DESIGN OF AN ACCELERATING TUBE FOR MEDICAL STANDING-WAVE ACCELERATOR BASED ON GENETIC ALGORITHM'S OPTIMAL CALCULATION

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Abstract

A compact medical standing-wave (SW) electron accelerating tube has been designed that operating frequency is 2998MHz, operating mode is π/2, final energy is 6MeV and beam current is 100mA based on genetic algorithm (GA)'s optimal calculation. It employed a bi-periodic structure with nose cone shape. We performed the simulation experiment which proved that GA was feasible and gave a set of geometric parameter with higher shunt impedance. We performed tuning of the whole tube by CST MICROWAVE STUDIO and SUPERFISH and calculation of beam dynamics by ASTRA and Parmela in this paper. The total length of the tube is less than 300mm.

INTRODUCTION

Low Energy Electron Linac have been widely put into use in industrial and medical aspects, such as application of accelerator in the radiation processing, non-destructive testing (NDT), container inspection, medical sterilization, radiation therapy, computed tomography (CT), etc. With the extensively application, smaller size, lighter weight and more compact accelerators have been made for required needs [1]-[3]. In order to satisfy these needs, people begin to design new accelerating structure with high accelerating gradient, high shunt impedance and high quality factor [4][5]. According to the theoretical analysis, an accelerating structure with nose cone shape would be superior to ordinary accelerating structure [6].

Accelerating structure of the optimization which is uniform structure is based on the operating frequency of f=2998MHz, the working mode of the π/2 mode, length of L=c/(2f), where c is the speed of the light, i.e. The optimal structure that the shunt impedance is up to 114 MΩ/m with nose cone have been optimized based on genetic algorithm [7].

In this paper, we calculated two non-uniform structures and performed tuning of the whole tube and calculation of coupling coefficient of input coupler in order to feed power into tube by SUPERFISH [8] and CST MICROWAVE STUDIO [9] respectively, and calculation of beam dynamics by ASTRA [10] and Parmela [11] for the 6MeV medical standing wave accelerating tube which included two half cavities and five whole cavities.

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ACCELERATING TUBE

The optimal uniform accelerating structure with nose cone shape was given based on genetic algorithm and SUPERFISH [9]. Its shunt impedance which is up to 114 MΩ/m is shown in Fig. 1 with the number of population iterations. Its shape with the electromagnetic field distribution is shown in Fig. 2.

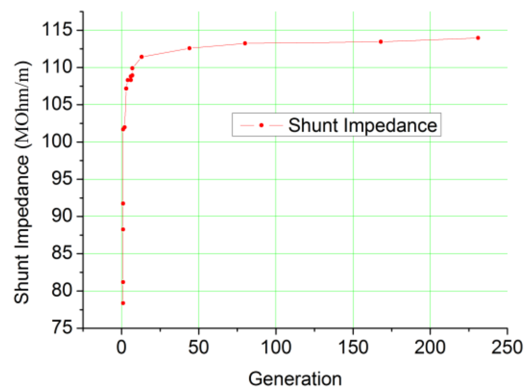

Figure 1: Shunt impedance of structure with the number of population iterations.

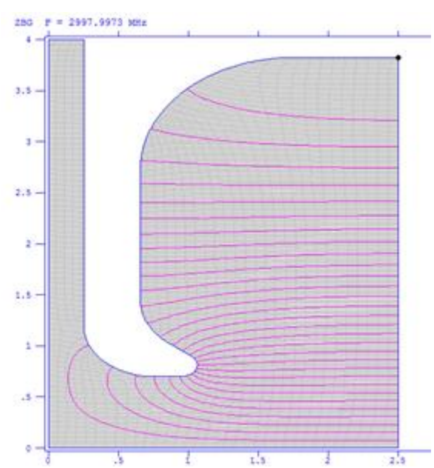

Figure 2: The shape of the optimal uniform structure.

The accelerating tube consists of two non-uniform cavities, four uniform cavities and half uniform cavity with outlet. The tuning of the structure is performed one by one with SUPERFISH. The parameter of cavities is shown in Table 1. Finally, we obtained the field distribution of the half of whole accelerating tube as shown in Fig. 3 and the normalized accelerating electric field distribution along the longitudinal axis as shown in Fig. 4.

