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AN X-BAND LINAC WITH TUNABLE BEAM ENERGY*

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INTRODUCTION

X-ray system is widely used in medical diagnosis and treatment [1]. In the existing medical imaging systems, the energy lower than 500keV X-ray is normally generated by X-ray tube. And the energy higher than 2MeV X-ray is generally generated by low energy electron linacs, energy between 0.5MeV and 1.5MeV X-ray source remains almost a blank. In the energy range, the ability of the X-ray tube has almost reached the limit. With the improvement of energy, the cost of X-ray tube rapidly rises [2]. Recently, the research of energy adjustable linac is of high interest and various institutions around the world are focusing on this topic [3-6].

In x-ray imaging, appropriate x-ray energy is required for different substances to meet a better sensitivity. The energy varies from several hundreds of keV to several MeV. In the low energy end, x-ray tubes has been well developed. However, tubes with energy higher than 500keV is not easy to obtain. Linacs with energy at MeV levels are also adopted in the industrial for radiographic applications such as non-destructive test and cargo inspection.

An X-band linac has been developed to produce beam with energy from 0.5MeV and 1.5MeV. During the design process, some kinds of software such as PARMELA and SUPERFISH have been used for cell optimization and beam dynamics study. After fabrication by high-precision machines tools, we measured the frequencies and field distribution in the cold test. The results were similar to the precious simulations.

MAIN PRINCIPLE

The tube of the accelerator is separated into two sections which is different from single accelerating tube. By changing the amplitude and phase of the second linac section, it is possible to realize the change of energy continuously.

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The principle of changing the beam energy is described as follows: The energy of the electron beam is correlate with the acceleration phase. If the accelerating tube is divided into two segments, the first section accelerates the electron energy to E_1, and the second section of the accelerating tube can accelerate the electrons to an Energy of E_2 while the phase is adjustable, so the final energy is (see Eq. 1):

$$E = E_1 + E_2 \cos\varphi \, . \qquad (1)$$

Figure 1 shows the schematic diagram of the system configuration of the X-band linac. The RF power is supplied by one source, which is a magnetron in this design. The power is divided into two parts: one is fed into the first accelerating section directly; the other is fed into the second accelerating section through an attenuator and a phase shifter, which are used to change the amplitude and the phase of the second tube [7].

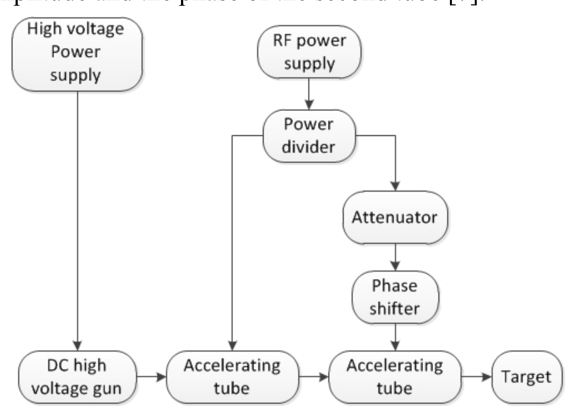

Figure 1: Schematic diagram of the linac system.

Since the electron beam energy is between 0.5MeV to 2MeV, the traditional industrial measurement method can not meet the needs of energy measurement accuracy.

During the measurement of electron beam energy, we can use current-thickness curvilinear to extrapolate the energy. Experiment results show that if we take aluminium as the absorbing material, we can get the database diagram about the current and the thickness of the aluminium plate. The simulation result is shown in Fig.2.

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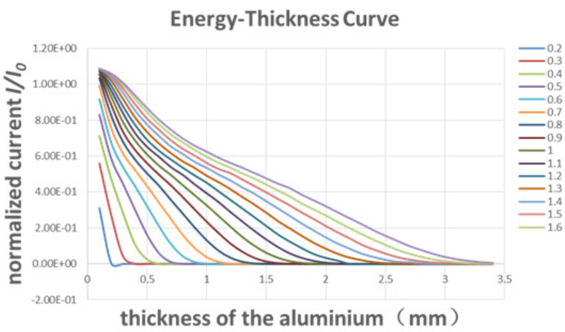

Figure 2: simulation data of the current ratio.

