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THE BEAM-STUDY OF THE SIDE AND ON-AXIS RF CAVITIES IN S-BAND 6 MeV LINACs

A. Khosravi†, B. Shokri, Laser and Plasma Research Institute (LAPRI), Shahid Beheshti University, Tehran, Iran
N. Khosravi, Institute for Research in Fundamental Sciences (IPM), Tehran, Iran

Abstract

The geometry of side and on-axis RF cavities are two magnetic-coupled designs for the different LINAC applications. The electromagnetic fields, RF power, beam parameters, thermal stability, and manufacturing costs are the most critical factors in cavity type selection in each application. In this article, both RF-cavities are optimized in POISSON SUPERFISH code to compare the beam parameters accurately. Then the optimized cavities are making a tube and compare in ASTRA 1D code and CST 3D software. At last, the thermal sensitivity of both models is studied in MPHYSICS module of the CST. As a result, the final decision can be achieved on the side or on-axis cavities considering the input power, costs, beam properties, and thermal stability for the different applications of the LINACs.

INTRODUCTION

The industrial and medical application of Linear accelerators has increased during the last decades. The essential criteria in each application will determine the accelerating tube type. In this article, the main features of the side or on-axis tube are compared on the final current, beam size, and the manufacturing equipment and costs.

At first, the accelerating cavities of each type are designed and optimized. Then the accelerating tube is presented and prepared to run in ASTRA 1D code [1]. Next, the asymmetry of the electric field in each tube is compared in an eigenmode solver. Then the final interaction of the beam with the 3D E-field is simulated in the 3D PIC solver of CST [2]. In the last section, we will take a look at the thermal stability of each tube. The studies are presented in the following sections:

- Cavity Design & Optimization.
- ASTRA.
- CST Particle Studio.

CAVITY DESIGN AND OPTIMIZATION

The geometric investigation of the side and on-axis cavities is done in the POISSON SUPERFISH code [3]. By omitting the coupled cavity from the longitudinal direction of the side cavity, a free space make in this direction. The geometrical changes increase the shunt impedance and quality factor. In addition, due to the noses become sharper, the Kilpatric factor is increased, and it should be controlled.

Simulation Details & Power Input Considerations

A 2 MW magnetron was supposed in the designing procedure. After the optimization procedure, the shunt impedance of side cavities is higher than on-axis. Therefore, a higher maximum of E-field and higher acceleration is possible for the side model. The geometry of optimized cavities is shown in Fig. 1.

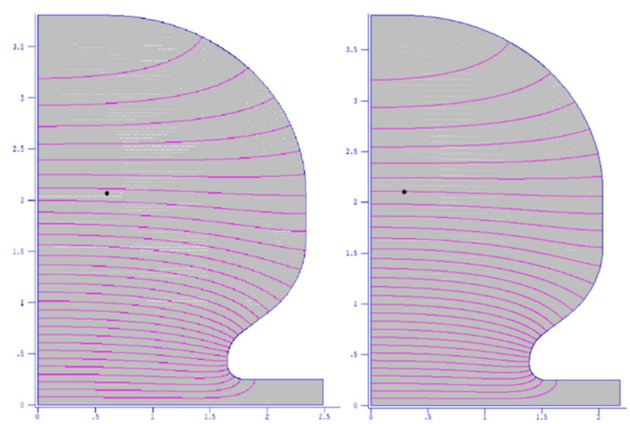

Figure 1: The geometry of side (left) and On-Axis (right) cavities in SUPERFISH software.

The arc threshold was supposed to be the same in both models. Thus, the gap size of each cavity was changed in order to reach a same Kilp. Factor. The geometrical parameters are in Table 1.

Table 1: The Optimized Geometrical Parameters of the Cavities (SUPERFISH & CST)

Parameters (cm)	Side Cavities	On-axis Cavities
Diameter	7.61	7.68
Gap Length	3.3	2.78
Outer Corner Radius	1.74	1.74
Inner Corner Radius	0.9	0.9
Outer Nose Radius	0.35	0.35
Bore Radius	0.25	0.25

All other geometrical features are kept the same and optimized into maximum shunt impedance, quality factor, and other figures of merits in accelerating cavities [4, 5]. The final figures of merit are presented in Table 2.

