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STUDY OF GEOMETRICAL PARAMETERS AND THEIR TOLERANCES IN OPTIMIZATION OF ACCELERATING CELLS OF SIDE COUPLED LINAC

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Abstract

After choosing the suitable geometry for accelerating cavity, evaluation of geometrical parameters effects on radio frequency characteristics is essential. In this paper after study of priority of geometrical parameters in optimization of accelerating cells of Side Coupled Linac, according to obtained results, new design of S-band accelerating cavity is suggested. By frequency sensitivity study of new dimensions, we can choose best technique to tune the accelerating cavity during magnetic coupling-hole adjustment.

INTRODUCTION

Cancer is third major cause of death in the world. Utilizing x-ray radiations produced by medical linear accelerators is one of the common methods for treatment of cancerous tumors [1]. Two types of cavity structures: Travelling Wave (TW) and Standing wave (SW) are used commonly in medical electron linear accelerators. Each of them has superiority and deficiency rather to other one [2]. In in-line medical linear accelerators, X-ray is generated from tungsten target mounted at the end of cavity by using electron beams. Generated X-Ray is used directly for tumors' treatment. In-line medical linac, structures contain a gantry that can rotate 360 degree around patients. The optimization of treatment is controlled by changing X-ray exposure directions. For this purpose accelerator cavity, electron gun, and X-ray target should be mounted on the machine head. It is essential to have enough free space in the gantry head to place other components such as shield, vacuum system, primary collimator, movable jaws, ionization chamber and flattening filter. The standard distance between X-ray target and the location of the tumors in these machines is about 100 cm. For shorter cavity length, the optimization of linac structure and dose distribution will be better [3]. Iran urgent need for building medical linear accelerators was main motivation of this study for domestically design of first such a prototype. In Figure 1, a schematic example of such an accelerator structures head is presented. At this work, the SUPERFISH and MATLAB codes was used for simulation.

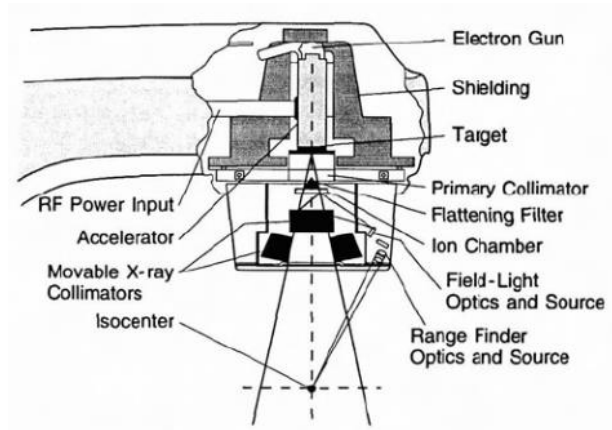

Figure 1: In-line medical linear accelerators head structure.

MATERIALS AND METHODS

Accelerator cavity was designed in different geometries because of their higher shunt impedance, main structures which are used in medical linacs are side-coupled and on-axis coupled standing wave cavities [4-6]. In-line medical linacs are constructed by using side coupled. Its shorter length meets limited space requirements of machine head. Primary design parameters are selected based on mechanical facilities, machining experts, and access possibility to TWYSTRON high power microwave tube.

The first step is to choose the cavity operating frequency. Because of using a 2.3MW TWYSTRON in the 2990 MHz to 3010 frequency range, and the successful buncher design and construction in the 2997.92 MHz, this frequency was chosen as cavity operating frequency [7]. Initial approximate cavity radius was calculated according to Maxwell Equations. Primary estimation of simple pillbox cavity obtained about 38 mm. Because of that most tumors can be treated with 6 MV photon beams, this energy was chosen for designing [1]. By assumption of 2.3 MW input power and its 10% reduction in reality, 400 kW output beams [8]. The cavity design should be done for 62 MΩ/m. According to measurements made in the Varian Company, maximum obtainable acceleration field without incident of electrical breakdown was about 19.7 MV/m. By considering the mentioned value, the maximum surface electric field is about 74 MV/m [3]. Also, electric field gradient is chosen around 14 MeV/m, and maximum surface electric field reaches about 54 MV/m with pulse length of 4 to 5 µs for

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the accelerator cavity with 0.45 m length [9]. The design of SCC* structures requires quality factor predicted about 15000 [3].

In this study, SUPERFISH should calculate quality factor approximately 17000 [11]. Two-dimensional SUPERFISH code has the ability to calculate electric field profile and the resonance frequency for symmetric structures. After these estimations, the shape of accelerator axial cells was optimized to obtain desired parameters. To speed up the optimization processes the MATLAB code was prepared that helps to impose geometrical changes at the SUPERFISH input text file, automatically execute the SUPERFISH code, and display results finally. The size of meshes used around nose cones of the acceleration cells determined the accuracy of the results and their size proper adjustment is very important. For cell optimization only half of its geometry is needed. In the SUPERFISH code, selection of correct boundary condition is significant [12]. By considering mechanical precision of construction, mesh size was chosen about 0.03 mm. Figure 2.a shows half of an accelerating cell by its designation geometrical parameters. Figure 2.b illustrates longitudinal and radial electric field components at the center and beam hole radius along the longitudinal direction of cavity, respectively.

