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CHARACTERIZATION OF THE RF-CAVITY GEOMETRY IN ORDER TO OPTIMIZE THE BEAM PARAMETERS IN S-BAND ON-AXIS LINACS

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Abstract

The RF characteristics of an accelerating tube are primarily assigned to geometrical features of a cavity. As a consequence of this geometry, the final electric field will make the shape of our Gaussian bunch and the final dose. The accelerating field can be studied considering the nose cone, gap, and bore radius. In dual electron linacs, the role of input power and bunch current is inevitable. Therefore, the geometrical issues of RF-cavities are studied in a 6 MeV electron on-axis SW tube. To make an accurate comparison, each RF-cavity is designed and optimized by POISSON SUPERFISH. The optimized cavities are imported to the PIC solver of CST. Then the beam characteristics are studied on a predefined target.

INTRODUCTION

The main application of the tube predominantly depends on the beam properties and power considerations. The geometrical properties of an accelerating cavity can affect the selection criteria effectively.

The main geometrical parameters that vary in an acceptable range choose for the start. All the geometries were optimized concerning the figure of merits in the cavity. The optimized geometries are inserted into 3D codes to complete the coupling calculations. At last, the final beam properties are studied in the PIC solver of 3D codes. The study can be divided into two main sections:

- Cavity Design & Optimization.
- Beam Dynamics.

CAVITY DESIGN AND OPTIMIZATION

POISSON SUPERFISH is one of the most accurate codes in cavity tuning and optimization procedures [1]. The geometric investigation of the cavities is classified into eight series. Each model is inserted into SUPERFISH code. These models are optimized with respect to the shunt impedance, quality factor, and other figures of merits in the cavity [2, 3].

Two sample geometries of these eight models are presented in Fig. 1.

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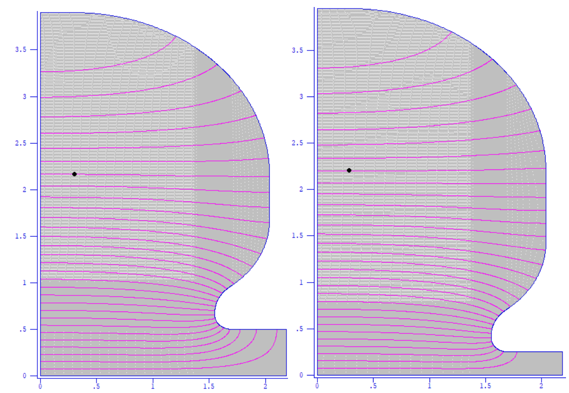

Figure 1: The geometry of the sample cavities in SUPERFISH code. The R5.0 at the left and the R2.5 at the right.

The sample geometries shown in Fig. 1 refers to cavities with a bore radius of 5 and 2.5 mm. The figures of merits of these two models are compared in Table 1 as a sample design.

Table 1: The Figures of Merit at Different Bore Radius Cavities (SUPERFISH Code [1])

Parameters	R5.0-F0.3-G3.1	R2.5-F0.3-G3.1
Frequency(MHz)	2998	2998
Quality-Factor	14896	15218
$ZT^2(M\Omega/m)$	75	82.81
Kilp.	1.47	1.46
Stored-Energy	0.1	0.095
r/Q	110	119
Transient Time Factor	0.76	0.77
Power Loss (kW)	129	119

Table 2 covers the Kilpatrick factor, effective shunt impedance and the E_{max}/E_0 of each designed model.

The parameter R in this notation refers to the bore radius, F is the flat section on the nose, and the G parameter is related to the gap length. The mentioned notation is preserved overall in this article.

Finally, the designed cavities are inserted in 3D CST software [4]. The asymmetrical features of the cavities are added to the structure. The size of the kidney slots is evaluated at this level. At last, the cavities are tuning, and the coupling factor of each neighbor cavity is adjusted to 6%.

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Table 2: The Shunt Impedance and Kilpatrick-Factor of the Optimized Geometries

Geometrical Parameters	E_{max}/E_0	Kilp.	ZT^2
R2.5-F0.0-G2.6	3.15	1.73	91.23
R2.5-F0.0-G3.1	2.63	1.53	82.83
R2.5-F0.3-G2.6	3.03	1.67	90.43
R2.5-F0.3-G3.1	2.49	1.46	82.81
R5.0-F0.0-G2.6	3.11	1.74	78.15
R5.0-F0.0-G3.1	2.63	1.49	75.26
R5.0-F0.3-G2.6	2.97	1.48	77.25
R5.0-F0.3-G3.1	2.52	1.47	74.99

By considering one-half cavity as a buncher, we could expand the designed cavities into an accelerating tube. One of the typical tubes is shown in Fig. 2.

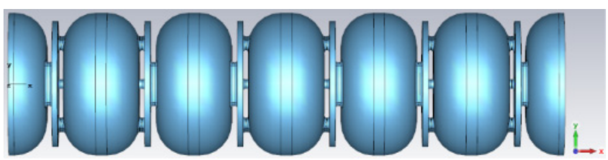

Figure 2: The 6 MeV sample tube.

A PEC plate is defined at the end of the tube as a target to calculate the final current, energy, and beam size.

