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Physical design of a 10 MeV LINAC for polymer radiation processing*

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Abstract In China, polymer radiation processing has become one of the most important processing industries. The radiation processing source may be an electron beam accelerator or a radioactive source. Physical design of an electron beam facility applied for radiation crosslinking is introduced in this paper because of it's much higher dose rate and efficiency. Main part of this facility is a 10 MeV travelling wave electron linac with constant impedance accelerating structure. A start to end simulation concerning the linac is reported in this paper. The codes Opera-3d, Poisson-superfish and Parmela are used to describe electromagnetic elements of the accelerator and track particle distribution from the cathode to the end of the linac. After beam dynamic optimization, wave phase velocities in the structure have been chosen to be 0.56, 0.9 and 0.999 respectively. Physical parameters about the main elements such as DC electron gun, iris-loaded periodic structure, solenoids, etc, are presented. Simulation results proves that it can satisfy the industrial requirement. The linac is under construction. Some components have been finished. Measurements proved that they are in a good agreement with the design values.

Key words radiation crosslinking, travelling wave linac, space charge effect, beam loading effect

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1 Introduction

Besides high energy particles experiments and synchrotron radiation application, charged particle accelerator can also be used in industry, agriculture, medicine, etc[1]. This kind of accelerator is usually called applied accelerator. Normally, the applied accelerator includes dynamitron, induction accelerator, insulating transformer accelerator, linear accelerator, rhodotron, etc.

In China, polymeric materials' radiation processing has become one of the most important processing industries. As we know, There are four fundamental radiation processes for polymers: radiation crosslinking, radiation degradation, radiation induced grafting and radiation polymerisation. Now, about 90% radiation processing products are obtained by radiation crosslinking in China. Rather than a radioactive source such as Cobalt-60, electron beam accelerators are usually used for commercial radiation modification of polymers because of their much higher dose rate and efficiency. In the paper, a 10 MeV electron linac is introduced which is the first electron beam facility designed for polymer radiation processing by NSRL. This linac will be applied for radiation crosslinking for USTC Chuangxin Stock Limited Company.

2 Structure & beam dynamics

As we know, energy of the electron beam determines its depth of penetration into the product. For thicker products, such as bulk polymers on continuous belts, a "medium energy" (1 to 5 MeV) or a "high energy" beam (5 to 10 MeV) would be required. Considering this factor, a 10 MeV electron linac has been designed, which is composed of the DC electron

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gun, the iris-loaded periodic structures, the RF power supply, the wave guides, the focusing solenoids, the vacuum system, the control system, and the beam measurement system, etc. Fig. 1 shows the layout of the linac. Main designing parameters of the machine can be found in Table1, which can satisfy the industrial requirement. This linac works in S band, and the RF frequency is 2856 MHz.

A start to end simulation about the linac is finished including the space charge effect and the beam loading effect[2]. The codes Opera-3d, Poisson-superfish and Parmela are used to describe the electromagnetic elements of the accelerator and track particle distribution from the cathode to the end of the linac.

Dc electron gun

The electron gun is a grid control DC gun[3—4], at the end of which 45 keV electron beam can be obtained. Beam pulse current is about 700-900 mA and macro pulse wide is 11.0 μs. Fig. 2 shows model of the gun. After optimization, 0.094 μP perveance of the gun can be gotten. The normalized beam emittance out of anode is 10 π mmmrad, and the transverse diameter of the beam at the distance 8 cm from the gun's exit is 2-4 mm. Beam emitting process is simulated by using Opera-3d code.

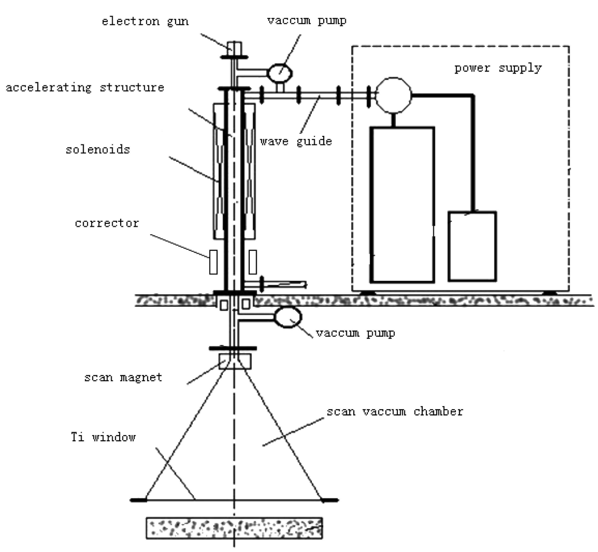

Fig. 1. Layout of the 10 MeV linac.

