ESS DTL

FACE ANGLES, MESH STUDY AND STEM REALIZATION METHODS USING POISSON SUPERFISH,

HFSS 3D TANK SIMULATIONS

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1. INTRODUCTION

For a DTL with constant synchronous phase, the synchronous particle travels from the center of a drift tube to the center of the gap in half an RF period, and continues to the center of the next drift tube in the next half period. Owing to the acceleration, the length of each cell must increase to maintain the synchronism. The required cell-length profile depends on the synchronous velocity β_s , which increases because of the energy gain in each cell. The energy gain in each cell depends on the electric field, and on the length of the cell. Because of the interdependency of the cell length and energy gain, the cell design is usually done by a method of successive approximations. First, the cell geometry at each β_s must be chosen, generally based on the criterion of maximum effective shunt impedance, consistent with (1) obtaining the correct resonant frequency, (2) allowing room within the drift tubes for quadrupole focusing lenses, and (3) keeping the peak surface electric and magnetic fields within the technological limits, determined by electric breakdown and drift tube cooling requirements. The fields, power, transit-time factor for the synchronous particle, and the shunt-impedance calculations are usually done using electromagnetic-field-solver codes like Superfish. This procedure results in an optimum cell geometry in which the gap length, drift-tube shape, and tank diameter are determined.

2. MESH STUDY IN SUPERFISH

A cell to cell mesh study was performed in Superfish, to observe the impact of the mesh element density change on the cell resonant frequencies.

When considering a DTL cell, some parameters have to be taken into account. Among these, the face angle α has a significant importance: it is a value that allows frequency adjustments, inside the cell, when needed, for example when the stem that supports the drift tube, is considered for the structure taken in account.

As it was said before, this study was performed on every single cell of the five tanks, and, for each tank and for each chosen mesh, f_{stem} vs cell number was plotted. In every case, the use of original face angles α_{nc} (not corrected, for a cell not containing a support stem), rather than corrected ones α_{stems} (that adjust cell frequencies in the way to take stems in account) was also taken in account.

Results can be seen in figures 1, 2, 3, 4 and 5. When creating a structure in Superfish, one defines the value of **MESH_size**; this is the smallest mesh size in cm to use in the Superfish calculation. The smallest mesh occurs near the smallest features in the problem geometry, usually where the electric fields are largest and change most rapidly. The tuning code increases the mesh size in other places if it can significantly reduce the total number of mesh points by doing so. For each tank, mesh values of 0.03, 0.02 and 0.015 was chosen, except for tank 1, whose study stops at mesh values of 0.03 and 0.02



<u>Tank 1</u>

Figure $1 - f_{stem}$ vs cell number for Tank 1, with mesh values of 0.03, 0.02.





Figure 2 – f_{stem} vs cell number for Tank 2, with mesh values of 0.03, 0.02, 0.015.



Figure 3 – f_{stem} vs cell number for Tank 3, with mesh values of 0.03, 0.02, 0.015.



Figure $4 - f_{stem}$ vs cell number for Tank 4, with mesh values of 0.03, 0.02, 0.015.



Figure 5 – f_{stem} vs cell number for Tank 5, with mesh values of 0.03, 0.02, 0.015.

From the plots above, it can be seen that the frequency shift is ≈ 1 MHz for the first and the last cell of each tank and ≈ 1.5 MHz for every other cell of each tank. It can also be noticed that, when a finer mesh is used, the frequency value shifts slightly below the value obtained through the use of a more coarse mesh.

3. E₀ RESULTS, SUPERFISH

In the process of tuning the single cells and subsequently the entire tanks, Superfish simulator calculates two different target frequencies: the first is the proper resonant frequency of the cell (or the tank) considered, and the second, named "Cavity frequency corrected for stems and post couplers", is the resulting resonant frequency when the simulator takes in account the subtracted cavity volume due to the presence of stems and/or Post Couplers. These two numbers can be found in the .SFO file created when the cavity/tank tuning is performed.

Superfish tunes the cells by making a revolution solid, around beam axis, from the 2D cell plot, and then it calculates the corrected frequency, $f_{stems + posts}$, using Slater perturbation theorem. These calculations are applications of the Slater perturbation theorem using fields calculated by Fish in the region occupied by the stem.

Another way to study the presence and the effects of stems on fields and resonant frequency could be the subtraction of a stem–proportional volume from the cell volume. By knowing the stem corrected frequency for each cell, this could be done by modifying the geometry of the single cells through subtraction of a volume (figure 6), in the way to tune the cell and reach the stem corrected frequency. Then, the entire tank can be assembled and the frequency, fields can be observed.



Figure 6 - Detail of Superfish's first cells of tank 4. Above are shown axis field lines obtained using non corrected face angles α_{nc} , below are shown axis field lines obtained using corrected face angles α_{stems} and inserted "stem volumes".

