# A SIMULATION STUDY ON ACCELERATOR CAVITIES FOR A SW LINAC

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*Abstract*

An on axis-coupled cavity structure has been studied using S-band microwaves at 2856MHz, suitable for industrial and research applications. It uses a bi-periodic SW structure with constant impedance that operates at π/2 mode. This structure consists of Bean-like shaped slots, placed symmetrically with respect to the accelerating axis. We compared different shapes, places and sizes of slots with respect to coupling coefficient, resonance frequency and some of cavity parameters. Sensitivity analyses of accelerating cavity on details of structure have been done and their behaviour, with respect to the resonance frequency has been investigated. According to the simulation results using SUPERFISH and CST Studio package, each accelerating cavity is capable to deliver 0.56 MeV to electrons in a 50μA beam.

## INTRODUCTION

In designing of accelerator cavities for SW linacs, we should consider some figures of merit such as quality factor, effective shunt impedance and also transit time factor of cavity. This linac is intended to deliver an electron beam up to 10MeV with a Klystron power of 2MW having a pulse width of 5 μsec and a waveguide operating in the TE01 mode. And our cavity will be operated in the TM010 mode.

## DESIGN CONCEPTS

Designing the cavity can be started with a simple pillbox cavity with beam holes on the end plates, adding nose cones to create a region of more concentrated axial electric field that it reduces the gap and raises the transit-time factor [1]. The optimization procedures depend on the constraints of our equipments. The nose cone, septum thickness and lower wall radius might be constrained by the technology of cavity machining. So they are known before starting our work. We should mention that Borehole radius $R_b$ is determined from beam dynamics considerations.

Some relations can help us to find other parameters. For example, Upper wall radius, $R_{co}$, is determined for each cavity by[2].

$$R_{co} = L/2 - S - \Delta x \qquad (1)$$

In which L and S refer to length and septum thickness of a cavity, respectively. A small straight section Δx on the circumference of the wall cavity might be required to increase effective shunt impedance ($ZT^2$) slightly. This effect is more evident for larger β values than for small ones. The best value of Δx is about 10% of half-cavity length. The two remaining parameters, D and g have the strongest effect on $ZT^2$ and frequency [2]. Thus the Sketch of the cavity had been done. In following by sensitivity analyzing the optimization of our cavity has been performed to maximize the efficiency. using diagrams of frequency, $ZT^2$, Z, Quality factor etc. respect to cavity geometrical parameters[2].

Some of electromagnetic codes have been used to solve Maxwell's equation with the specified boundary conditions. In this paper SUPERFISH[3] and CST suit studio package[4] have been used for simulation of our designs.

Sensitivity analysis and benchmarking for all cavity parameters have been done. But two diagrams which are more determinative have been shown in Fig (1) and (2). Fig (1) Shows Resonant Frequency vs. Gap Length. As it is clear, there is a good agreement between CST and SUPERFISH results. The SUPERFISH results are more accurate than CST results. This discrepancy is due to different normalization coefficients, although the behavior of results in is the same in both. It can be seen in Fig (2) that these results can be coincident by varying Effective Shunt Impedance in vertical Axis. Effective Shunt Impedance is a very significant parameter in SW cavity, since it can be set to achieve a maximum value by sweeping this parameter in gap length and optimization demanded cavity [2].

