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PRELIMINARY PHYSICS DESIGN OF A LINAC WITH THE VARIABLE ENERGY FOR INDUSTRIAL APPLICATIONS*

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Abstract

This paper describes the physics design of a S-band (2856 MHz) linear accelerator (linac) with variable energy tuning. The system consists of a DC gun for generating electron, prebuncher for velocity modulation and two travelling wave (TW) accelerating sections for acceleration. The accelerating structure is a $2\pi/3$ mode constant gradient TW structure, which comprises TW buncher cells, followed by uniform cells. The structure is designed to accelerate 45 keV electron beam from the electron gun to 3.2 MeV, and then 10 MeV. An important feature of the TW linac is that the RF output power of the first linac is as the RF input power of the second linac. Three dimensional transient simulations of the accelerating structure along with the input and output couplers have been performed to explicitly demonstrate this feature. Beam dynamics is performed to calculate the beam parameter.

GENERAL DESCRIPTION OF THE SYSTEM

Besides high energy electron experiments, synchrotron radiation and FEL, linac can also be used in industry, agriculture, medicine, etc. This kind of accelerator is usually called applied accelerator [1].

Radiofrequency (RF) accelerating structure is the most crucial component of an electron linac, where the electromagnetic wave is utilized to accelerate the electron beam. There are generally two types of accelerating structure: standing wave (SW) accelerating structure and travelling wave (TW) accelerating structure. In a SW accelerating structure, the RF power is fed into it through an input coupler, which sets up SW electromagnetic field to accelerate the electron beam. On the other hand, in a TW accelerating structure, RF power is fed into it through an input coupler, which sets up a progressive electromagnetic wave to accelerate the electron beam, and the power remaining at the end of the structure is dumped into a matched load through an ouput coupler. The SW structure is preferred for relatively low-energy applications. A disk-loaded waveguide is typically a choice for TW structure. Based on several considerations, such as ease of fabrication, compactness of the structure, RF power to beam energy conversion efficiency etc. The TW structure is preferred for relatively higher energy applications. The TW structure has an additional advantage that for the matched input coupler, there is no reflection from the RF structure, even in transient case. This implies that no circulator is needed after the klystron in a TW structure, which results in cost reduction as circulator is an expensive microwave component. Also, the coupling of RF power to the accelerating structure in a TW linac is not affected by beam loading, unlike the SW linac. Based on these considerations, a TW structure has been chosen for the electron linac.

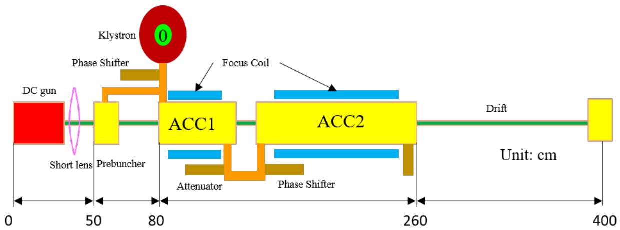

Figure 1: Schematic of the system.

To increase efficiency capture, we have adopted a prebuncher and an integrated buncher-cum-accelerator structure, where the low-energy beam is first bunched in the buncher cells, and then accelerated in accelerating cells. Figure 1 shows the schematic of the electron linac, and the desired parameters of the linac are shown in Tab. 1. We have performed the electromagnetic simulation of the structure using the electromagnetic codes SUPERFISH [2] and CST MWS [3].

The design parameters is shown in Table 1.

Table 1: Parameters of the Linac

Parameter	Vaule	unit
Operating frequency	2856	MHz
Energy	3.5~10	MeV
Average current	0.01~1	mA
Energy spread	<2.5	%
Emittence	30	μm

Design of DC Gun

The electron gun is a grid control DC gun, at the end of which 45 keV electron beam can be obtained. Beam pulse current is about 1 A and macro pulse wide is 16.0 μs. Figure 2 shows model of the gun. After optimization, 0.094 μP perveance of the gun can be gotten. The transverse diameter of the beam at the distance 50 cm from the gun's exit is about 3 mm with a short lens. Beam emitting process is simulated by using CST PS [3]. This scheme adjusts the average current by changing the filament current and the grid-controlled bias.

