THE BEAM CHARACTERISTICS OF INTENSITY-MODULATED RADIOTHERAPY 6MEV STANDING WAVE ACCELERATING TUBE

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Abstract

The method of intensity-modulated radiotherapy (IMRT) is increasingly concerned by the medical world in recent years. Based on the performance characteristic of IMRT accelerator, a 6MeV S-band on axis-coupled SW, suitable for IMRT, electron linear accelerating tube has been developed in Accelerator Lab of Tsinghua University. This paper provides the design performance characteristics of the tube and the results of the high-power tests, analyzes the performance and problems in the operation.

INTRODUCTION

Accelerator Lab of Tsinghua University has been researching the axis-coupled SW accelerating structure since 1979. We have succeeded in designing and producing more than 200 medical electron linear accelerators with beam energy of 6MeV, 14MeV and 20MeV, most of which has been provided for many manufactures and institutes. With the development of radiation therapy, IMRT has become an important field and relevant accelerator, in which a maximum dose rate of 600MU/min X-ray (in a 40 ×40 cm^2 field) could be produced, is required.

However, it is a great challenge to achieve 600MU/min at 6MeV beam energy in a 40×40 cm^2 field. The current maximum dose rate generated by domestic medical accelerator is only 400MU/min when beam energy and square radiation fields were scaled to the same. We decided to attack this problem from two aspects:

- Based on the former 6MeV SW accelerator in our lab, optimizing the structure geometry without increasing the tube length to enhance maximum beam intensity
- Developing the magnetron to increase input power into the accelerating structure from 2.6MW (MG5193) to 3.1MW (MG5349).

Beside, the effect of target geometry and material should also be considered to reach the desired criteria.

Based on the performance characteristic of IMRT accelerator, a 6MeV S-band test structure accelerating tube has been developed. Now the test of operating character is still underway. This report will give the current result.

DESIGN PARAMETERS

The medical accelerator needs to achieve certain beam energy in limited distance. After making the balance between the accelerating tube length and beam energy, the goal of beam energy is set to 6.3MeV. The required average beam current is 138uA for IMRT.

Both the cell structure and beam dynamics have been optimized to maximize the beam intensity by using a simulation code developed in our lab, and a better design has been achieved. The basic operation parameters of the accelerator structure are listed in Table1:

Table 1: Parameters of the Structures

Parameter:		Design value:
Accelerator Length:	L[mm]	285
Beam Intensity:	Im[mA]	130
Average Current	I [uA]	138
Beam Energy:	P0 [MeV]	6.3
Shunt Impedance:	ZT^2[MΩ/m]	122
Input Power:	Pin[MW]	2.4
Input Coupling:	β	1.6

One test structure based on the design mentioned above has been fabricated. For the purpose of beam characterization, an 80μm-think titanium vacuum window was welded at the beam exit instead of a target, and the beam could pass through the window.

HIGH-POWER RF TESTING

Generally, our High-Power RF Test Facility can be divided into three parts:

- High-Power RF system which supplies the required input power.
- A magnetic analyzer designed to measure the energy spectrum.
- A Faraday Cup used to measure the beam intensity.

The energy spectrum measurement was performed as follows: the accelerated beam passed through the titanium window and entered into the magnetic analyzer, whose vacuity was kept at 1.5 × 10^{-4}Pa by the turbine molecular pumps. The electron beam turned about 60 degrees in the analyzer and passed through a 50μm-think titanium window, behind which there was a phosphorescent screen and a CCD camera. Eventually the beam hit the screen and its position could be accurately determined through the observed bright spot. The PC controlled the camera, recorded and analysed the data to get the energy spectrum automatically.

When the magnetic analyzer was not operating, the beam would not bend in the magnetic dipole and directly entered into the Faraday Cup where the beam intensity could be measured.

High power RF system mainly consists of MG5349 magnetron made by E2V Company, four-port circulator made by China and spectrum analyzer utilized for real-time performance monitoring. However, the magnetron has broken down just before the experiment. The former MG5193 2.6MW magnetron was installed to supply the power instead.