Table 1. Main parameters of linac.

beam energy/MeV	8.5-10
beam current power/kW	$\sim$10
pulse current/mA	300-400
energy spread	$<\pm5\%$
pulse repeat frequency/Hz	100-200
beam size at the window/mm	$\Phi10-15$
number of klystron	1
klystron output power/MW	5.4
output pulse wide/μs	2
RF frequency/MHz	2856
accelerating type	Constant impedance
dose uniformity	$<5\%$

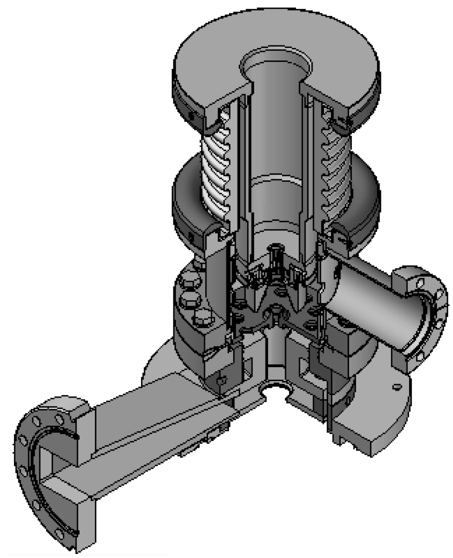

Fig. 2. Model of DC electron gun.

Traveling wave accelerating structure

After the beam dynamics optimisation depending on the theory formula with C code, there are three constant wave phase velocity accelerating structures used: β_p=0.56 of 2 cells, β_p=0.9 of 3 cells, β_p=0.999 of 45 cells. Fig. 3 shows the accelerating structure model. Table2 gives the microwave parameters of iris-loaded periodic structure with a=11.0 mm. 0.48 μs filling time has been obtained and the total attenuation along the structure is 2.7418 dB.

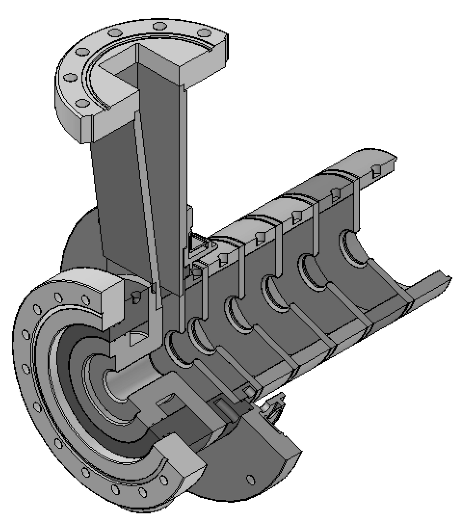

Fig. 3. Iris-loaded periodic structure with input coupler.

Table 2. Microwave parameters of Iris-loaded structure.

No.	1	2	3
β_p	0.56	0.9	0.999
b/mm	41.882	41.216	41.105
D/mm	19.5943	31.4908	34.9548
Q	8632.54	12939.19	13926.87
Rs/(MΩ/m)	20.77	53.04	61.32
α/(Np/m)	0.32897	0.19552	0.18074
β_g	0.010539	0.011830	0.011890

Longitudinal dynamics[1, 5]

Considering the beam loading effect, Fig. 4 shows the electric field distribution along the linac with the input RF power 4.8 MW and beam current 0.4 A. In this condition, energy gain of particles with different initial phase is shown in Fig. 5 and the energy distribution has also been calculated, from which one can get that the centre particle energy is about 8.5 MeV and the energy spread is ±4.3%. Same calculation as above has been finished in the condition of 0.3 A beam current. In this way, the centre particle energy is 10.0 MeV and the energy spread is about ±4.5%, which can satisfy Table1's requirement.

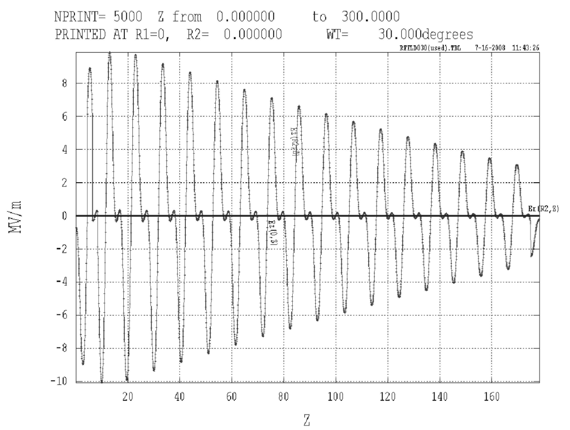

Fig. 4. Electric field distribution along the linac.

