A NOVEL SIDE COUPLING STANDING-WAVE ACCELERATING STRUCTURE FOR A MEDICAL LINAC

Z. X. Tang†, Y. J. Pei, NSRL, USTC, Hefei, China

Abstract

A novel side coupling standing-wave (SW) accelerating tube for low energy medical LINACs has been designed operating at 2998 MHz. With an operating mode of π, the tube can accelerate the electron beam from 10keV to about 6MeV with current of 130mA. A novel bridge hole between accelerating cavity and coupling cavity has been utilized to reduce the mutual effect between two cavities and improve the anti-jamming capability and the long term stability. The inner end plate of the inlet of the first accelerating cavity includes the nose cone to realize self-focusing in transverse to improve the beam quality. The simulation of the electromagnetic field of structure and beam dynamic has been carried out with the SUPERFISH, CST Microwave studio and Parmela, respectively.

INTRODUCTION

Low-energy electron accelerators ranging from a few hundreds of keV to a few MeV have been widely used in industrial and medical aspects, such as application of LINAC in the radiation processing, non-destructive testing, container inspection, medical sterilization, radiotherapy, computed tomography and so on [1-3]. The required electron beam energy, beam current, and operation models were different due to the application. From a commercial point of view, miniaturization and cost reduction are the basic considerations. The low-energy accelerating structures should be relatively simple, compact, especially medical LINAC.

In order to satisfy these needs, new accelerating structures were developed with high accelerating gradient, high shunt impedance and high quality factor [4, 5]. According to the theoretical analysis, a side coupling accelerating structure would be superior to ordinary accelerating structure [6].

In this paper, a novel side coupling standing-wave accelerating cavity is described, which works in the π mode with a frequency of 2998MHz. The novel bridge hole has been utilized to separate the accelerating cavity and the coupling cavity to reduce the mutual interference and improve the anti-jamming capability and the long term stability. The structure has been optimized through enough computation and analysis. As a result, the effect shunt impedance is up to 106.9 MΩ/m and the quality factor is 16646. The inner end plate of the inlet of the first accelerating cavity includes the nose cone to realize self-focusing in transverse to improve the beam quality. According to the recent studies, linear accelerator tube has been designed to generate electron beam with energy of 6 MeV and current of 130 mA.

In this paper, we performed the tuning of the four type cavities and the whole tube with SUPERFISH [7] and CST MICROWAVE STUDIO [8] and beam dynamics with Parmela [9]. Finally, we calculated the coupling coefficient of the input coupler.

NOVEL ACCELERATING TUBE

The novel design is the bridge hole between accelerating cavity and coupling cavity, as shown in Fig. 1. It is utilized to couple the electromagnetic field between these cavities. On the other hand, it is used to reduce the mutual effect of the resonant frequency through adjusting the geometry of the accelerating cavity and coupling cavity.

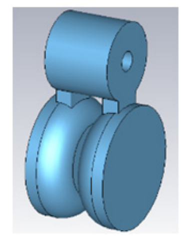

Figure 1: The novel bridge hole.

The first two bunching cavities and uniform accelerating cavity have been tuned to the resonant frequency 2998 MHz with the electromagnetic code SUPERFISH as shown in Fig. 2, 3 and 4, respectively. According to Fig. 2, the nose cone is used to realize self-focusing of the beam in transverse to improve the beam quality, when the low energy beam is injected into the tube.

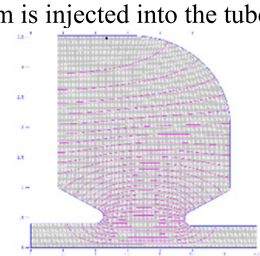

Figure 2: The first bunching cavity (Unit: cm).

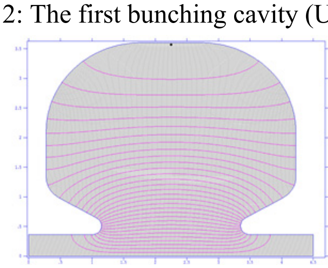

Figure 3: The second bunching cavity (Unit: cm).

† tangzhx@mail.ustc.edu.cn

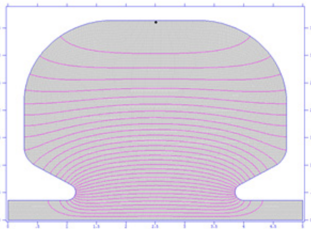

Figure 4: The uniform cavity (Unit: cm).

The coupling cavity has been calculated with the software CST as shown in Fig. 5.