The ordinate of the simulation chart is the normalized current I/I_0, the abscissa of the chart is the thickness of the aluminium plate, by changing the thickness of the plate, we can get the different current curve which represent the adjustable beam energy of the linac.

THE ACCELERATOR TUBE

All the cells were machined by high-precision machine tools. The machined cells and the rf components are shown in Fig. 3.

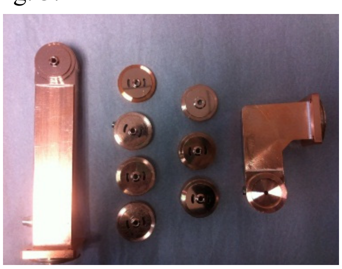

Figure 3: Machined cells of accelerator tube.

The disks of the structure are brazed together, as well as all kinds of flanges, RF windows and water cooling plates. Figure 4 shows the picture of the accelerator tube. The left figure is the CAD design, while the right figure is the real product.

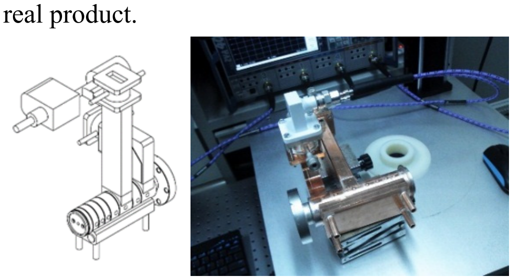

Figure 4: Photo of the accelerator tube.

After the accelerating tube is brazed, we measured the frequency of the tube, and it is tuned by tuning holes outside the cell wall with push-pull set up. A snapshot of the measurement data is shown in Fig.5. The frequency of the first section is 9.296657GHz, and the frequency of the second section is 9.296662GHz, the frequencies are meet the requirement of design, since the frequency tuning range of the magnetron is 20MHz.

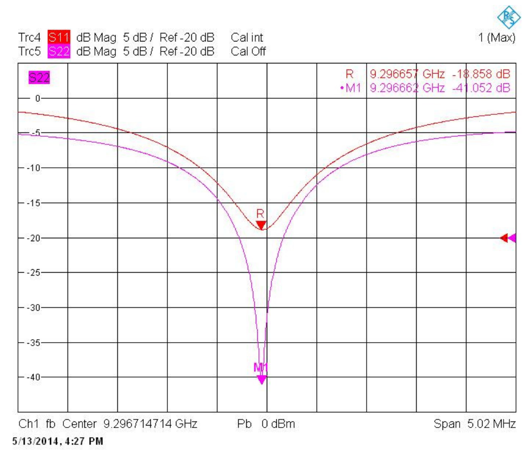

Figure 5: Frequency of the accelerating tube.

HIGH POWER RF TEST RESULTS

After cold test, we tested the tube under high power. Figure 6 shows the incident wave and the reflected wave of the second section in the high power rf test. By tuning the frequency of the magnetron, the SWR represented less than 1% of the input power of the accelerating system. During the experiment, we could measure the incident wave and the reflected wave. This is in good agreement with the cold test result and the software simulation.

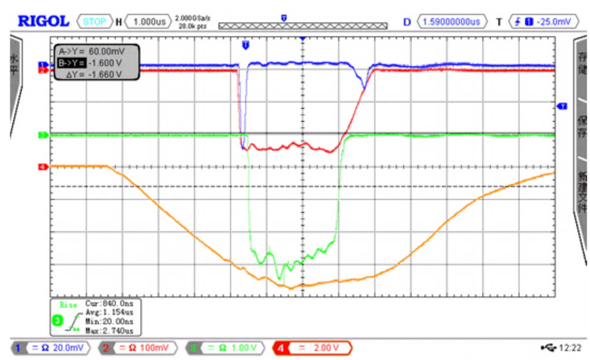

Figure 6: Incident wave (pink), reflected wave (blue), target current (green) and the voltage of electron gun(orange).

During the high power rf test, the gun voltage was 15kV. The current of the electron gun was about 456mA. The accelerating pulse beam current was at 86.8mA. The capture radio was 19 %.

