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Physical design and cooling test of C-band standing wave accelerating tube*

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The physical design and cooling test of a C-band 2MeV standing wave (SW) accelerating tube are described in this paper. The designed accelerating structure consists of 3-cell buncher and 4-cell accelerating section with a total length of about 163mm , excited with 1MW magnetron. Dynamic simulation presents that about 150mA beam pulse current and 30% capture efficiency can be achieved. By means of nonlinear Gauss fit on electron transverse distribution, the diameter of beam spot FWHM (full width at half maximum of density distribution) is about 0.55mm. Cooling test results of the accelerating tube show that frequencies of cavities are tuned to 5527MHz and the field distribution of bunching section is about 3:9:10.

Keywords: C-band, standing wave, accelerating tube, space charge effect
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1. Introduction

Miniature linac has a broad application prospect, not only potential to provide medical departments with portable x-ray source, but also the possibility to be used as an injector of free electron laser. In contrast with the S-band or L-band microwave technique, the dimension of the accelerator can be minimized and higher electron energy can be obtained under the condition of the same microwave power source for C-band or X-band microwave technique. Therefore, in the middle of last the century, the research and design of C-band and X-band accelerator were started internationally.[1]

At the same time, the accelerator with small beam spot is a perfect x-ray source in computerized tomography (CT) and medical radiation therapy areas. Therefore, in order to enhance the sensitivity of CT image system, to restrain the growth of transverse dispersion of the electron beam launched from the electron gun and moving in the accelerator for optimizing the design of accelerating tube, is one of the main measures for getting a small beam spot.

2. Physical design of C-band accelerating tube

Electrons move in the accelerating tube under the force of RF field as well as space charge. In the lower energy section, phase oscillation of the particles is very violent, and the space charge effect is the main factor which results in the augmentation of beam's transverse dimension. In the higher energy section, however, phase oscillation of particles almost ceases, and the space charge effect is offset by the focusing force of RF field.[2,3]

So, in order to obtain a small electron beam spot, it is necessary to design a reasonable bunching section to avoid the beam's transverse dispersion produced by strong space charge effect in lower energy section.

2.1. Design of bunching section

In our physical design of C-band accelerating tube, a bunching section consisting of three bunchers with E-field ratio 3:9:10 is selected.

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The first buncher has a phase velocity β_1=0.51, it is an asymmetric cavity, of which the injecting aperture is bigger than the beam passage aperture (Fig.1(a)). Accordingly, the radial field component E_r in the fore part is distinctly less than that in the back part (Fig.1(b)). In this way, it can be avoided that the transversal dimension of the electronic space group diminishes rapidly due to the excessive focusing, or that it will induce a strong space charge force. Thus, the space charge effect can be restrained to some degree.

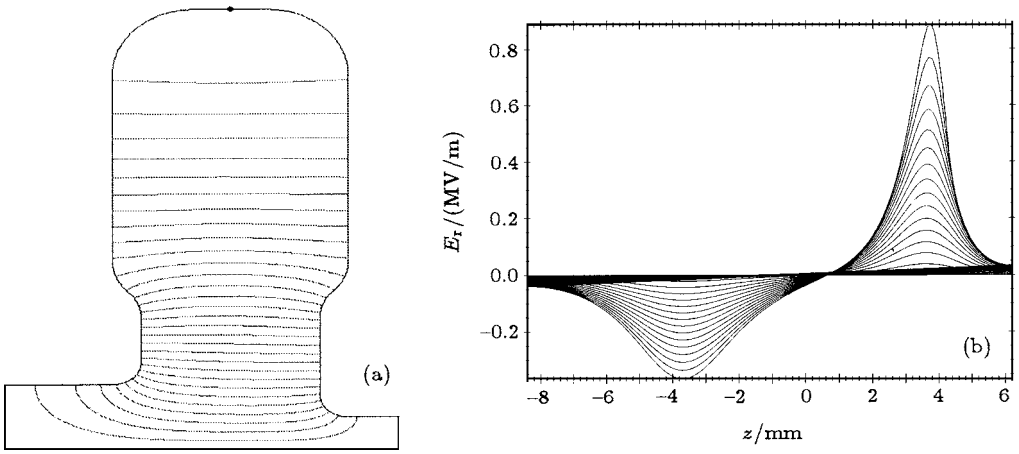


Fig.1. (a) Shape and E-field of first cavity; (b) Radial field distribution of the first cavity.

