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EFFECT OF HIGH-MAGNETIC FIELD REGION GEOMETRY ON THE EFFICIENCY OF A 750 MHz IH STRUCTURE*

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Abstract

High frequency structures generally translate to high efficiency performances thanks to reduced surfaces of the inner cavity. Two round-profiles geometry and some variations of two important parameters of a 750 MHz IH-DTL are proposed in this paper in order to improve shunt impedance performance regarding an existing solution with flat-walled cavity developed by CERN. The proposed designs are shaped such that they guarantee an easy connection of RF and vacuum auxiliaries. Electromagnetic simulations are checked with CST Microwave Studio.

INTRODUCTION

H-mode accelerator structures, which work in transverse electric (TE) modes, stand out mainly because of their high efficiency performance in low β regimes, compared to other accelerator structures such as Alvarez linac type cavities [1]. Among the different types of H-mode DTL structures, two are emphasised above all, the so-called crossbar H-mode (CH), which operates in TE210 mode; or the interdigital H-mode (IH) structure, operating in TE110 mode. It is for a specific particle's velocity range, below β ~0.15, where IH cavities show the most efficient performance [2], and become a necessary component in linac injectors for light and heavy ions. An example is the bent-linac injector for medical applications with carbon ion beams [3] proposed at CERN, which comprises a compact 750 MHz RFQ in the first RF acceleration stage (0.4-5 MeV/u) [4]. After such cavity, the use of an optimised 750 MHz IH structure capable of covering the first range up to 5-10 MeV/u range has been proposed [5].

There are some factors that can define the high value of the RF cavity efficiency, such as its external structure. Refining the shape in the auto-inductive dominated regions of the cavity allows for further optimisation of the power consumption. Concerning this idea, this work explores the shaping and geometry parametrisation of a 750 MHz IH cell aiming at improving its efficiency.

The shunt impedance (Z) parameter is a good variable to study the optimisation of the cavity. This variable is defined as the ratio between the square of the longitudinal voltage in the cavity and the consumed power. Thus, with a constant longitudinal voltage, the value of Z reaches its highest value when the power dissipated in the cavity walls is minimised. One usually deals with the effective shunt impedance (ZTT), which includes the transit time factor of the voltage noticed by the beam. Under this consideration, in order to achieve the objective of this study, some proposals for geometric modifications to the 750 MHz IH structure together their ZTT values are presented here. These structures are capable of reducing the dissipated power while maintaining the dimensions of the drift tubes.

With a view to carry out this analysis, the CST Studio Suite 2021 software was used. This software allows for the simulation of the resonance frequencies of an RF cell, EM fields and some determining parameters such as the effective impedance ZTT.

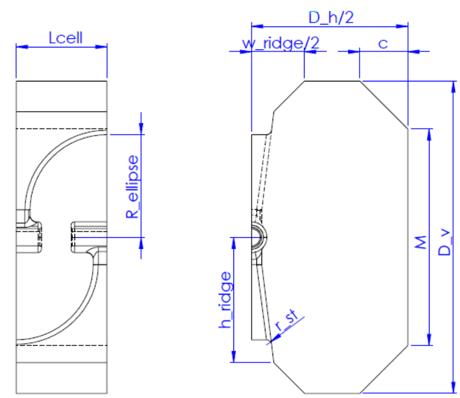

Figure 1: Front view (right) and lateral cross section (left) of half standard IH cell.

Figure 1 shows the baseline cavity in which the analysis was carried out, as well as the nomenclature of key parameters that have been studied in the optimisation. It is a regular cell that belongs to an IH cavity with a structure inspired by the S. Benedetti et al. study [5]. With a length of 25.16 mm and a gap equal to 8.99 mm, this cell has a series of flat copper walls for the outer profile, motivated by an easy machining and insertion of auxiliaries. These flat walls will be modified during this study.

EFFICIENCY AND CAVITY WALLS

Choosing the best acceleration structure for a given application is a complicated task. To narrow down the spectrum of possibilities, it is useful to set some constraints. In this work, the orifice size, the gap and the operating frequency were fixed. The decision on the orifice radius comes from

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beam dynamics considerations, although this size greatly affects the RF optimization, as does the gap [6].

On metallic surfaces that are not perfectly conductors, the electromagnetic fields (E_s and H_s) penetrate into the material through a certain depth, leading to a power density dissipated in the walls:

$$\frac{dP}{dA} = \frac{1}{2} R_s H_s^2 \tag{1}$$

R_S is the surface resistance of the cavity, in this case made of copper, and H_S is the magnetic field, which can be considered uniform on the cavity profile at first order approximation. Equation (1) reveals that one would need to reduce the area of the copper walls that enclose the cavity in order to reduce the dissipated power in the cell, as it is confirmed in simulation results shown in Table 1[1].