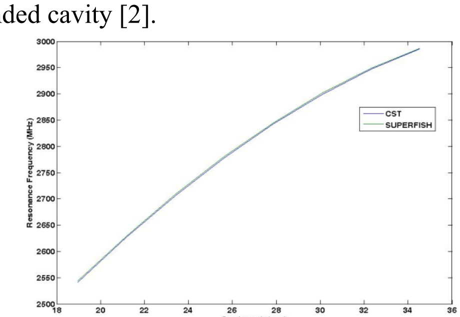


Figure 1: Resonant Frequency vs. Gap Length

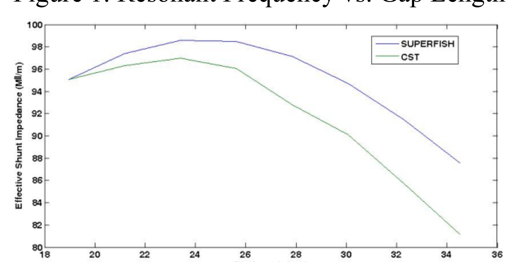


Figure 2: Effective Shunt Impedance vs. Gap Length

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## SIMULATION DETAILES

Both electric and magnetic field have been taken for coupling in SW cavities. These cavities are coupled by two slots in their walls. Although SUPERFISH can simulate resonance frequency in cavity by precision within 1-3% [5], but it is inefficient in simulating the geometry of these slots in three-dimensions. So the CST software with the accuracy of 5% can be useful for our propose [5]. To reduce this error, that's better to calibrate the Microwave Studio CST results by SUPERFISH.

The coupling calculations between two cavities are very important. After importing slots, it can be obtained by the equation 2 [5].

$$K_{ac} = -(1 - \frac{\omega_{\pi/2}^4}{\omega_0^2\omega_{\pi/2}^2 + \omega_{\pi/2}^2\omega_\pi^2 - \omega_0^2\omega_\pi^2})^{1/2} \qquad (2)$$

In which $\omega_{\pi/2}$ is the proper accelerating mode and $\omega_\pi$ and $\omega_0$ are adjacent modes. After calculating the coupling coefficient and obtaining the frequency effect of these slots on cavity, we can import ΔF to SUPERFISH. Geometrical parameters and dimensions for desirable cavity are shown in Fig (3) and Table (1) respectively

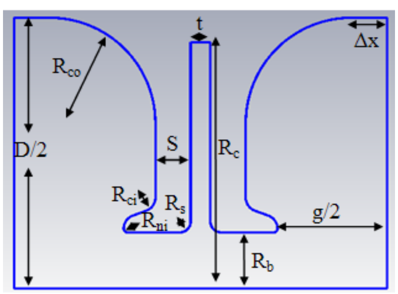


Figure 3: Geometrical Parameters.

Table 1: Geometrical Dimensions

| Geometrical Parameters | Dimensions (mm) |
|---|---|
| Bore Radius ($R_b$) | 5.0 |
| Outer Corner Radius ($R_{co}$) | 17.5 |
| Inner Corner Radius ($R_{ci}$) | 5.0 |
| Outer Diameter (D) | 77.257 |
| Gap length (g) | 25.649 |
| Nose Cone Angle | 20 |
| Septum Thickness (S) | 5.0 |
| Coupling Cavity Thickness (t) | 3.0 |
| Rounding Radius ($R_s$) | 1.5 |

In what follows, the coupling coefficient in different slots has been discussed.
The final parameters of desire cavity is shown in table (2)

Table 2: SUPERFISH Calculated Parameters

| Figures of merit | |
|---|---|
| Transit Time Factor | 0.83 |
| Quality Factor | 16616.7 |
| Shunt Impedance | 144.771 MΩ/m |
| Effective Shunt Impedance | 100.413 MΩ/m |
| Maximum Electric Field | 25.649 Mv/m |
| Kilpatrick Limitation | 1.2826 |
| r / Q | 142.22 Ω |
| Rs * Q | 233.679 Ω |
| Power Dissipation | 23.4 kw |

### *Different Shape of Slots*

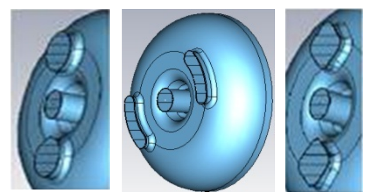

Figure 4: Circular Slot(Left),Bean Liked Slot(Center), Square Slots (Right).

Effective Shunt impedance is calculated indirectly by using the electric field and total loss that are obtained by CST and importing them to equation (3). Transit time factor is not dependent on slots, so it can be replaced from SUPERFISH results [3].

$$ZTT = \frac{E_0^2}{P/L} T^2 \qquad (3)$$

Fig (4) shows the three different types of slots. As is shown in Table 3, cavity parameters have been calculated and compared for them.