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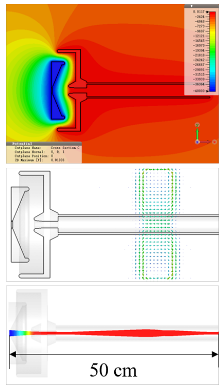

Figure 2: DC electron gun.

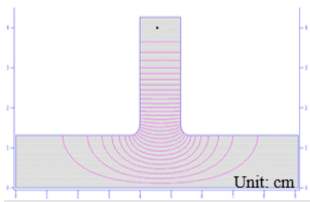

Figure 3: The electric field configuration of π mode of pre-buncher.

Electromagnetic Design of the Accelerating Structure

The prebuncher is a π mode SW structure with operating frequency 2856 MHz as shown in the following Fig. 3.

The first linac is a $2\pi/3$ mode TW structure with buncher cells followed by the accelerating cells. Operating mode is chosen as $2\pi/3$ mode because the shunt impedance of a TW linac is maximum for this case. In this mode, the phase of the travelling electromagnetic wave changes by 120° as it progresses through each cell. Design of the buncher section is important because it decides the beam characteristics at the exit of the linac. The second linac is similar the first one without buncher. The longitudinal electric field distribution along the beam direction is shown in the following Fig. 4.

An important feature of a travelling wave linac is that the RF output power of the first section linac is as the RF input power of the second section linac. To verify validity of RF power scheme, the result of simulation is performed with CST MWS as shown in Fig. 5.

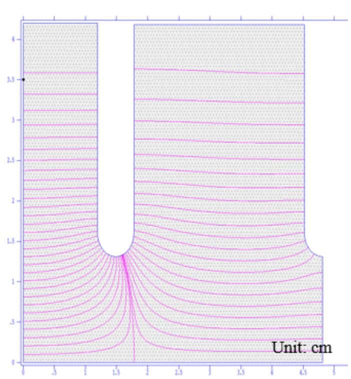

Figure 4: The longitudinal electric field distribution along the beam direction.

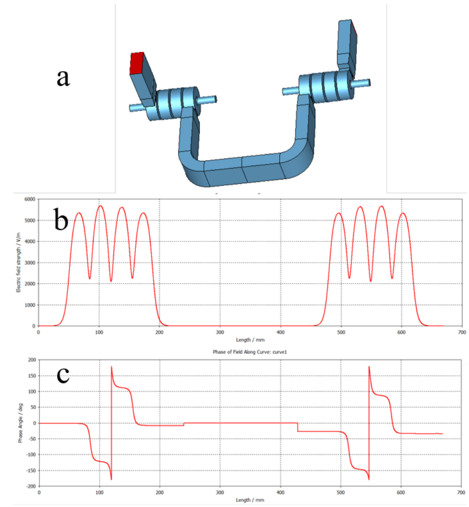

Figure 5: a: Layout of the linac; b:The longitudinal electric field distribution along the beam direction; c: The phase change between two linacs.

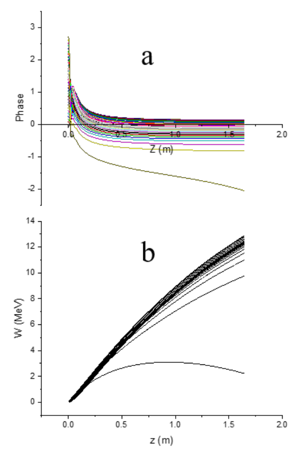

Figure 6: a: Phase plot; b: Energy gain plot.

BEAM DYNAMICS

The beam dynamics studies involve the study of evolution of the electron beam through the accelerating structure by tracing the motion of the particles, taking the space charge forces into account. In designing the bunching section of the travelling wave linear accelerator, the choice of the phase velocity of RF is very important. The first three β_ϕ of the buncher are different 0.6, 0.68 and 0.9, respectively. The input power at the coupler is 5 MW. The initial energy of electron is 45 keV. Evolution of phase and energy of an electron is calculated with the self-compiled program. The phase motion of the particles with different initial phases and energy gain are shown in Fig. 6.