Beam holes radius (ξ) was chosen around 4 mm [3, 13]. Web thickness between two neighbor cells (2tW) was chosen 3 mm for heat exchanging by convection with outer air and mechanical strength consideration of structure [14]. At the beginning of simulation, primary value of R1, R2 and R3 was selected from dimension of Varian linac parameters, and their values were 1.5, 2.5, and 2.5 mm, respectively. During optimization, resonant frequency should be fixed around 2997.92. Tolerances for resonant frequency at this step can be about 3MHz [15].

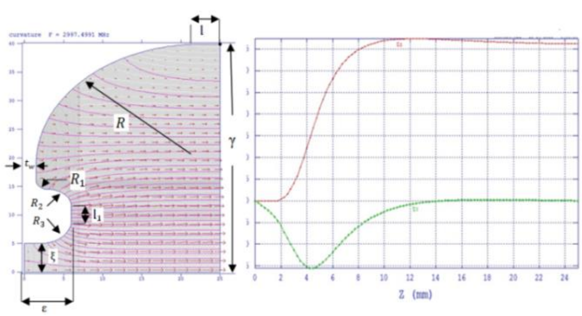

Figure 2: a) Half of accelerator cell by its geometrical dimension parameters, b) longitudinal (red) and radial (green) components of electric field at the longitudinal axis direction.

RESULTS

At the beginning of simulations, some parameters have been kept constant and several other parameters have been changed and optimized. Without changing the other parameters, the effect of accelerator cells radius was studied. Several values was selected around γ=38. At this step, resonant frequency should be kept constant during the changes of cells radius. This purpose was provided by changing ε simultaneously with variation of γ. Table 1 shows radius values which were used for optimization. At the end of this step γ=39.89 was selected. As it is shown in Table 1, the effective shunt impedance has its maximum value at the certain radius. At the next step, effects of tw, ξ and l1 on ZT2, T and E max/E0T have been studied. Electrodynamics parameter variations with TW are shown in Table 2. Also, its radius selected 5mm. Table 3 shows its variation results. At the end of optimization process, the effect of nose cones straight section was considered. This parameter is selected around 2.5 mm after optimization. Its variation results are shown in Table 4.

Table 1: Cells radius values for electrodynamics parameters optimization.

Parameters	**Values**				
Cavity radius (mm)	40	39.9	39.5	39	38.5
Nose cones length (mm)	5.8	6	6.5	7.2	7.7
Frequency (MHz) 2997	2.45	0.43	0.46	0.36	0.6
ZT^2 (MΩ/m)	64	70.5	130	113.6	102.7
Transit time factor	0.92	0.92	0.93	0.93	0.93
E_{max}/E_0T	3.7	3.8	4	4.2	4.3

Table 2: Electrodynamics parameters variation with regard to web thickness.

Parameters	**Values**				
t_W (mm)	3	2.5	1.5	1	0.5
ZT_2 (MΩ/m)	70.35	70.4	70.47	127.79	117
Transit time factor	0.923	0.923	0.924	0.927	0.930
E_{max}/E_0T	3.79	3.79	3.79	3.95	4.11

Table 3: Electrodynamics parameters variation with regard to beam holes radius.

Parameters	**Values**					
ξ(mm)	5.5	5	4	3.5	3	2.5
ZT^2 (MΩ/m)	69.4	70.5	72.8	73.5	75.2	76.4
Transit time factor	0.922	0.924	0.927	0.929	0.930	0.932
E_{max}/E_0T	3.72	3.79	3.91	3.98	4.05	4.11

Table 4: Electrodynamics parameters variation with regard to nose cones head straight section length variation.

Parameters	**Values**				
L_1(mm)	3	2	1.4	0.8	0.5
ZT_2 (MΩ/m)	69.53	71.41	72.53	73.64	74.318
Transit time factor	0.923	0.923	0.923	0.923	0.923
E_{max}/E_{0T}	3.7	3.86	4	4.14	4.22

* Standing wave side coupled cavity

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In Table 5, primary and final dimensions of cells and in Table 6, final electrodynamics characteristics of designed geometry are reported.

Table 5: Preliminary Dimension of Axial Cells of Accelerator Cavity.

Parameters	Values(mm)
Cavity radius (ξ)	39.89
Straight section on the wall (l)	2.5
Straight section on the nose cone head (l_1)	2.5
on the wall Curvature radius (R)	21
Curvature radius that joint cavity wall to nose cones (R_1)	1.5
Nose cones head upper curvature radius (R_2)	3
Nose cones head lower curvature radius (R_3)	4
Web thickness (t_W)	1.5
Beam hole radius (ξ)	5
Nose cones length (ε)	6

Table 6: Electrodynamics Characteristics of Designated Cell.

Parameters	Values
Transit time factor	0.9235
Shunt impedance (MΩ/m)	82.637
Effective shunt impedance (MΩ/m)	70.485
Cavity quality factor	19568
E_{max}/E_0T	3.77
Number of cavity's cells	9

CONCLUSION

In-line side coupled standing wave structure selected for simulation and design. Cause of this selection is higher shunt impedance of standing wave structure and reduction of complexity and cost of medical linac machine construction. After performing required calculations and simulations by using of SUPERFISH and MATLAB codes, axial cells of a side coupled cavity designated and optimized. Simulation results have been shown that proper boundary condition and meshing size selection have strict effect on the accuracy of results. Selection of mesh size was performed based on the precision of mechanical construction. After simulation and optimization the effective shunt impedance and quality factor reached to about 70.485 MΩ/m and 17000, respectively. After providing coupling irises, some of these parameters should be corrected. Final purpose of this research is construction of first prototype of side coupled cavities. This work provides initial condition for medical linear accelerator construction feasibility.

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