Table 3: Comparing the Different Types of Slots

| Cavity Parameters | Bean Like | Circular | Square |
|---|---|---|---|
| Total Loss(W) | 1.786e6 | 1.699e6 | 1.694e6 |
| Shunt Impedance (MΩ/m) | 129.74 | 137.153 | 137.887 |
| Effective Shunt Impedance (MΩ/m) | 92.38 | 97.54 | 98.177 |
| Coupling Coefficient (%) | -4.7 | -0.75 | -0.73 |
| Resonant Frequency (MHz) | 2824.26 | 2850.14 | 2851.4 |

Square or circular slots couldn't be a good replacement for coupling slots, although both of them have less power dissipation and higher Effective Shunt Impedance than bean slots.

By choosing bean liked slots, two possible sources of inaccuracy in the performance of the cavity would arise and should be considered, that you can see them in Fig (5): first, rounding defect in the edges of slots and second, symmetrical defect.

Sensitivity Analysis of Bean Slots is shown in table (4). Note that, Asymmetric slots won't make any special problem. But its effect will influence on decreasing the accelerating field. Rounding defect doesn't have especial effect on this field, as is shown in Fig (6).

Table 4: Sensitivity Analysis of Bean Slots

| Cavity parameters | Our design | With rounding defect | With symmetrical defect |
|---|---|---|---|
| Total Loss(W) | 1.786e6 | 1.819e6 | 8.880e5 |
| Z (MΩ/m) | 129.74 | 126.1942 | 240.464 |
| ZTT (MΩ/m) | 92.38 | 89.851 | 171.212 |
| Coupling Coefficient (%) | -4.7 | -4.6841 | -4.7369 |
| Resonant Frequency (MHz) | 2824.26 | 2831.1 | 2830.69 |

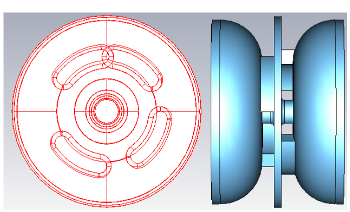

Figure 5: Asymmetric slots (left), Pointy Slots (right)

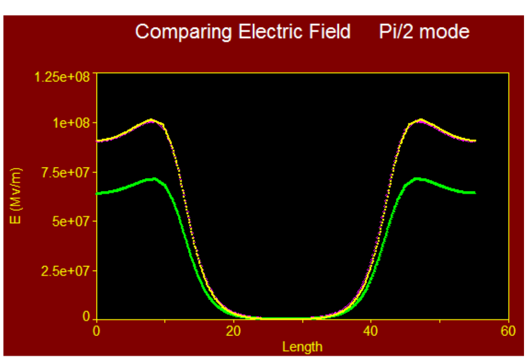


Figure 6: Electric Field in Accelerating Mode. Yellow Graph (Our Cavity), Green Graph (Symmetrical Defect) And Pink Graph (Rounding Mistakes).

### *Thermal Analyzing*

After designing the geometry, our structure has been simulated in CST MPhysics Studio for thermal analysis. This simulation has been done by thermal conductivity of 0.024 (W/K/M) and heat capacity of 1.005 (KJ/K/Kg) in ambience air conditioning. The temperature of cavity wall was determined 300 K and boundary condition has been considered open in order to heat exchange with environment. A power source of 2MW has been considered for our system.

If roundness of the slot edge is not properly designed this part would be the hottest section in the cavity. The roundness edge of 2 mm has been selected for slots by sensitivity analysis as a function of temperature. Fig (7) shows the thermal behaviour of designed cavity, after entering a pulse of power.

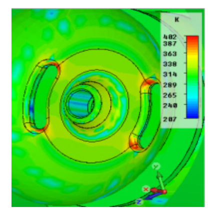

Figure 7: Thermal Analyzing of Cavity

## CONCLUSION

The geometrical dimensions of an accelerating cavity in a SW linac are designed. This linac is intended to deliver an electron beam up to 10MeV with a Klystron power of 2MW.

## ACKNOWLEDGMENT

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