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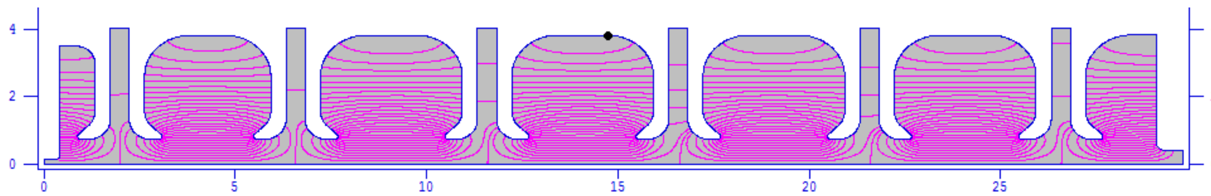

Figure 3: The field distribution of the whole accelerating tube.

Table 1: Parameter of Cavities

No.	Freq. (MHz)	Zs (MΩ/m)	Q	r/Q (Ω)
1#	2997.998	25.051	6110.64	56.535
2#	2998	103.252	15561.7	210.981
3-6#	2997.997	113.975	16560.5	231.775
7#	2997.998	55.449	10443.8	121.316

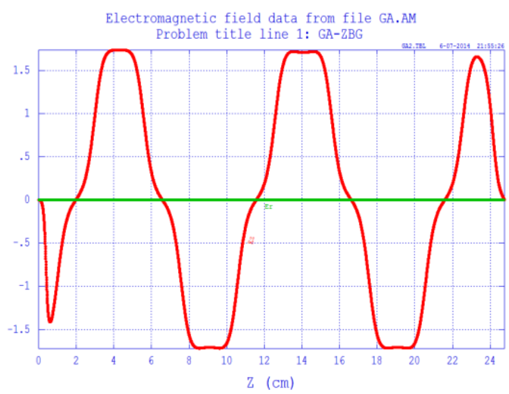

Figure 4: The accelerating electric field distribution along the longitudinal axis of the structure.

BEAM DYNAMICS

The beam dynamics is simulated with the code ASTRA and Parmela. The final kinetic energy is 6MeV and 6.02MeV at the exit of the tube respectively. It varies with the longitudinal axis as shown in Fig. 5. The beam size of 0.72cm and the energy spread of 2.99% and the energy spectrum are shown in Fig. 6 and Fig. 7 at the exit of the tube from Parmela respectively.

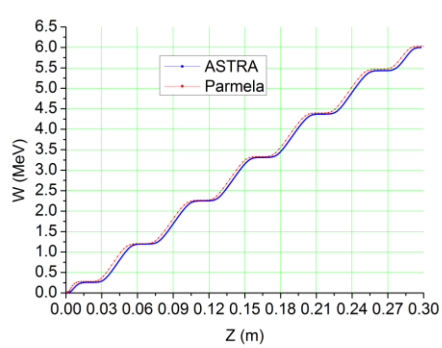

Figure 5: Beam energy varies with the longitudinal axis.

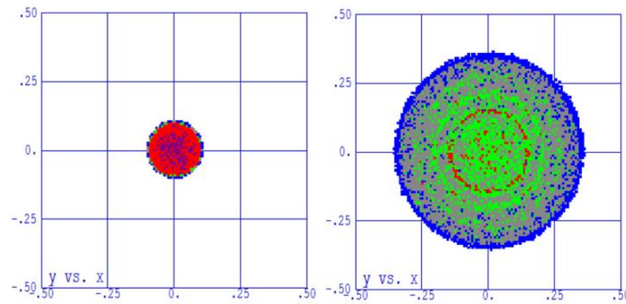

Figure 6: Beam size at the entrance (Left) and exit (Right) of the tube (Unit: centimeter).

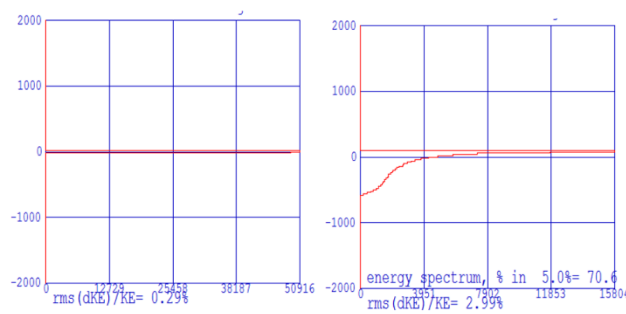

Figure 7: Energy spectrum at the entrance (Left) and exit (Right) of the tube.

