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PHYSICAL DESIGN OF A 10MeV HIGH SCANNING FREQUENCY IRRADIATION ELECTRON LINEAR ACCELERATOR*

S. Zhang[1]†, J. R. Zhang, Z. S. Zhou[1], M. Iqbal, Z. D. Zhang[1], Y. L. Chi
Institute of high energy physics, Beijing, China
[1]also at University of Chinese Academy Science, Beijing, China

Abstract

A compact 10 MeV irradiation S-band electron linear accelerator has been proposed to carry out the electron radiation effect test of materials and devices. The Linac includes a standing wave pre-buncher, a traveling wave bunching accelerating structure and a traveling wave accelerating structure. The traveling wave accelerating structure uses a 5MW klystron as RF source, and provides electron beam energy 3.5-10MeV and average current 0.01-1mA. The required irradiation scanning frequency is very high, up to 100Hz and irradiation area is large (200mm×200mm). To meet the requirements, a novel beam scanning system, including one kicker for horizontal scanning and one magnet for vertical scanning, have been proposed. This paper presents the physical design of the 10 MeV electron Linac and beam dynamics simulation results.

INTRODUCTION

The beam irradiation generated by the electron linear accelerator has been applied to various fields of the national economy. For example, radiation sterilization and preservation of food, degradation of chemical pollutants; industrial radiation processing, customs inspection; disinfection and sterilization of medical equipment; Moreover, it can also be used to simulate the electronic environment of extraterrestrial space and conduct anti-radiation experiments. The 10 MeV high scanning is an important part of the comprehensive environment simulation system of “Space Environment Ground Simulation Device” [1-4].

The accelerator has high requirements in beam parameters, as shown in Table 1. Based on the scanning frequency requirements, the traditional scanning magnet method is improved, and a new method combining kicker and scanning magnet is proposed.

The structure design and simulation results of the linac from the electron gun to the beam transport line are presented.

PHYSICAL DESIGN AND DYNAMIC SIMULATION

The 10MeV electron linac is mainly composed of an electron gun, a microwave acceleration cavity, and a beam transport line (as shown in Figure 1). According to the requirements of the accelerator parameters (see Table 1), EGUN, PARMELA and ELEGANT are used to calculate the dynamics of the electron gun, accelerating structure and beam transport line respectively to meet the design requirements.

* Work supported by Institute of high energy physics, Beijing, China
† zhangshu@ihep.ac.cn

Table 1: 10MeV Accelerator Parameters

Parameters	Values
Beam energy (MeV)	3.5-10
Beam average current (mA)	0.01-1
Energy spread (10MeV)	≤2.5%
Beam pulse duration (us)	15
Emittance(6**σ**)/（mm·mrad）	≤30
Scan frequency (Hz)	100
Irradiation area (m·m)	0.2×0.2
Beam spot uniformity	≥90%
Repetition frequency (Hz)	500

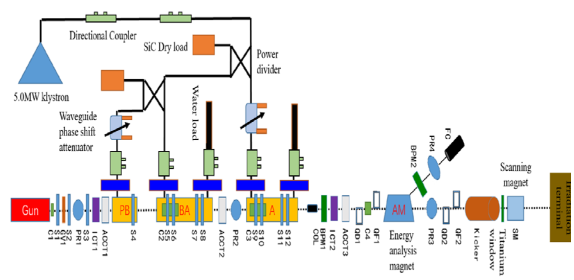

Figure 1: Layout of 10 MeV electron accelerator.

Electron Gun

After calculation, the beam current provided by the electron gun needs to be readjust within the range of 2-200mA to achieve beam average current. Using a three-pole grid controlled electron gun, the beam current can be controlled by changing the current emission density through the grid; and in order to improve the quality of beam emission, the horizontal (vertical) emittance is reduced as much as possible. The electron gun is designed in the EGUN program, and the calculation results of the beam dynamics at 2mA and 200mA are shown in Figure 2 and given in Table 2.