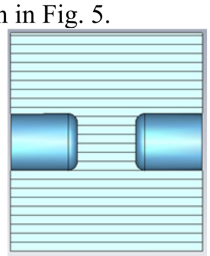

Figure 5: The coupling cavity.

The whole tube consists of two bunching cavities, five uniform cavities and six couplers. The tuning of the structure is performed one by one with CST Microwave Studio. As a result of tuning all, the field distribution of the whole accelerating tube, the accelerating electric field distribution along the longitudinal axis and the dispersion curve are shown in Fig. 6, Fig. 7 and Fig. 8, respectively. The resonant frequency of the tube is 2998 MHz. The quality factor is 15052. The effect shunt impedance is 104 MΩ/m. According to the Fig. 7, the field amplitude of the first cavity is more than other cavities, it can improve the beam energy in the short distance to suppress the space charge effect.

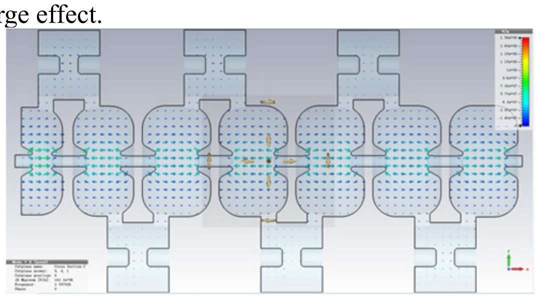

Figure 6: 3D electromagnetic field of the whole tube.

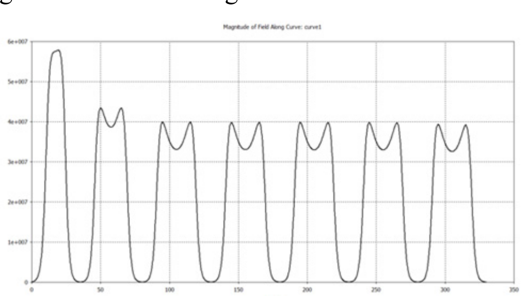

Figure 7: The electric field along the longitudinal axis.

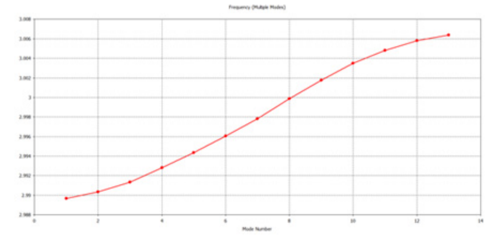

Figure 8: The dispersion curve of the tube.

BEAM DYNAMICS

According to the DC electron gun scheme, the initial beam parameter is as follow: the beam energy is 10 keV, the beam current is 0.5 A, and the beam size (rms) is 0.5 mm. The beam dynamics is simulated with the code Parmela. The detail beam parameters are shown in Fig. 9, 10 and 11. The final kinetic energy is 6.17 MeV, the beam current is 130 mA, the beam size (rms) is 2.6 mm and the beam energy spread is 21.75% at the exit of the tube.

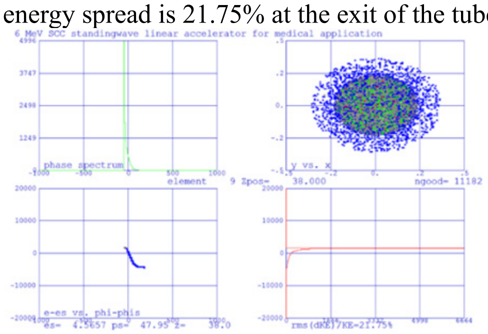

Figure 9: Beam size and energy spread.

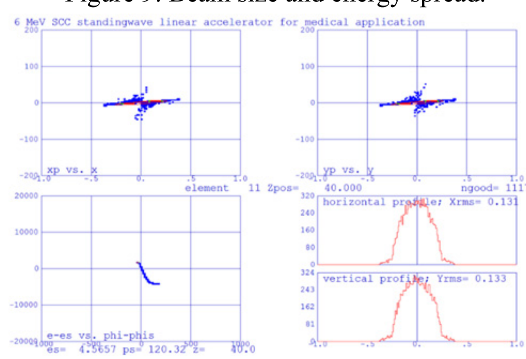

Figure 10: Beam profile at the exit of the tube.

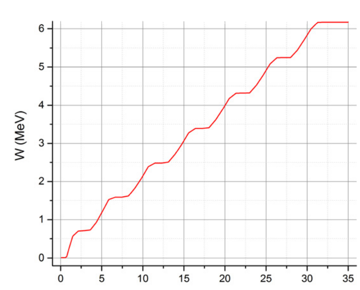

Figure 11: Beam energy along the longitudinal axis.