The calculated capture ratio was about 30%, which is about 10 % higher than the measured ratios. The difference may be caused by the titanium window scatter and the loss of electron from the window to the Faraday cup in the air. The loss in the Titanium window should be evaluated.

During the measurement of electron beam energy, we used a Faraday cup to extrapolate the energy. The design of the Faraday cup and its measurement position is shown in Fig.7.

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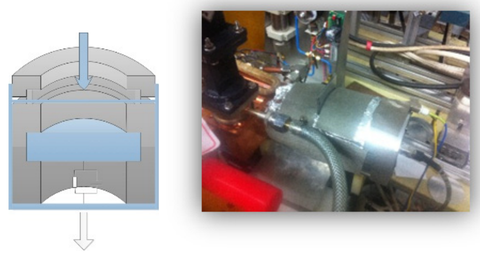

Figure 7: The design of the Faraday cup and its measurement position.

By changing the thickness of the aluminium plate, we get some actual measurement curves. Figure 8 shows the actual energy-thickness curves (red), we compare them with the simulation result (green).

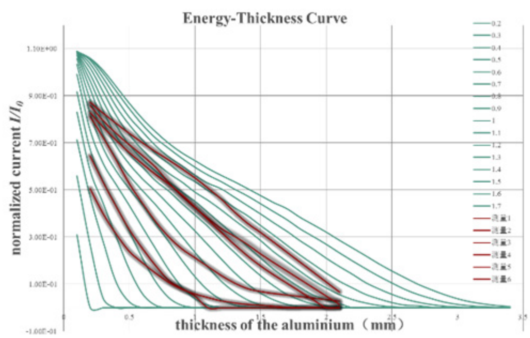

Figure 8: The actual energy-thickness curves compared with the simulation result.

We used some mathematical method to analysis the actual curves to get the energy spectrum. Figure 9 shows the energy spectrum at different RF phase.

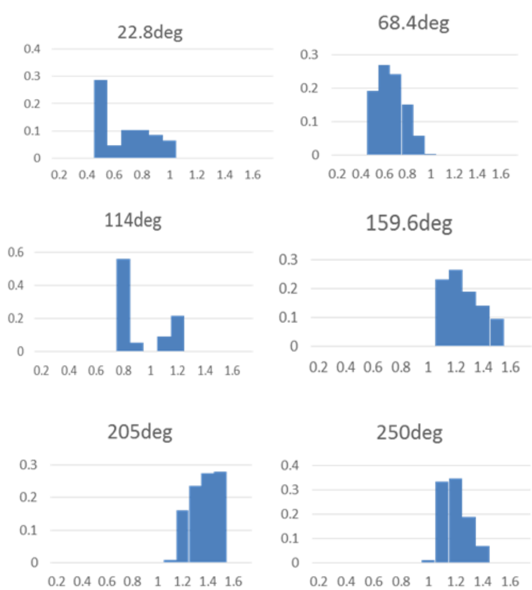

Figure 9: The energy spectrum changed with the phase.

By comparing the average energy spectrum with the phase, we get the energy-phase curve shown in Fig.10. It shows a sine change trend and matches with the design simulation.

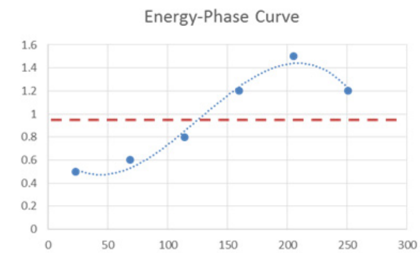

Figure 10: The actual energy-phase curves.

CONCLUSION

The X-band Linac can change energy continuously between 0.5MeV to 1.5MeV, by tuning the RF phase of the second section of the accelerator. The linac system is under development and testing at the accelerator laboratory of Tsinghua University. This accelerator can change its energy continuously which can be used for medical applications or non-destructive test.

We used SUPERFISH and PARMELA before the cold test, and the simulation results show agreement with the cold test results. After fabrication, we do a series of beamtests to measure the capture ratio, energy spectrum, and beam spot size.

However, the performance remains lower than expected because the magnetron does not have an ideal output power and the energy attenuation and beam loss exist inside the Titanium window.

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