† at_khosravi@sbu.ac.ir

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Table 2: The Figures of Merit at Optimized Cavities in the Superfish Code [3]

Parameters	Side Cavities	On-Axis Cavities
Frequency (MHz)	2998	2998
Quality-Factor	16800	14700
ZT^2 $(M\Omega/m)$	97.9	88.4
Kilp.	1.85	1.71
Transient Time Factor	0.79	0.81
Power Loss (KW)	150.4	132.1

In order to add more cavities in some applications, the highest possible coupling factor was considered in each type. For example, On-axis cavities were supposed to have a 6% coupling factor between cavities. Unfortunately, the 6% coupling factor causes a high distortion in the E-field of the side cavities. Therefore, the coupling factor was reduced to 4% in the side model. Then the CST Eigenmode and SUPERFISH code were used to optimize the cavities for the frequency 2998 MHz [6]. The accelerating tube consists of the five main cavities and a half cavity as buncher and the last cavity. The side and on-axis tubes are presented in Fig. 2.

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

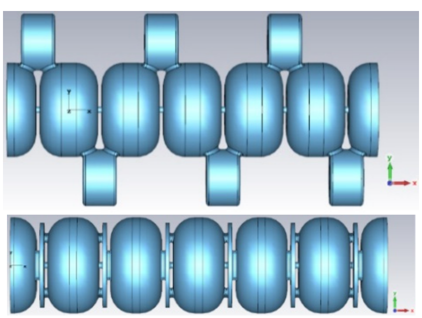

Figure 2: The 6 MeV side tube (up), on-axis tube (down).

ASTRA

The 1D ASTRA code can be run by preparing the electric field on the longitudinal axis. Since the side and on-axis designs are different in gap size, the axial E-field is different. The effect of it on the beam is shown in Table 3. The energy-spread and beam size in the side tube is only a bit lower.

Table 3: The Beam Emittance in the Side and On-Axis

Cavity Type	Side	On-Axis
Sigma X (mm)	2.67	2.74
Bunch length (mm)	2.4	2.35
Trans. Emittance (π.mrad.mm)	24	25
Long. Emittance (π.Kev.mm)	190	178
Energy Spread (Kev)	180	180
Energy (MeV)	6	6

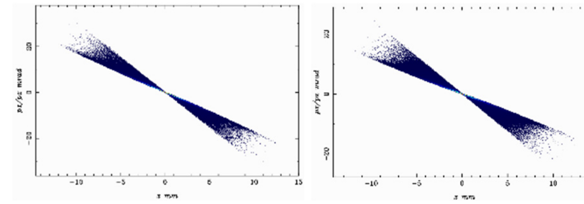

Figure 3: On-axis- (left) & Side (right) at 6 MeV.

The main reason for this tiny difference is reducing the gap size. As a result, the interaction chance of the field and electrons reduce in this case. Therefore, the phase space reduces to a lower range (Fig. 3).

The beam pattern and bunch length of each tube are comparable in Fig. 4.

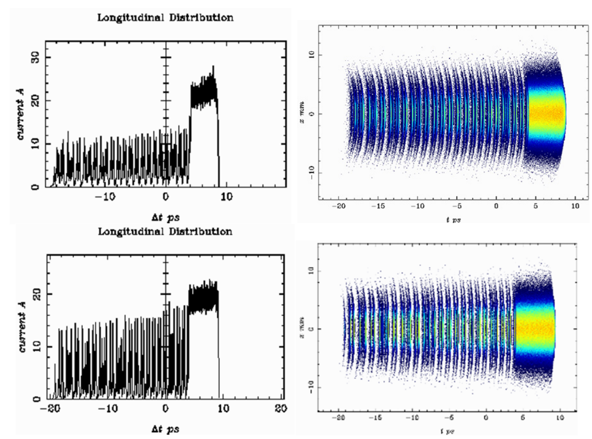

Figure 4: The on-axis tube (up), side tube (down) on 6 MeV.

As shown in the design procedure, a higher E-field is possible for the side tube. On the other hand, the accelerating gap is better to produce a more effective interaction space for the beam and electromagnetic field.

Therefore, as a conclusion of ASTRA studies, a higher acceleration happens in the side model. In addition, the beam is more focused on size and phase space.

Although all the studies are 1D, and the field asymmetries are not considered in this study. It was shown an asymmetry in the E-field of side cavities during the optimization procedure. All field distortions are only possible to study in a 3D PIC code. It is presented in the following section.

CST PARTICLE STUDIO

The geometry of coupled cavities is the main difference in the structures. For example, the On-axis model contains a bean-shaped slot to couple with the main cavities. Besides, the coupling in the side type is through an elliptical hole. Therefore, the position and surface of each model are different. Therefore, it is expectable that we have different patterns in E-field.

As it said formerly, the coupling coefficient of the side model is reduced to 4 percent. Although, the E-field still has a distortion in cross-section. For seeing the effect of the

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E-field distortion on the beam, the simulations should be repeated in a 3D PIC code like CST.