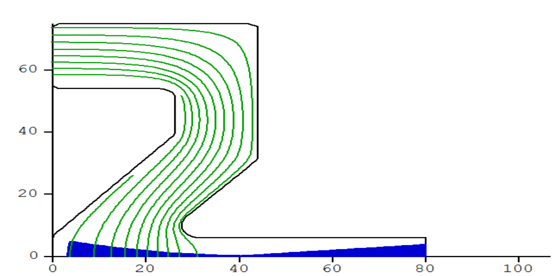

Figure 2: 200mA beam simulation results in EGUN.

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Table 2: The Results of Beam Parameters

Parameters	2mA	200mA
Micro-Perveance (uP)	0.000136	0.013608
Average Current Density (A/cm^2)	0.00295	0.419
Emittance(4σ)（mm·mrad）	16.72	17.63

Accelerating Structure

In order to improve the transmission efficiency, a pre-buncher (PB) is introduced to focus beam into a bunch at the exit of the electron gun. Using a 2-stage accelerating structure, the bunching accelerating structure (BA) accelerates the energy to about 6.5MeV, and the accelerating structure (A) changes the accelerating phase, so that the beam energy gain is within the range of -3-4MeV and the energy can be adjusted between 3.5-10MeV. To better control the beam envelope and reduce the beam loss without occupying the longitudinal space, we use dozens of solenoids to generate the magnetic field (S1-S12) [5].

Therefore, the beam generated by the electron gun enters the accelerating structure composed of PB, BA and A through vacuum tubes and focused by the solenoids (as shown in Figure 1).

The two typical working currents of 2 mA and 200mA calculated by EGUN are used as the beam input of PARMELA, and carry out dynamic calculations of accelerating structure. Figure 3 shows the 200mA beam distribution of the beam passing through PB to the entrance of BA. It can be seen from the results that the beam is effectively bunched.

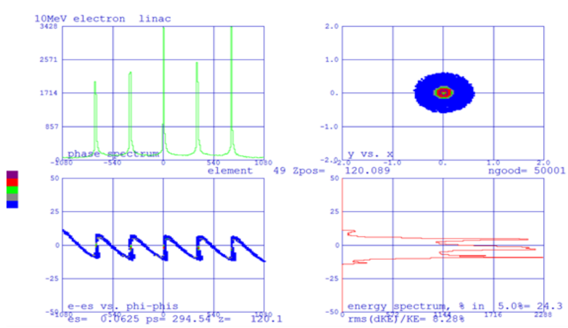

Figure 3: Beam distribution at BA entrance.

Figures 4 and 5 show the 200mA beam distribution at the BA exit and the A exit, respectively. After the beam focused by solenoid focusing and accelerated by the accelerating structure, most of the particles are accelerated and the envelope is well controlled.

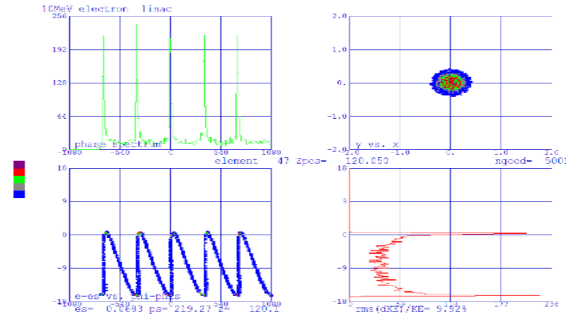

Figure 4: Beam distribution at BA exit.

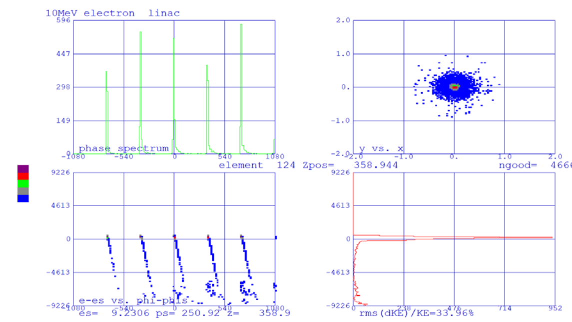

Figure 5: Beam distribution at A exit.

