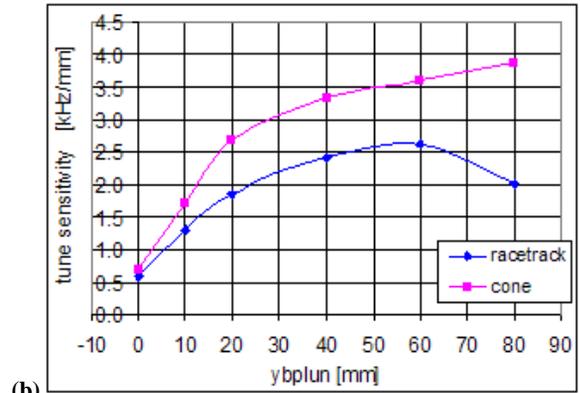
(b)

Figure 19: Tune sensitivity of rHWR.

REFERENCES

[1] E. Zaplatin et al, "Low-ß SC RF Cavity Investigations", SRF01, Tsukuba, Japan, 2001.
E. Zaplatin et al, "Very Low-ß Superconducting RF Cavities For Proton Linac", ESS 01-122-L, Juelich, Germany, 2001.

[2] E. Zaplatin et al, "IFMIF Superconducting β=0.094 Half-Wave Resonator Design", PAC09, Vancouver, Canada, 2009.