COUPLER

To obtain beam energy 6MeV with available magnetron power of 2.2MW, the medical accelerating tube that the length is 297.75mm consists of four and half uniform cavities and two non-uniform cavities (1/2+5+1/2 cavities).

The well-known expression gives the average electric field of the beam loading accelerating tube [12]:

$$E_a = \frac{2\sqrt{\beta_c}}{1+\beta_c}\sqrt{\frac{Z_s P_0}{L}} - \frac{Z_s}{1+\beta_c} I_b \cos\varphi_s \cdot \quad (1)$$

Where β_c - the coupling coefficient of feeding waveguide with accelerating tube, P_0 - the input microwave power, Z_s - the shunt impedance, I_b - the beam current.

The optimum coupling coefficient can be calculated using expression [12]:

$$\beta_{opt} = \left[\frac{I_b}{2}\sqrt{\frac{ZsL}{P_0}} + \sqrt{\left(\frac{I_b}{2}\sqrt{\frac{ZsL}{P_0}}\right)^2 + 1} \right]^2 \quad (2)$$

According to (1) and (2), the optimum coupling coefficient is 1.3. The coupler of the tube and the result

S_{11} Parameter and Smith chart of simulation are shown in Fig. 8, 9and 10 respectively, where S_{11}=0.131, namely, β_c=1.3.

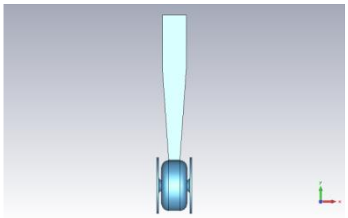

Figure 8: Coupler of the tube.

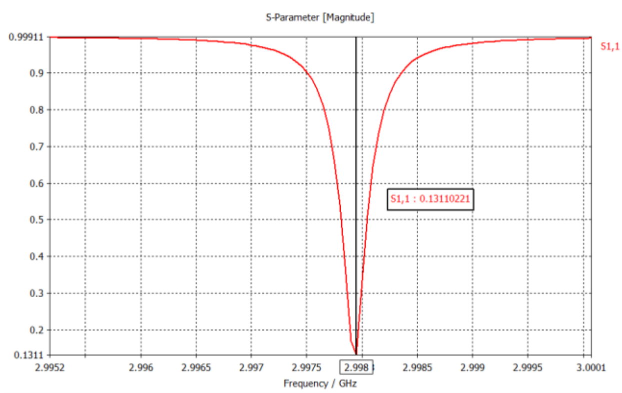

Figure 9: S11 parameter of Coupler.

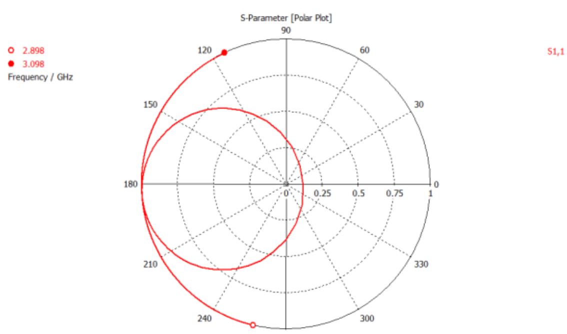

Figure 10: Smith Chart of Coupler.

The summary of design parameter of tube is shown in the Table 2.

Table 2: Summary of the Design Parameter of the Tube

Parameter	Unit	Value
Beam Energy	MeV	6
RF Frequency	MHz	2997.992
Input RF Power	MW	2.2
Beam Current	mA	100
Injection Energy	keV	15
Structure type		Bi-periodic
Number of Cell		1/2+5+1/2
Shunt Impedance	MΩ/m	92.6
Quality Factor		14449.7
Length of Tube	mm	297.75
Coupling Coefficient		1.3

CONCLUSION

The design study of a 6MeV compact SW electron accelerating tube has been performed using software SUPERFISH, CST MICROWAVE STUDIO, ASTRA and Parmela based on genetic algorithm's optimal calculation. We obtain a very short tube which is less than 300mm by simulation of microwave and beam dynamics. The parameter of the accelerating tube and coupler is shown in the paper. It can be employed in medical and industrial application. The next step, we will manufacture the tube and take a cold test and beam measurement to be used in the practice application.

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