The details of the magnetic analyzer and auxiliary equipment are given in Fig.1. A very stable (better than 0.1%) and adjustable power system supplies the power to the magnetic analyzer. Magnetic shielding has been installed at the entrance and exit to reduce the fringe field effect. Besides, in order to enhance the resolution, there is a 38mm-long and 0.2mm wide slit at the entrance to limit the beam size. And accurate discrete calculations were performed in the computer with the carefully measured data of the magnetic field.

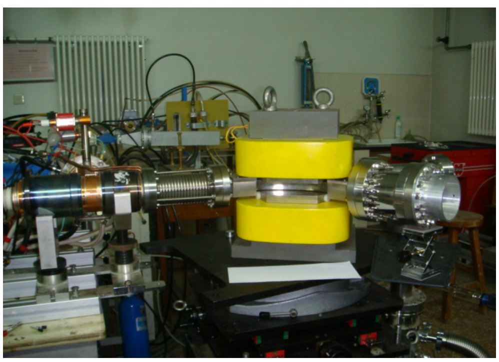

Figure 1: The magnetic analyzer and auxiliary equipment.

Taking all various factors into consideration, the energy resolution can be promoted to less than 1%.

EXPERIMENTAL RESULT

The high power test has been performed on our system described above. The test result will be presented as follows:

Power Character

Figure 2 shows the beam energy at 130mA for different input power.

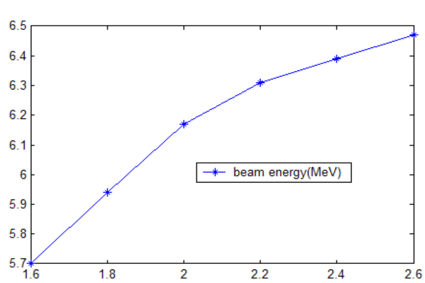

Figure 2: Beam energy vs. input power.

The beam energy rise with the increasing of input put. The curve fitted the square root relation: $W_e \propto \sqrt{P_o}$.

Beam Loading Effect

Fig. 3 shows dependence of beam energy on the beam intensity. This test was performed at 2.4MW input power and 2.856GHz working frequency. The beam energy decreased linearly with the increasing beam intensity. This correlation could be employed to adjust the radiation dose during radiotherapy operation.

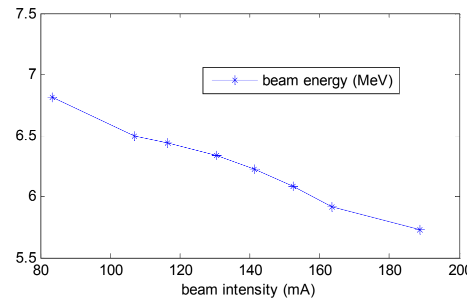

Figure 3: Beam energy vs. beam intensity.

The Injecting Voltage Effect

The injecting voltage of the electron gun directly affects the injected beam intensity into the accelerating tube, thus also has impact on the beam energy. The measured curve of this correlation was similar to the above, as shown in Fig.4. The capture coefficient slowly increased with increasing injecting voltage, and gradually reached saturation, as shown in Fig.5. Both tests were performed at 2.4MW input power.

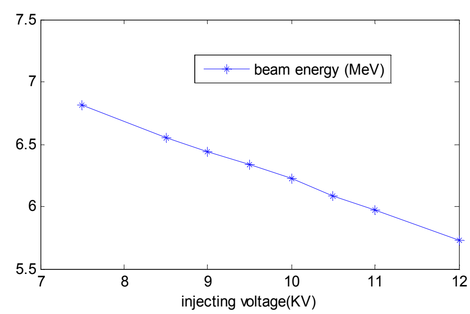

Figure 4: Beam energy vs. injecting voltage.

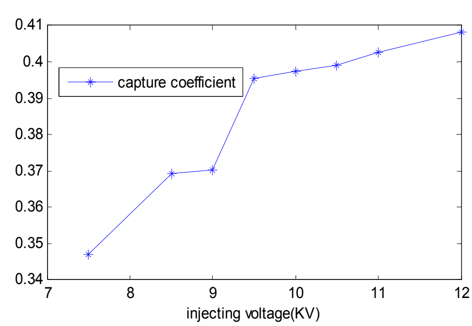

Figure 5: Capture coefficient vs. injecting voltage.