By adjusting the accelerating phase of A, the energy spread, transmission efficiency, and emittance in different energy are shown in Figure 6 under the two operating currents of 2 mA and 200mA

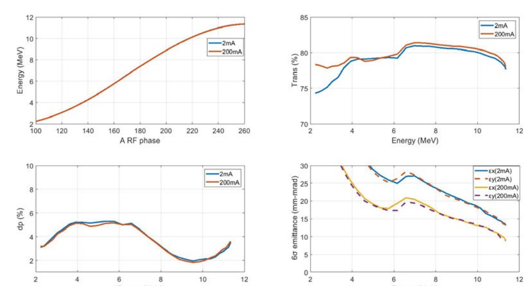

Figure 6: Beam dynamics of accelerating structure.

It can be seen from the figure 6 that in 2mA and 200mA of typical working currents, the energy can be adjusted at 3.5-10MeV. The transmission efficiency at 10MeV energy is greater than 80%, energy spread is less than 2.5%, and the 6σ emittance is less than 30mm • mrad. which both meet the requirements of beam parameters.

Beam Transport Line

The beam transport line includes a transmission unit, a beam expansion unit, a scanning unit, etc.（as shown in Figure 1）. The transmission unit uses a combination of quadrupole magnets to constrain the beam envelope to ensure its transmission in the vacuum tube; the beam expansion unit also uses a combination of quadrupole magnets to focus(defocus) to meet the size requirements of beam irradiation; in order to achieve a scanning frequency of 100Hz,

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Beam irradiation with a range of 0.2m×0.2m, the scanning unit adopts a combination of kicker(horizontal scanning) and step scanning magnet(vertical scanning).

According to the beam irradiation parameters, the beamline adopts the scheme of beam expansion in the vertical direction and scanning both horizontally and vertically. As shown in the Figure 7, a kicker with a linear change in the magnetic field is used to expand a 15us beam pulse in the horizontal direction of the target; the scanning magnet realizes 5 steps of the magnetic field, and 5 beam pulses are deflected to different positions through the magnetic field and superimposed in the vertical direction of the target. Therefore, it is necessary to adjust the strength of the quadrupole magnet and expand the beam spot in the vertical direction for achieving a wide range of beam irradiation.

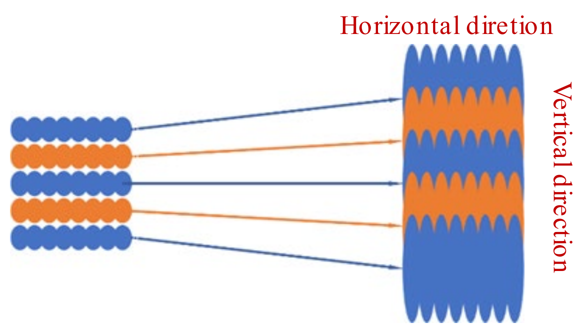

Figure 7: Schematic diagram of beam scanning.

The beam output from PARMELA is used as the beamline input of ELEGANT. Figure 8 shows the simulation results of the beam. We can see that the irradiation area reaches 0.2m×0.2m, and the beam spot uniformity is better than 90%.

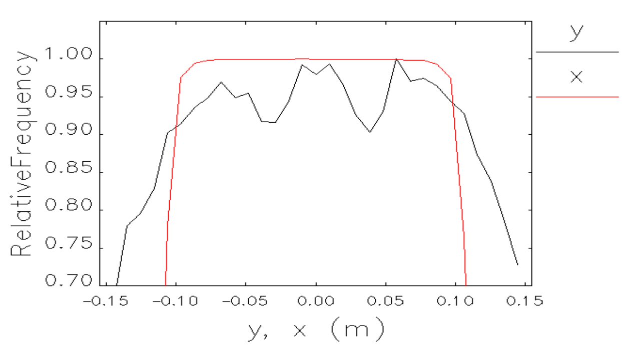

Figure 8: The results of beam scanning.

SUMMARY

We have completed the design of an accelerator with high beam parameters and passed the simulation calculation. Based on the scanning frequency of 100Hz, it is difficult for the traditional scanning magnet method to complete the beam scanning with large area and high uniformity in a short time [6]. We introduced kicker as a horizontal scanning magnet, and it is easy to spread the beam uniformly in one direction because of the 15 us long pulse. Therefore, as long as the uniformity in the vertical direction is ensured, a larger area of beam scanning can be achieved theoretically. We will continue to optimize accelerator structure to meet a wider range of irradiation.

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