The next two bunchers are symmetrical cavities whose phase velocities are both 0.77. They continue to focus the beam in one hand and accelerate the beam in the other hand.

2.2. Optimization of cavities

In order to gain a higher accelerating efficiency and a smaller beam spot, we make a detailed optimization of accelerating cavities. SUPERFISH software is used to calculate the electromagnetic field and to optimize the cavities of C-band 2MeV on-axis-coupled standing wave (SW) linac. After optimization, the ratio between the first cavity's injecting aperture and the beam passage aperture is about 2:1; the diameter of the beam passage aperture is 3mm, and the septum thickness is 1.2mm, the longitudinal length of the coupling cavity is about 1.6 mm. The following table lists some other parameters of the cavities:

Table 1. Dimension and microwave performance parameters of the cavities.

cavities	inner diameter R/mm	cavity length L/mm	transit time factor T	effective shunt impedance $Z*T*T/(\mathrm{M}\Omega/\mathrm{m})$	Q Value
buncher cavity 1	40.3	14.6	0.851	52	7140
buncher cavities 2, 3	41.4	20.8	0.784	99	11146
accelerating cavity	38.8	26.6	0.861	141	11782

2.3 Dynamic simulation

In dynamic simulation, the linac is exited with 1MW magnetron as microwave power source, and the initial parameters of the injected beam are listed in the following table.

The software General Particle Tracer (GPT)[4] is used to simulate the dynamics of 3000 particles in the accelerating tube, Figs.2–4 show the results.

Table 2. Initial parameters of the injected beam.

current/mA	beam diameter/mm	energy/keV	particles in simulation N	phase distribution
500	1.4	20	3000	evenly $(-\pi \sim \pi)$

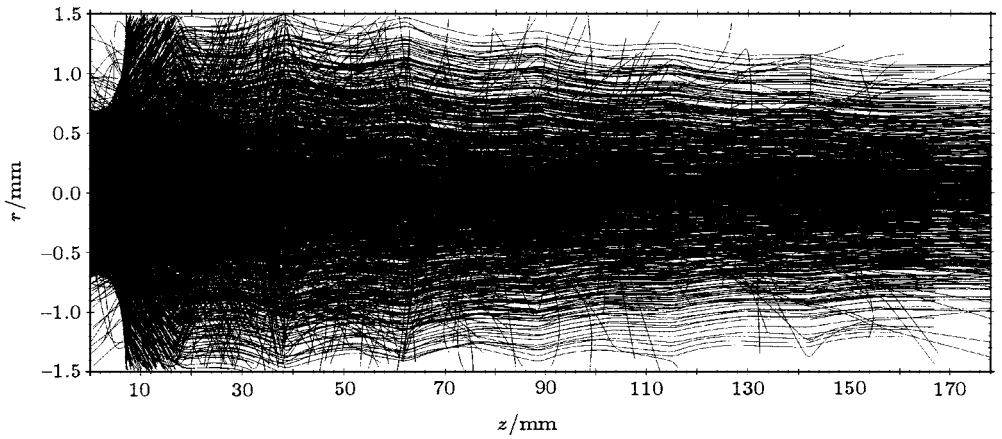


Fig.2. Electron trajectories along the accelerating tube.

Figure 2 shows the trajectories of these particles along the longitudinal direction. And the simulated results indicate that more than 30% particles get through the accelerating tube. Figure 3 displays the spacial density distributions (3D and 2D distribution) of particles reaching an imaginary screen at the end of the accelerating tube.