Power Consumption

A 2 MW magnetron was supposed to be used in the designing procedure. First, the gradient of the E-field is calculated to support a 6 MeV electron beam. Then the input power is evaluated by Eq. (1) [5].

$$E_0T = \sqrt{\frac{ZT^2 \times P_{input}}{L_{tube}}} \tag{1}$$

The dissipated power in each cavity, calculated by superfish, is presented in Table 3. In addition, the total power loss in a tube is added to this table.

Table 3: The Dissipated Power in Each Cavity, Total Loss, and the Input Power of the Designed Geometries

Geometrical Parameters	$P_{Loss\ per\ cavity}$ (kW)	$P_{total\ loss}$ (MW)	P_{input} (MW)
R2.5-F0.0-G2.6	91.12	0.547	1.49
R2.5-F0.0-G3.1	115.9	0.695	1.58
R2.5-F0.3-G2.6	112.3	0.674	1.53
R2.5-F0.3-G3.1	118.7	0.712	1.62
R5.0-F0.0-G2.6	128.2	0.769	1.75
R5.0-F0.0-G3.1	119.2	0.715	1.63
R5.0-F0.3-G2.6	103.3	0.620	1.41
R5.0-F0.3-G3.1	128.6	0.772	1.75

BEAM DYNAMICS

The Eigenmode solver of the CST Microwave Studio can be used to calculate the accelerating field. Then it can be imported to Particle Studio as a predefined E-Field. A particle source by initial energy of 15 keV was defined to calculate the beam dynamics in a PIC solver. By defining a PEC plate at the end of this tube, we can analyze the current, beam size, and energy bandwidth on the target. Finally, the emittance of the beam in transverse directions is compared in Table 4.

Table 4: The Beam Emittance in the Optimized Geometries

Cavity Type	u-emittance (m)	v-emittance (m)	u/v
R2.5-F0.0-G2.6	1.40e-6	2.14e-6	0.65
R2.5-F0.0-G3.1	1.47e-6	1.76e-6	0.83
R2.5-F0.3-G2.6	2.15e-6	2.42e-6	0.89
R2.5-F0.3-G3.1	1.46e-6	1.89e-6	0.77
R5.0-F0.0-G2.6	9.65e-6	13.43e-6	0.72
R5.0-F0.0-G3.1	7.14e-6	15.54e-6	0.46
R5.0-F0.3-G2.6	1.15e-5	15.9e-6	0.72
R5.0-F0.3-G3.1	8.09e-6	9.90e-6	0.82

The bunch-length of all the models are mostly the same. In advance, in Fig. 3, compare one of the bunch shapes for all the designed models.

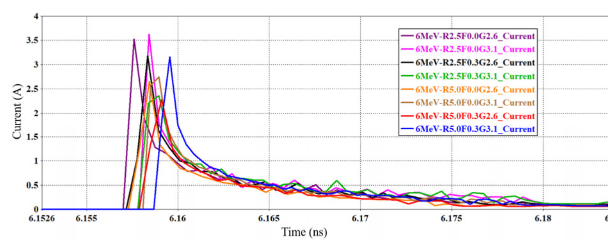

Figure 3: The final bunch shapes on the target.

The averaged current of the target is presented in Table 5. The percentage of the captured electrons is also added to this table.

Table 5: The Captured Electrons in a 6 MeV Tube with 150 mA Initial Current

Geometrical Parameters	Averaged Current on the Target (mA)	Captured Electron
R2.5-F0.0-G2.6	0.046	31%
R2.5-F0.0-G3.1	0.052	34%
R2.5-F0.3-G2.6	0.045	30%
R2.5-F0.3-G3.1	0.051	34%
R5.0-F0.0-G2.6	0.037	25%
R5.0-F0.0-G3.1	0.042	28%
R5.0-F0.3-G2.6	0.037	24%
R5.0-F0.3-G3.1	0.041	27%

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As is shown in Table 5, the most captured electrons occur at R2.5 and Gap 3.1.

The histogram of the energy on the target for all the models is illustrated in Fig. 4. Clearly, for the R5 and Gap 3.1 designs, the concentration of the electrons on one energy is more.

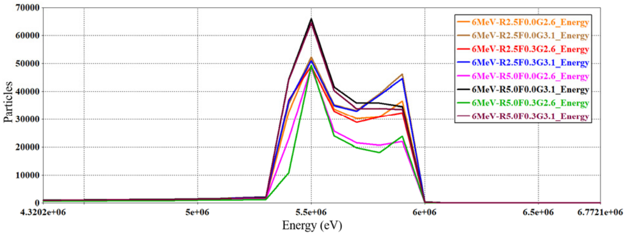

Figure 4: The histogram of the energy for the last bunch on the target.

CONCLUSION

In conclusion, defining a flat length on the nose of the cavities does not have any disturbing effect on the final beam. On the contrary, it helps to reduce the Kilpatrick factor of the cavity. Therefore, higher input power can be added to these structures.

Reducing the bore radius to 2.5 mm helps to have a smaller beam size, higher brilliance, and lower emittance in a beam.

Although the particles' concentration in one energy is higher at a 5 mm, bore radius, the beam size at this tube is around eight times higher than R2.5.

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