Energy Spectrum

The energy spectra were measured under a constant input power of 2.4MW but different injecting voltages, shown in Fig.6, and then under a constant injecting voltage of 9.5KV but different input power, shown in Fig.7. The input power from magnetron was determined by measuring the anode current. And the energy spectrum were measured and calculated by the magnetic analyzer system.

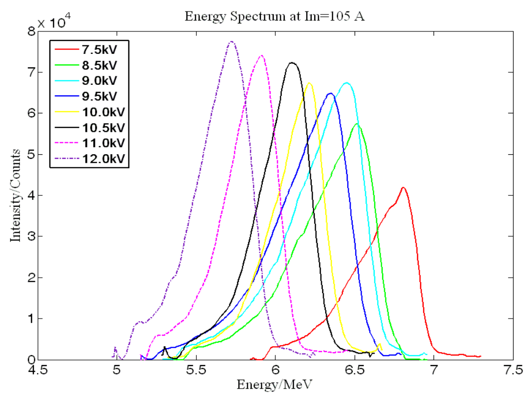

Figure 6: Measured energy spectrum for different injecting voltage(from 7.5kV to 12kV).

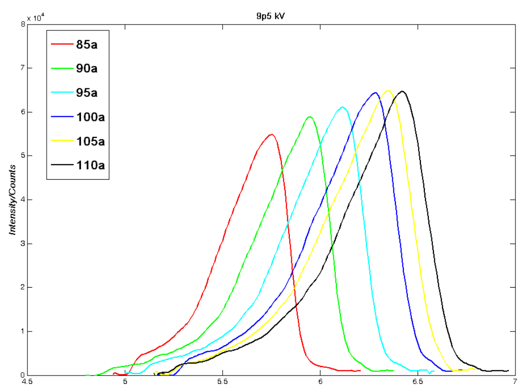

Figure 7: Measured energy spectrum for different input power (anode current from 85A to 110A).

CONCLUSION AND OUTLOOK

Despite the problem in the magnetron, High power test result of this accelerator for IMRT is satisfying.

Beam Energy and Beam Intensity

Though the required magnetron MG5349 was not used in this experiment, the input power supplied by the alternative, MG5193 has reached 2.4MW, which meets the specifications well. The measured beam energy was 6.3MeV and the beam intensity was about 135mA. Both corresponded to our expectation, which was good indication that an average current of 138 uA could be achieved with the installation of MG5349 and the realization of a repletion frequency of 280 pps.

Energy spectrum

The energy spectrum of electrons from the accelerator is one of the most important characters of a radiotherapy electron beam, which directly determines the curve of absorption rate as a function of depth. The beam energy should attain the design goal and spectra should be narrow. The result was pretty well. The accelerating tube could produce a beam with an energy spread of 3.5%, which was even lower than our expectation.

Effective Shunt Impendence

The efficient shunt impendence is also a key parameter for an accelerator. The shunt impendence is calculated using the beam loading curve, as shown above in Fig.3. The calculation has given a satisfying result: 95MΩ per meter, which was 15% lower than the theory but consistent with our prediction.

Capture Coefficient

The measured data of the capture coefficient indicates that the capture coefficient was 35% to 40% within injecting voltage: 7.5kV to 12kV range, which has reached our design goal.

In conclusion, the test has shown that the performance parameter of this accelerator has reached our design goal. The measured beam energy and intensity was consistent with our expectation and the beam spectrum was even better.

In spite of the success of the test accelerator, further research and development is still underway. The MG5349 is under repair. As soon as it can operate normally, it will be installed to supply the power and the repletion frequency will be greatly enhanced to test whether the average beam intensity can reach 138uA. The target chamber geometry and target material needs improvement for IMRT. After X-ray can be generated properly, water phantom will be installed on our system to measure X-ray dose distribution with depth in order to make further adjustment.

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