The following figures 7, 8, 9, 10 and 11 show E_0 field plots obtained by the application of the two methods illustrated above, for the five tanks of the DTL. To verify the correctness of the studied "volume subtraction" method, a similarity between no stems DTL E_0 field (use of α_{nc}) and DTL with stems (use of α_{stems}) E_0 field, is needed.



Figure 7 - EO field for tank 1. Tank resonant frequency is 351.3 MHz.



Figure 8 - E0 field for tank 2. Tank resonant frequency is 351.31 MHz.



Figure 9 - E0 field for tank 3. Tank resonant frequency is 351.29 MHz.



Figure 10 - E0 field for tank 4. Tank resonant frequency is 351.28 MHz.



Figure 11 - E0 field for tank 5. Tank resonant frequency is 351.29 MHz.

4. E₀ RESULTS, HFSS

In order to check the reliability of the fields obtained with Superfish, another set of simulations was performed in full 3D with Ansys HFSS. These simulation were performed for tank 3, 4 and 5. Figures 12, 13 show the *xz* plane section section of the full realized tank 5 and a detailed view of the first cell. Figure 14 shows a mesh detail for the last cells of tank 5: for each tank, a minimum mesh size equal to 5 million tetrahedrons was used. For example, tank 5 was meshed using 6.304.260 tetrahedrons, to obtain quite faithful fields results.



Figure 12 - 3D model of tank 5 built in Ansys HFSS.



Figure 13 - Detail of tank 5 first cell. 16



Figure 14 - Mesh detail for the last cells of tank 5.

The number of mesh elements was increased in the beam axis zone, where electric field mostly resides.

We are interested in E_0 , that is the average axial electric field. The way to obtain it is to calculate E_{0i} for each cell of the tank, and then plot the entire field vs distance.

To obtain E₀, two ways have been followed.

First method – Axial field integral

For each cell, it is known that the average voltage value can be obtained as $V_0 = \int_L E(z)dz$, where L is the cell length and E(z) is the cell axial field value. So, from the definition of electric field, one can now obtain the desired E₀ value with $E_0 = \frac{V_0}{L} = \frac{1}{L} \int_L E(z)dz$.

Second method – Faraday-Neumann's law



Applying the integral form of Faraday's law within a single cell over a rectangular path Γ that includes the beam axis and the outer wall, one finds that:

$$\oint_{\Gamma} E(z) \cdot dl = -j\omega \iint_{S} B \cdot \hat{n} dS$$

But the electric field is present only near the beam axis (it vanishes on the two stem walls and on the tank outer wall), therefore:

$$\oint_{\Gamma} E(z) \cdot dl = E_0 \beta \lambda$$

From first and second equation:

$$E_0\beta\lambda = -j\omega\Phi$$

where Φ is the magnetic flux per unit length that circulates azimuthally in the cell. Finally:

$$E_0 = -\frac{j\omega\Phi}{\beta\lambda} = -\frac{j\omega\Phi}{L}$$

In figures 15, 16 and 17, E_0 field for tank 3, 4 and 5 is plotted. In particular, four versions of the average field are presented for each tank: E_0 obtained in Superfish through use of original face angles (face angles "not corrected", that is face angles used in a tank without stems), E_0 obtained in Superfish through use of face angles corrected to take in account stem presence and insertion of "stem triangles" (for each cell, subtraction of a volume representative of the stem volume + effects of the fields in that area), E_0 obtained in HFSS through integration of axial field E(z), E_0 obtained in HFSS through use of Faraday-Neumann's law.



Figure 15 - E0 field for Tank 3. HFSS tank frequency = 351.8 MHz.







Figure 17 - E0 field for Tank 5. HFSS tank frequency = 351.79 MHz.

5. SUMMARY OF OBTAINED VALUES

In table 1 values of tank frequency and E_0 , obtained in Superfish and HFSS, are summarized. E_0 values are **field excursions** for each tank ([max(E_0) - min(E_0)]/ave(E_0)] and, for Superfish, α_{nc} , α_{stems} cases are indicated.

	Superfish, α _{nc}		Superfish, α _{stems} +		HFSS	
	freq (MHz)	E ₀ excursion	freq (MHz)	E ₀ excursion	freq (MHz)	E ₀ excursion
Tank 1	351.79	0.0672	351.30	0.0789	-	-
Tank 2	351.77	0.0224	351.31	0.0943	-	-
Tank 3	351.77	0.0316	351.29	0.0264	351.80	0.0459
Tank 4	351.77	0.0327	351.28	0.0357	351.80	0.0211
Tank 5	351.78	0.0440	351.29	0.0381	351.79	0.0255

Table 1 - Values of tank frequency and EO field, obtained through Superfish and HFSS.

6. CONCLUSIONS

Regarding DTL study for ESS, a novel method of stem simulation through 2D simulator Superfish has been investigated. Results are also in good agreement with those obtained in 3D tank simulations, using HFSS.

7. BIBLIOGRAPHY

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