COUPLER

The well-known expression gives the average electric field of the beam loading accelerating tube as [10]:

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

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 as [10]:

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

According to (1) and (2), the input power P_0 is 3.2 MW, the optimum coupling coefficient β_c is 2.23. The coupler of the tube, the result S_{11} Parameter and Smith chart of simulation are shown in Fig. 12, 13 and 14 respectively, where S_{11}=0.375, namely, β_c= 2.23. Considering beam loading, it needs overcoupling, Smith Chart includes the original point as shown in Fig. 14.

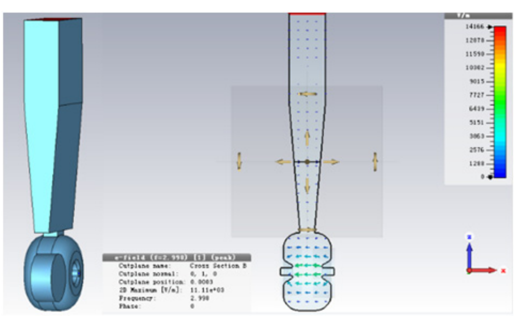

Figure 12: 3D electromagnetic field of the coupler.

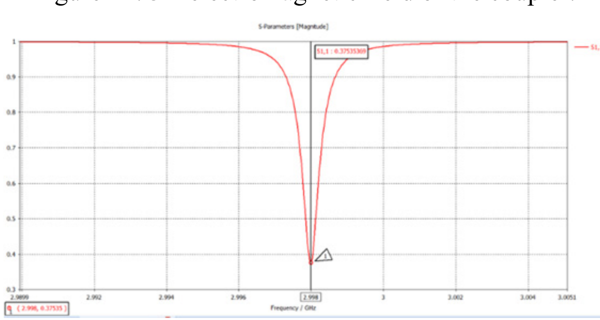

Figure 13: S11 parameter of the coupler.

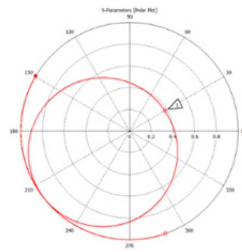

Figure 14: Smith chart of the coupler.

CONCLUSION

The design study of a 6 MeV novel side-coupling SW electron accelerating tube has been performed with the software SUPERFISH, CST MICROWAVE STUDIO and Parmela in this paper. The bridge hole is designed to improve the performance of the tube. The length of the accelerating tube is 35 cm, the beam current is 130 mA. 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.

REFERENCES

[1] Whittum, David H., Trail, M.E., Meddaugh, G.E., "State of the art in medical and industrial linear accelerator systems," Vacuum Electronics Conference, 2008. IVEC 2008. IEEE International, pp.8-11, doi: 10.1109/IVELEC.2008.4556556.

[2] R.B. Miller, G. Lodaa, R.C. Miller, R.Smith, D, Shimer, C. Seidt et al. "A high-power electron linear accelerator for food irradiation applications," Nuclear Instruments and Methods in Physics Research B 211 (2003), pp.562–570, doi: 10.1016/j.bbr.2011.03.031.

[3] N. Nepal, Kim, Y.K., Bae, Y.S., Ko, I.S., Cho, M.H., Namkung, W., "Design study on standing-wave linear accelerator," Particle Accelerator Conference, 2001. PAC 2001. Proceedings of the 2001, pp.2802 - 2804 vol.4, doi: 10.1109/PAC.2001.987912.

[4] Auditore, L., Barna, R.C., De Pasquale, D., Emanuele, U., Trifiro, A., Trimarchi, M., et al., "A compact 5 MeV S-band electron LINAC based X-ray source for industrial radiography," Particle Accelerator Conference, 2005, pp.2428 – 2430, doi: 10.1109/PAC.2005.1591134.

[5] T. S. Dixit, R. Krishnan, S.N.Pethe, C.S. Nainwad, A.P. Deshpande, "Shunt impedance of a 6 MeV standing wave side coupled structure", Proceedings of PAC09, Vancouver, BC. Canada, pp.2021-2023.

[6] Thomas P. Wangler. RF linear accelerators, WILEY-VCH Verlag GmbH & Co.KGaA, Weinheim, 2008, pp.32-47.

[7] K. Halbach and R. F. Holsinger. Poisson Superfish.

[8] CST, CST Microwave Studio, user manual, 2006.

[9] Lloyd M. Young. Parmela, user manual, 2005.

[10] Yuanji Pei. The foundation of the electron linear accelerator design, Science Press, 2013, pp. 197-199.