Table 1: Values belonging to the flat cavity IH (Fig. 1) with different modifications of Dv and Dh, simulated in CST.

***Dv* [mm]**	***Dh* [mm]**	***c* [mm]**	***Area* [mm^2]**	***ZTT* [MΩ/m]**
91	104.91	26.50	2473	329.21
92	104.70	27.00	2487	328.18
95	104.16	28.50	2532	324.96

Generally, there is an increment of ZTT when reducing the vertical size (Dv) of the cavity, but we have to increase the horizontal size (Dh) to retune the resonance.

Another solution to reduce the area of walls is to make them round. Also, some variations of two parameters have been adopted in this study for this purpose.

SHAPE VARIATIONS

Flat Walls Profile

The reduction of Dv is limited at a certain level by other parametrised dimensions of the stems, such as $R_{ellipse}$, as it is obvious that the cavity size cannot be smaller than the stem size. In Fig. 2, the variation of the ZTT parameter was evaluated as a function of Dv and $R_{ellipse}$ for the flat-walled IH cavity (Fig. 1). This could not be assessed for values of Dv below the mentioned limit and, for this reason, the trend of increasing ZTT is cut. It is found optimal to maximise $R_{ellipse}$, so that the ellipse edge which describes the stem shape ends on the corresponding ridge. That is:

$$R_{ellipse}^{opt} = h_{ridge} - r_{st} \tag{2}$$

where r_{st} =1.5 mm is the small rounding at the ridge edge.

We also found the size of the lateral wall, which is indicated in Fig. 1 by the M dimension, to be critical for the optimisation (being an analogous dimension definition as parameter c). This flat wall, for both left and right sides,

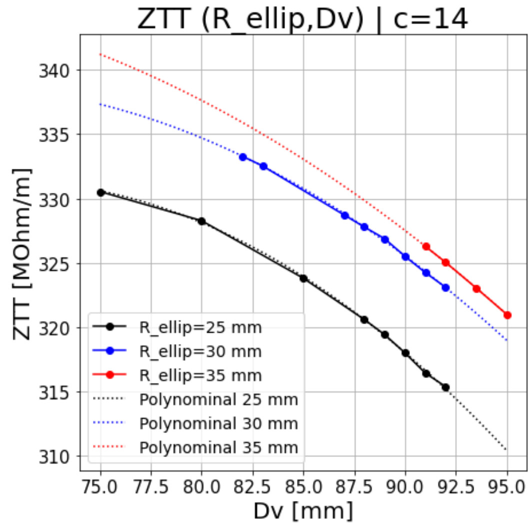

Figure 2: ZTT analysis for $R_{ellipse}$=25,30,35 mm as a function of Dv in the flat-walled cavity.

is intended to allocate power couplers, vacuum ports and tuners, thus a minimum width of 38 mm will be required as it was designed for the RFQ [4]. In Fig. 3, the ZTT parameter is analysed as a function of M, and establishing the optimal $R_{ellipse}$ in each case. ZTT is consistently larger as the lateral wall width shrinks. For this reason, it is found convenient to restrict the M dimension to its minimum possible value of 38 mm.

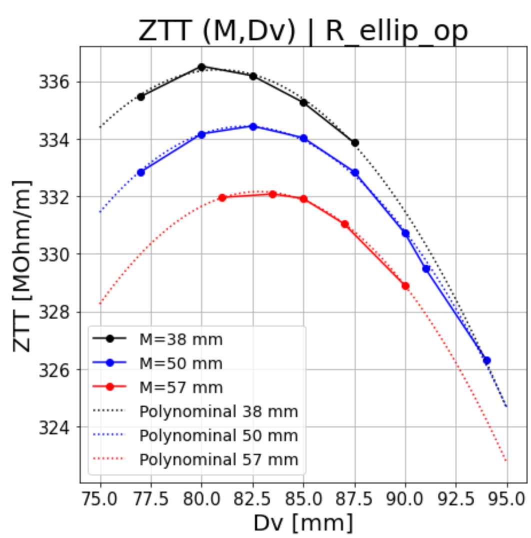

Figure 3: ZTT analysis for the values M =38,50,57 mm as a function of Dv and maximising the value of $R_{ellipse}$.

Round Walls Profile

Based on the principle of area reduction to improve ZTT, two structure models with round profile walls were proposed (see Fig. 4). Model 1 substitutes the straight boundaries on the corners of the original one by two arcs, of radius $R1$ and $R2$, that are tangent to the lateral wall line (width is maintained at 38 mm) and the angled line of the stem. Instead, Model 2 breaks the tangent bounds of the second

[1] Others constant values used in the simulations carried out in Table 1: h_{ridge} =30.29 mm, $R_{ellipse}$ =28.79 mm, M =38 mm and $Freq$ = 749.48 MHz.

