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STUDY OF AN L-BAND CW LINAC*

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Abstract

We have studied an L-band linac based on a cheap industrial magnetron, which works at CW mode with 75 kW averaged output-power. The designed energy-gain of electrons is 500 keV. Low accelerating gradient was the dominant problem encountered during the structure design. We adopted standing-wave structure with magnetically coupling and nose cones to increase the effective shunt impedance. A 7-cell design has been completed, of which the transverse dynamics and thermodynamics was simulated. Results showed that this accelerating structure could work stably at 59 °C and 100 mA output beam current was achieved. This L-band design provided a cheap and efficient way to generate low-energy electrons for industrial irradiation processing.

INTRODUCTION

Modern irradiation electron linac has the potential to be widely used in daily life [1-3]. However, high cost of modern irradiation electrons lianc limits its widespread application [4-6], and the price of RF power source, such as modulator and klystron, often accounts for more than 50% in the total cost. Such high expense limits the using of low-energy radiation accelerators, and the klystron dedicated for linac system also restricts its extension. In the low-energy range (below 1.5 MeV), magnetrons with lower price have become an economical and reliable RF power source. Moreover, for irradiation processing, less attention is paid on the transverse emittance and beam spot size, making it possible to accelerate electrons without an external solenoid. No solenoid applied provides the possibility to construct an irradiation linac system with simple compositions.

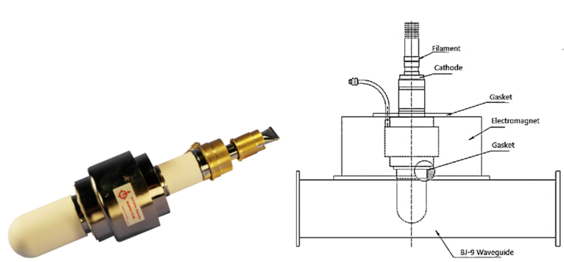

Figure 1: CW L-band (915 MHz) magnetron.

We use an L-band (915 MHz) CW low-energy magnetron as the RF power source, to achieve an irradiation linac system with low cost and simple structure. This magnetron has a low output power 75 kW, and is commonly used in industrial heating, such as microwave thawing. The appearance is shown in Fig. 1. At present, this L-band linac study is mainly divided into two parts. One is the frequency-locked and phase-locked RF power synthesis of magnetrons to achieve higher power feeding into the Linac. The other is the design of the standing-wave accelerating structure. The low-energy section is aimed at achieving 100 mA beam current at the exit, without external solenoids involved. This article primarily talks about the design of accelerating structure, with RF power fed by one 75 kW CW magnetron. Figure 2 displays the layout of this linac system, and the solenoid can be taken out if transverse dynamics meets the output requirement.

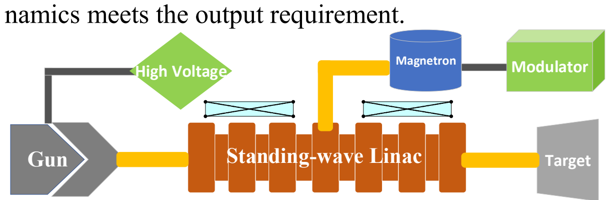

Figure 2: Layout of the designed linac system.

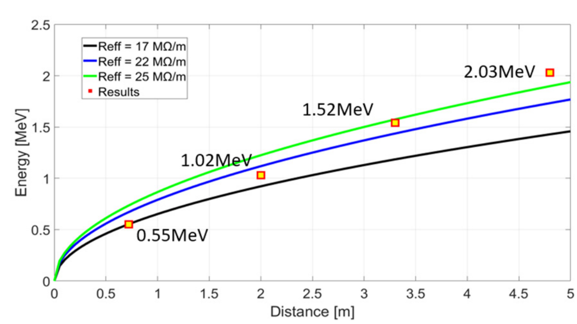

Figure 3: Predesign of different energy schemes.