The simulation results are reported in this section. A 150 mA beam with 18 KeV initial energy is imported to simulations. The electric boundary condition and an OFHC copper are considered as background. The input power in the side tube is 1.19 MW and on the on-axis tube is 1.49 MW to produce a 6 MeV beam in each case. Both of the accelerated beams are presented in Fig. 5.

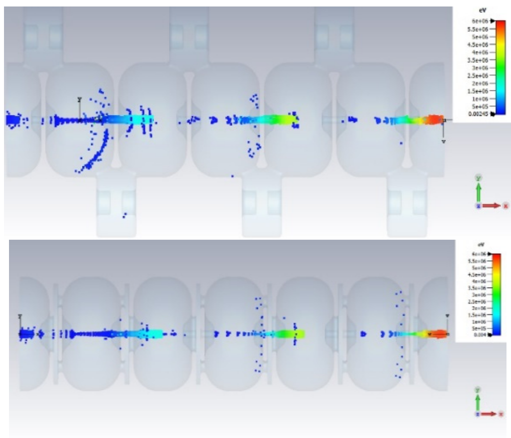

Figure 5: The acceleration of the beam in the side (up) and on-axis (down) tube.

The better shunt impedance in the side cavities was determined by a lower input power to reach a 6 MeV beam. Therefore, from an economic point of view, the side tube is much better. Although, the asymmetries in the electric field should be considered too. Figure 6 shows the effect of the field distortions on the bunch shape.

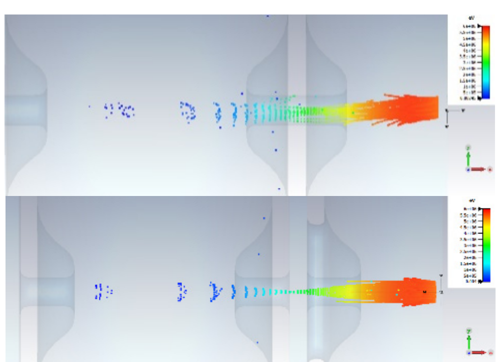

Figure 6: The bunch shape near the target in the side (up) and the on-axis (down) tube.

As is shown in Fig. 6, the bunch shape in the side model is distorted from a circular shape. The beam properties are reported in Table 4. As a result of asymmetries, the beam in the side tube is changed to an elliptical shape. In addition, the beam size is grown up and is twice that of the on-axis model.

The beam properties can be studies on the target. The results are presented in the next part.

Table 4: The Beam Emittance in the Side and the On-Axis Tubes

Cavity Type	u-emittance (m)	v-emittance (m)	u/v
On-Asix	1.70e-6	1.56e-6	1.09
Side	3.09e-6	2.52e-6	1.23

Beam Properties on Target

The final current and beam power are compared in Fig. 7 (1st) and Fig. 7 (2nd). According to plots, the on-axis model covers a higher current and beam power on the target. The histogram of the energy on the target for the on-axis model is more narrow and more focused on one energy (Fig. 7 (3rd)).

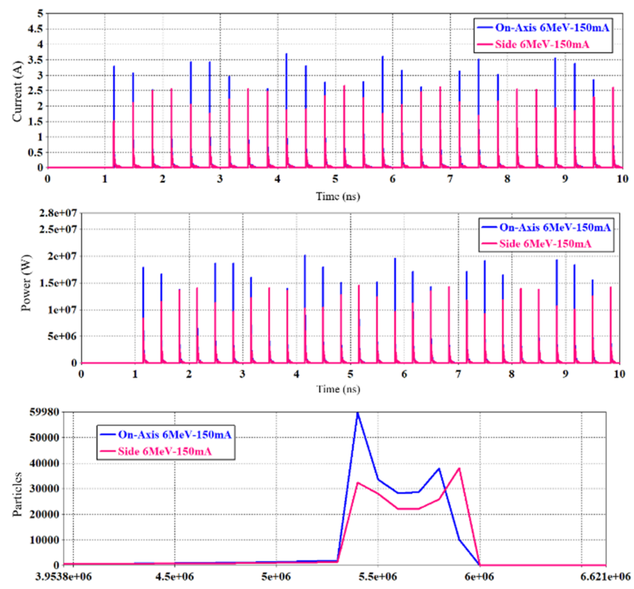

Figure 7: Current (1st), beam power (2nd), energy histogram (3rd) comparison on target for the side and on-axis tube.

CONCLUSION

Side accelerating tubes have a high potential to cover higher shunt impedance and quality factors. Therefore, power consumption is more economical in this model. Although, considering the asymmetrical features of the E-field inside the side tube, the quality of the beam properties comes down.

The on-axis tube supports a narrow histogram of the energy, a more focused circular beam, and a higher captured current on the target.

The reported facts in this article can present some criteria to select the proper model for each accelerating tube's specific application.

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