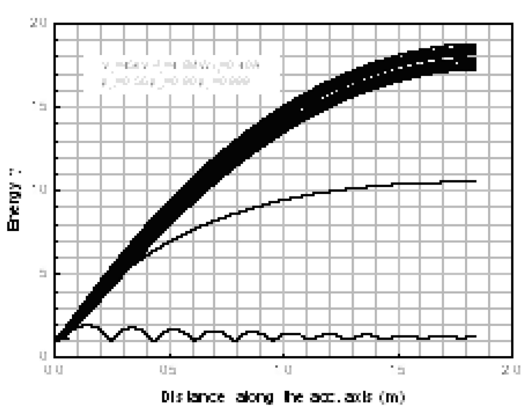

Fig. 5. Energy gain about different phase particles.

Transverse dynamics

Transverse focusing elements for the linac includes fifteen solenoids. Usually they will be needed when the beam energy is lower. Longitudinal magnetic fields produced by the solenoids are used for electron beam focusing. Table3 shows parameters of the solenoids, and magnetic fields distribution is shown in Fig. 6, calculated with Parmela code[6].

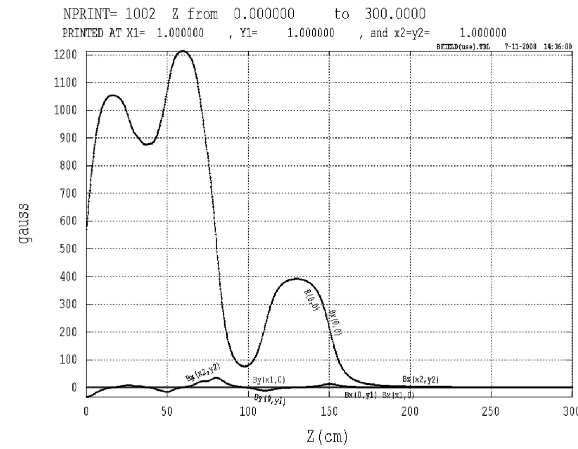

Fig. 6. Magnetic fields produced by solenoids.

Table 3. Main parameter of solenoids.

No.	I/A	8	8185.11
1	9890.33	9	0.0
2	9890.33	10	0.0
3	8867.24	11	0.0
4	4774.66	12	3410.47
5	8185.11	13	3410.47
6	12277.7	14	3410.47
7	12277.7	15	3410.47

From Fig. 7, one can see that the transverse beam diameter (rms) is 12 mm at the output window, where simulation also shows it approximates to a parallel beam.

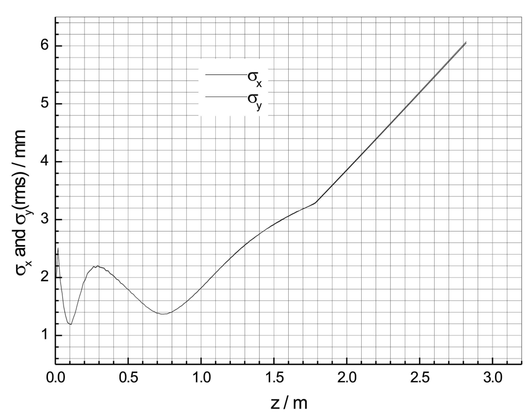

Fig. 7. Rms beam size evolution along the linac.

Elements measurements

The DC electron gun's fabrication has been finished. Test experiments proves that 900 mA electron beam current can be gotten under the conditions of I_f=1.9 A, V_a=45 kV, V^+=130 V, V^-=40 V, f=200 Hz; I_b=700 mA when I_f=1.75 A under the same other conditions. The beam size measurements show that the transverse beam diameters are all smaller than 3 mm in all conditions.

NSRL Hall probes fields measurement system consists of a computer, a Hall probe and Teslameter, a digital volt meter (DVM) , a mechanical assembly, stepping motors and drivers. The magnetic field was measured using the Teslameter and Hall probe. The output voltage of the Teslameter was digitized in the DVM whenever the DVM received a trigger pulse from the trigger pulse generator. The control program was written in Labview, and the data were post-processed by using Matlab. The solenoid B_z profile was scanned using Hall probe. Experiments shows that the measurement results agree with the predictions of Poisson 2d simulation well: the maximum B_z residuals are about ±1.5Guass.at a radius 5 mm in the solenoids.

Other elements of the linac are being fabricated or tested now.

3 Conclusion

A 10 MeV travelling wave electron linac has been designed for polymeric materials' radiation processing. Main parts of the linac such as electron gun, iris-loaded periodic structure, solenoids, have been introduced in detail. A start to end simulation for beam dynamics has been finished. Computed results prove that it can satisfy the industrial requirement. The linac is being constructed now. Some components have been finished. Measurements proved that it is coincident with the design values.

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