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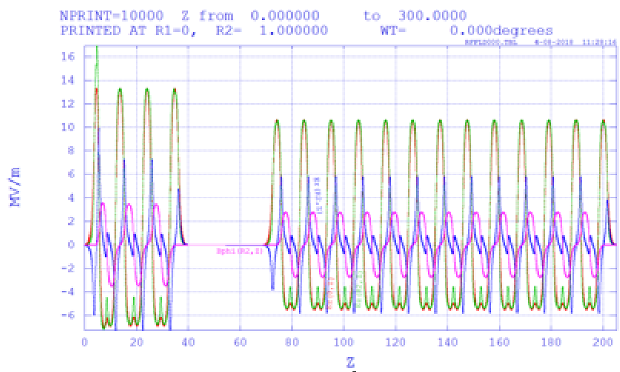

Figure 7: The longitudinal electric field distribution with beam loading.

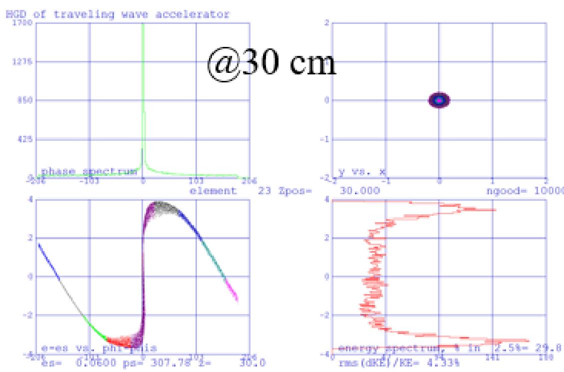

Figure 8: The velocity modulation of the particles after prebuncher.

In a constant gradient structure, the attenuating RF power establishes a longitudinal electric field. The axial electric field for each of the cell is calculated by taking attenuation and beam loading into account and then used in PARMELA [4]. Figure 7 shows the electric field with beam loading.

The velocity modulation of the particles after prebuncher at the entrance of the first linac is shown in Fig. 8. The energy spread of the particles, phase width and beam spot are shown in Fig. 9. The energy vary with the RF power is shown in Fig. 10.

CONCLUSION

A travelling wave electron linac with the variable energy has been designed for industrial applications. Main parts of the linac such as electron gun, short lens, prebuncher, two iris-loaded periodic structures, have been introduced in detail. A start to end simulation for beam dynamics has

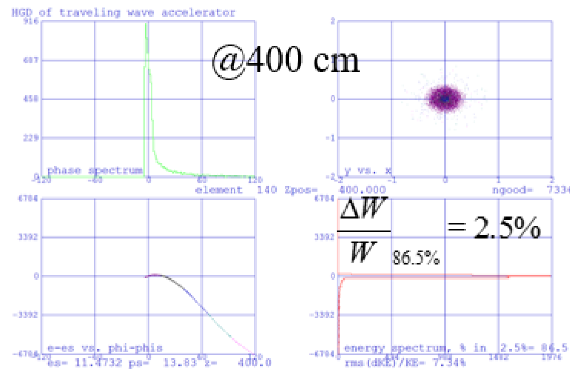

Figure 9: The energy spread of the particles, phase width and beam spot.

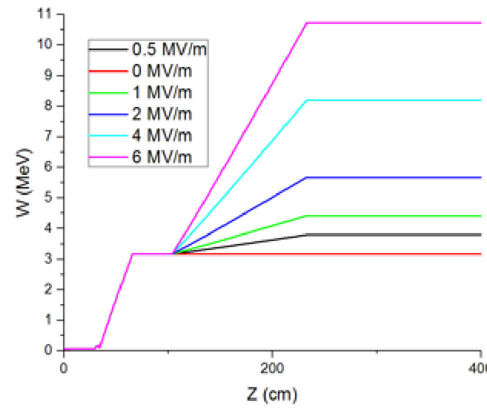

Figure 10: The energy vary with the RF power.

been finished. Computed results prove that it can satisfy the industrial requirement.

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