STRUCTURE DESIGN

There are some difficulties encountered during the design work: I. low accelerating gradient, II. back bombardment inside the 1st cavity, III. thermal deposition of RF power loss, IV. thermal deposition of beam loss, V. beam quality. Figure 3 shows the pre-design results of different length using one magnetron to supply RF power. It is foreseeable that this magnetron as a power source will result in low E-field amplitude, i.e. low accelerating gradient. In order to realize a design with short longitudinal length and reduce the difficulty of practical placing, we have adopted the conventional high shunt impedance methods to

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improve the gradient, including the standing-wave structure, π mode, magnetically coupling and nose cones. The nose cone structure has been optimized to obtain highest shunt impedance.

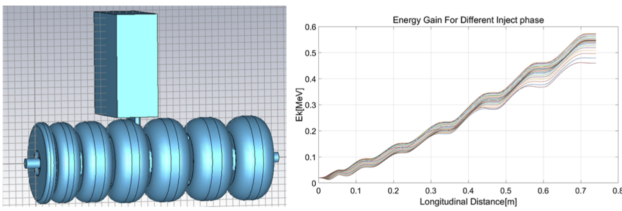

Figure 4: Vacuum model of the accelerating structure in CST (left) and kinetic energy evolution longitudinally(right).

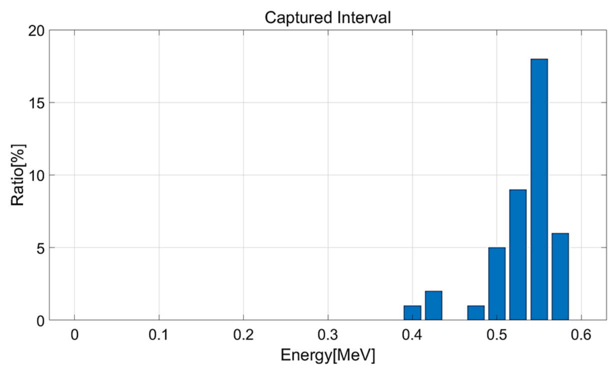

Figure 5: Energy distribution of the captured electrons.

Table 1: Parameters of the 7-Cell Design

Parameter	Value
Coupling factor	0.02
Cavity number	7
Total length	0.72 m
R_{eff}	17.1 MΩ/m
Q_0	21,000
β	3.1
Input RF power	75 kW
Energy gain	0.52 MeV
Capture ratio	33.1%

The vacuum section model is built In the electromagnetic simulation codes CST, and its longitudinal dynamics is calculated, as shown in the Figs. 4 and 5. At present, it is only powered by a single magnetron, with designed energy gain of 0.5 MeV, which can used in some industrial irradiation treatments for wastewater treatment. 7-cell design parameters are presented in Table 1. The beam load is larger than the RF loss inside the structure, thus the coupling factor is set as for reflection optimization. The capture ratio is 33%, which means more than 30% electrons can be accelerated above 0.5 MeV. Higher capture ratio calls for thermal-cathode gun with higher injecting voltage.

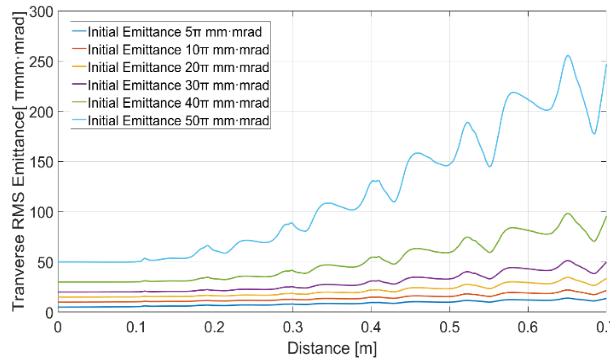

Figure 6: Evolution of transverse RMS emittance along the longitudinal axis, for various initial emittance injected.