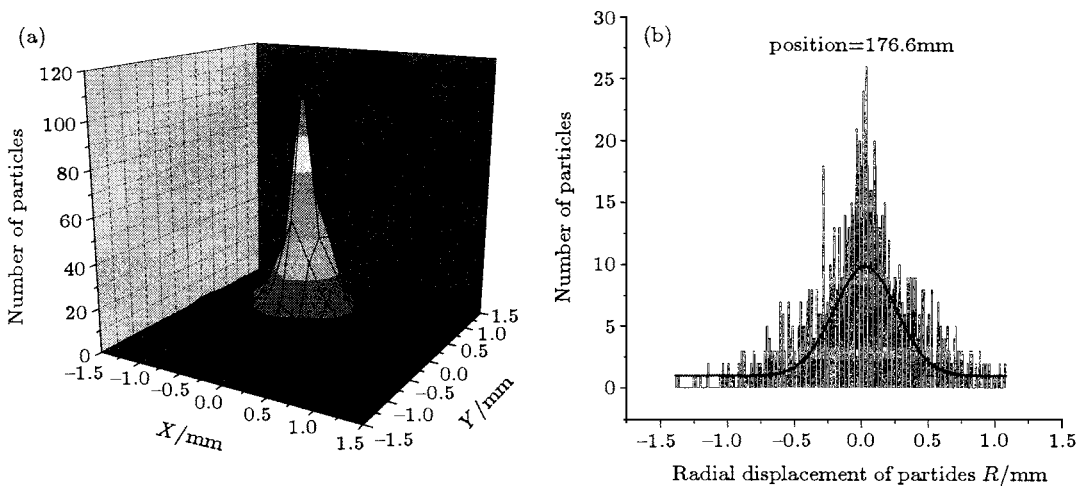


Fig.3. Density distribution of particles. (a) Spacial density distribution (3D) of particles on screen; (b) Radial distribution (2D) of particles on screen and Gauss fit curve.

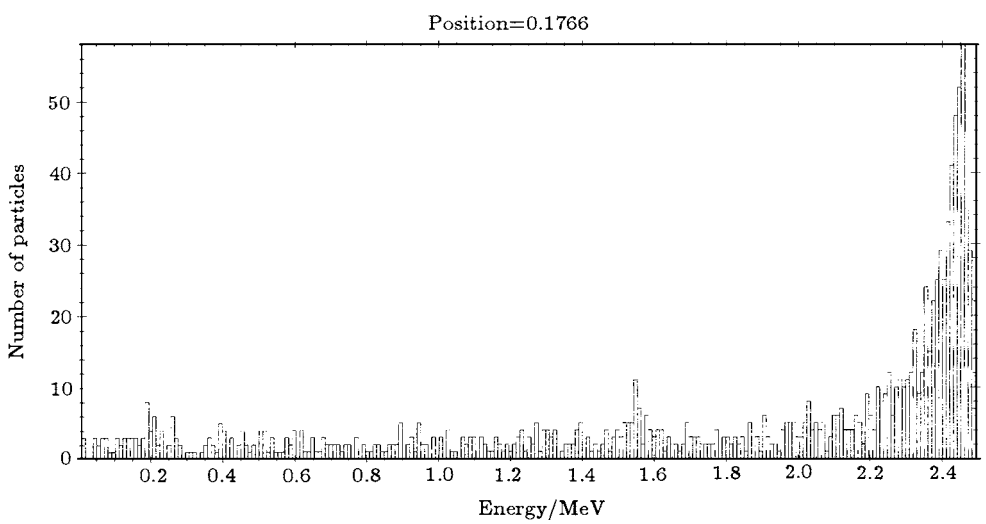


Fig.4. Energy density distribution of particles on screen.

As is shown in Fig.3, the distribution of particles on screen resembles Gauss distribution. By means of the nonlinear Gauss fit on electron transverse distribution, the diameter of beam spot FWHM is about 0.55mm. And Fig.4 displays the energy density distribution of particles on screen.