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arc because the $X1$ coordinate of the centre of the arc 1 is fixed at 2 mm. This makes the $R1$ larger than in Model 1.

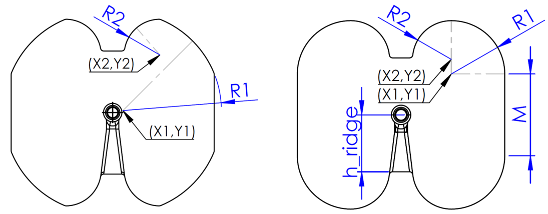

Figure 4: Model 1 (M1) and Model 2 (M2) of the studied IH cells with round profile.

Table 2: Model 1 and Model 2 of the IH cells studied with round profile.

	Flat Walls	Round Walls (M1)	Flat Walls	Round Walls (M2)
Dv [mm]	90.00	90.00	90.00	90.00
Dh [mm]	104.74	94.76	105.45	99.77
M [mm]	38.00	38.00	38.00	38.00
h_{ridge} [mm]	31.27	31.27	28.78	28.78
$R_{ellipse}$ [mm]	29.77	29.77	27.28	27.28
ZTT CST [MΩ/m]	331.12	333.25	327.74	337.48

Table 2 shows two comparisons made between the three IH cell profile variations that have been studied. The first two columns show the results of *ZTT* obtained for the flat walls profile and for the first model made of round walls. For the sake of a fair comparison, the stems and drift tubes dimensions are the same, that means that h_{ridge} and its optimal $R_{ellipse}$ are fixed, and only the parameters that define the outer profile are adjusted. An enhancement of 0.65 % of *ZTT* was obtained by adopting the first variation of round walls. It should be noted that this comparison was carried out at a Dv value equal to 90 mm, since it provides the highest *ZTT* (see Fig. 5). The same procedure was performed for the last comparison between the flat profile cell and the second variation of a round profile cell. In this case, model 2 gives a *ZTT* increase of 2.9 % over the flat profile cavity.

The values obtained in Table 2 have also been simulated with the HFFS software. Although the mesh generation process is different in the CST and HFFS sofwares, the same settings have been applied in order to make results comparable. A fine mesh of maximum 0.8 mm is specified in a box containing the drift tube region while, for the rest, meshing elements are limited to 10 mm. In addition, curved surfaces are approximated to a maximum normal deviation of 10 degrees.

Under these considerations and achieving a similar number of meshing cells, the results define that the HFFS software offers very similar values to those of CST. The biggest difference found is a 1 % reduction of the *ZTT* values with HFFS compared to the values with CST.

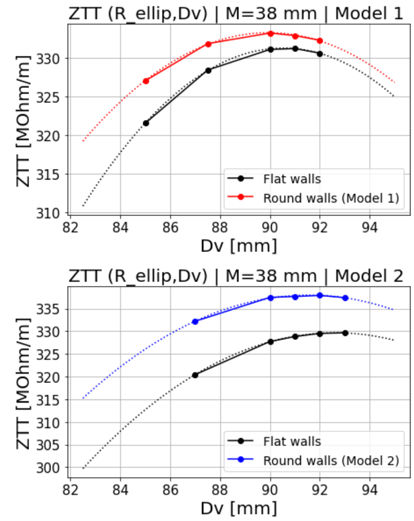

Figure 5: Model 1 and Model 2 of the studied IH cells with round profile and the flat profile cavity.

CONCLUSIONS

After the parametrization effort on a regular cell of an IH structure, the $R_{ellipse}$ and M dimensions were proven to be of great importance in the interest of enhancing power efficiency. To sum up, $R_{ellipse}$, which outlines the shape of the stem base, needs to be maximised up to the ridge level, while the lateral wall width M should be as small as possible, as long as the structure allows and facilitates power coupling and tuning.

Regarding the outer profile of the cavity, aiming at reducing the high magnetic field area, where power losses take place, simulations show a slight improvement of shunt impedance when adopting round walls, up to 2.9 % for the second proposed model. The approach of rounding the walls of the IH tank is beneficial to electricity consumption costs, however at the expense of a somewhat higher degree of complexity in its fabrication. Nonetheless, the outer profile of the cavity does not require the tightest tolerances, as it does for the drift tubes, since any undesired machining errors are intended to be corrected with external tuning tools. It should also be mentioned that the efficiency enhancement achieved in this study makes no special relevance in the choice of the power source (solid state amplifiers), considering that the maximum available power will be safely foreseen to be well above the required input power.

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