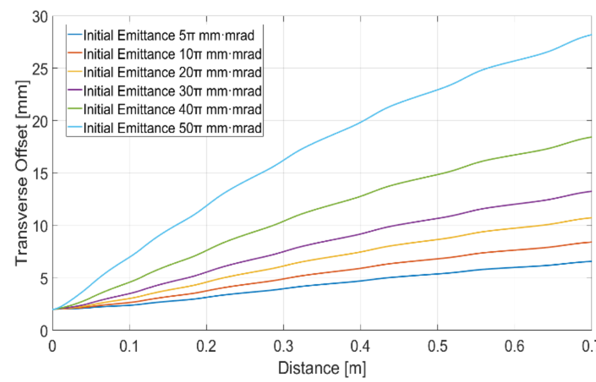

Figure 7: Evolution of transverse RMS bunch size along the longitudinal axis, for various initial emittance injected.

Due to no longitudinal magnetic field provided by an external solenoid, we pay more attention to the transverse movement of electrons. With 0.5 MeV kinetic energy obtained, electrons move in the non-light-speed range, the self-field (i.e. space charge effect) cannot be ignored. Space charge effect will lead to growth of the transverse emittance. During the accelerating process, the beam spot becomes larger and the loss of electrons on the beam hole will increase, causing decrease of beam current at the exit.

We have carried out detailed simulation calculation of the transverse dynamics, using CST, Astra and other computing software. The results show that the transverse RMS emittance and transverse RMS size of the bunch near the reference particle injection phase, grows slowly, as shown in Fig. 6. While the transverse RMS emittance and transverse RMS size of the bunch in the non-capture interval grows fastly, which contributes to the beam loss on the beam hole, as shown in Fig. 7.

Using ANSYS thermodynamic codes, the RF thermal deposition and steady-state temperature distribution with 75 kW power fed in, were simulated. The outer wall of the accelerating structure is cooled by water at 25 ℃, and the transferring convection heat coefficient is set as 10,000 at turbulent regime.

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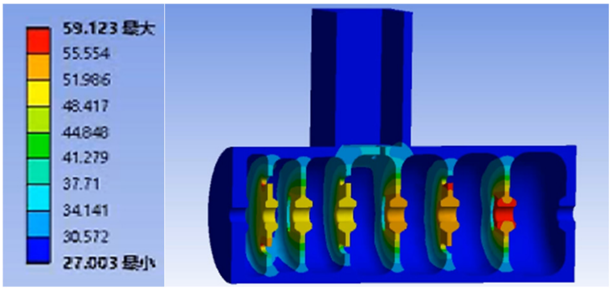

Figure 8: Steady-state temperature distribution in ANSYS simulation.

The simulation results show that the highest steady-state temperature of the accelerating structure is about 59 °C, which is positioned at coupling hole and the nose cone inside last accelerating cavity where the electromagnetic field is strongest. The steady-state average temperature is 38.6 °C. Relevant results are displayed in Figs. 8 and 9.

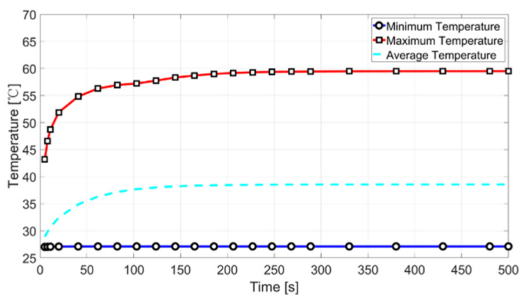

Figure 9: Temporal evolution of the steady-state temperature.

CONCLUSION

We describe the design and dynamics simulation of an 7-cell standing-wave accelerating structure, in this short paper. Without external solenoid applied, we complete the 0.5 MeV & 100 mA beam design successfully. For the thermodynamics, we prove that the highest temperature is no more than 60 °C with 75 kW CW RF power fed in.

In the future, our research will include RF power synthesis and accelerating structure design for higher kinetic energy. Multiple magnetrons can synthesize higher feeding RF power to achieve higher acceleration gradient, with frequency-locked and phase-locked methods. Longer longitudinal length is required to achieve high kinetic energy scheme, i.e. several MeV, which can be applied in widespread range of industrial irradiation process. And it also puts forward higher requirements on the electrons transverse dynamics.

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