2.4. Physical design of C-band accelerating tube

According to the cavity optimization by SUPERFISH and the dynamic simulation results brought out by GPT (General Particle Tracer), a C-band accelerating tube is designed. Figure 5 is the engineering view of the tube.

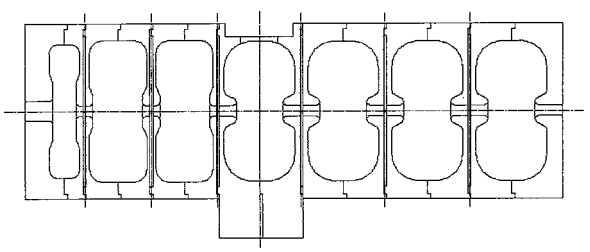


Fig.5. Schematic diagram of the tube.

3. Cooling test results of C-band accelerating tube

The main difficulties in the cooling test on C-band accelerating tube rests on the fact that the cavity is small and the quality factor is low. And the measured data is quite sensitive to the dimension of the probe and the location of it. Therefore, a precise testing device is established (Fig.6).

Utilizing this device, the frequency consistency of accelerating cavities is tuned to $\pm$1MHz, and that of coupling cavities is $\pm$2MHz. At present, we have get the frequency spectrum of the cavities chain (Fig.7) and the axile field along the tube (Fig.8).

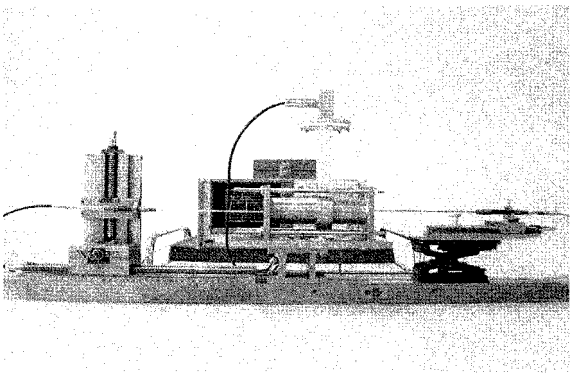


Fig.6. Cooling test device of C-band 2MeV SW linac.

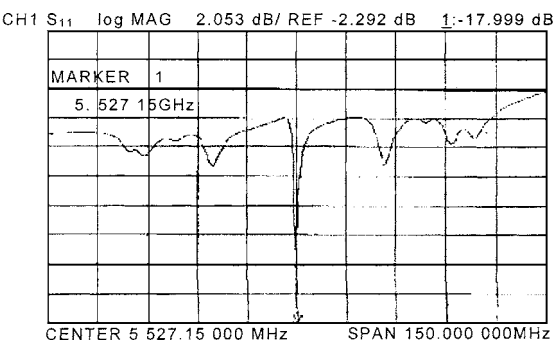


Fig.7. Frequency spectrum of the cavities chain.

Figure 7 shows that frequencies of cavities are tuned to 5527MHz, and Fig.8 explains the field distribution is about 3:9:10.

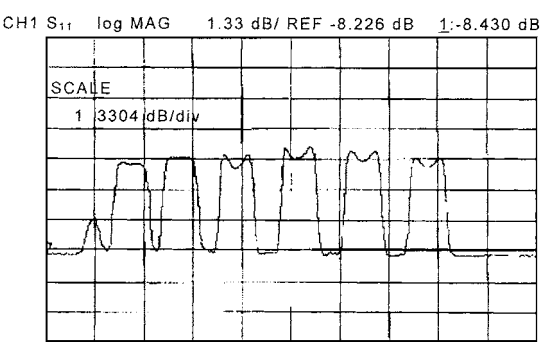


Fig.8. Axile field along the tube.

4. Conclusion

According to the result of cavity optimization and beam dynamic simulation, a physical design of a C-band 2MeV standing wave accelerating tube has been carried out. At present, the cooling test of the model is finished. The frequency of the cavities is tuned to 5527MHz and the field intensity distribution basically satisfied the requirement of the physical design.

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