

BEAM DYNAMICS STUDIES OF AN ACCELERATING TUBE FOR 6 MeV ELECTRON LINAC

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Abstract

Side coupled standing wave accelerating tubes are widely used in a low energy linear accelerator because of relatively high accelerating gradient and low sensitivity to construction tolerances. The effective interaction of particles and electromagnetic fields is important for accelerate electrons to intended energy with the greatest efficiency and beam quality output.

In this paper, we present the beam dynamics of a 6 MeV Side coupled standing wave accelerating tube using a space charge tracking algorithm (ASTRA). The designed accelerating tube that feeds by a maximum power of 2.6 MW resonant at frequency of 2998.5 MHz in $\pi/2$ mode.

37.5 percent capture efficiency, 6.82 pi-mm-mrad horizontal emittance, 6.78 pi-mm-mrad vertical emittance, 2.24 mm horizontal and vertical beam size and 1079 keV energy spread of the output beam have been determined from the results of beam dynamics studies in ASTRA.

INTRODUCTION

The design stage of the desired accelerating tube is first electromagnetic simulation, and then is the analysis of longitudinal and transverse dynamics of the beam inside tube. Some common codes such as Parmela [1] and ASTRA [2] are used to simulate beam dynamics within the tube.

In this article, the results of beam dynamics studies of the side coupled standing wave tube have been investigated which is in progress for construction a 6 MeV electron linear accelerator (e-Linac) in Nuclear Science and Technology Research Institute (NSTRI) [3].

Figure 1 shows the schematic layout of the desired tube that consists of 6 accelerating cavities and 5 coupling cavities and feeds by a 30 keV electron gun. The characteristics of the tube is shown in Table 1.

The electromagnetic simulations of the tube have been carried out using the finite element method (FEM) program COMSOL Multiphysics [4].

The accelerating cavity is designed in order to achieve effective shunt impedance, coupling coefficient and quality factor of 115 MΩ/m, 0.011 and 17000 respectively.

Table 1: Desirable tube specification

Parameters	Value
RF frequency	2998.5 MHz
Input beam energy	30 keV
Output beam energy	6 MeV
Operating mode	$\pi/2$
Maximum RF power	2.6 MW

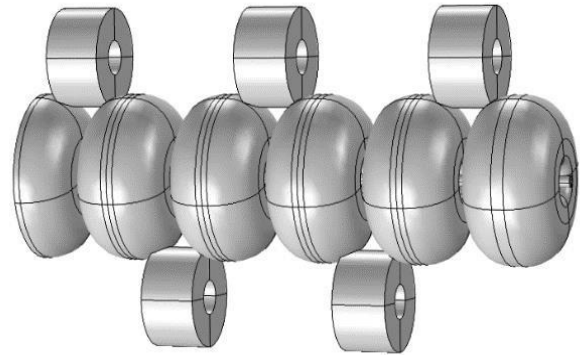


Figure 1: The entire accelerating tube.

MATERIALS AND METHODS

ASTRA code

It is important to study beam dynamics through the tube, In order to predict the quality of electron beam such as beam size, capture efficiency, bunches phase space at the end of the tube and energy spread of the output beam.

ASTRA code is one of the three-dimensional particle tracking codes with an input particle generator and multi-user graphics processor based on PGPLOT library. This program tracks particles (electrons, positrons, protons and hydrogen ions) through user defined external fields taking into account the space charge field of the particle.

For ASTRA code, the space-charge fields are calculated in the beam rest frame via Poisson's equation in free space and Lorentz's transformed back into the laboratory frame. ASTRA is based on Runge-Kutta integration of 4th order with fixed time step through the user defined external electric and magnetic fields, taking into account the space charge field of the particle cloud. A cylindrical grid, consisting of rings and slices, is set up over the bunch extension for the space charge calculations. The code automatically updates the mesh size as the simulation progresses. The space charge effect is a principal cause of emittance growth when the beam energy is low [5]. This code is one of the common valid codes is referred for validation of new codes [6-7].

Input Beam and Electromagnetic Field Define

Because the side coupled tube has asymmetric, 3D electromagnetic fields for the designed tube are defined for ASTRA code that include the effects of asymmetry of the field in particle tracking. The axial electric field and transverse electric field of defined 3D fields on the axis of the accelerating tube is shown in Figure 2 and Figure 3.

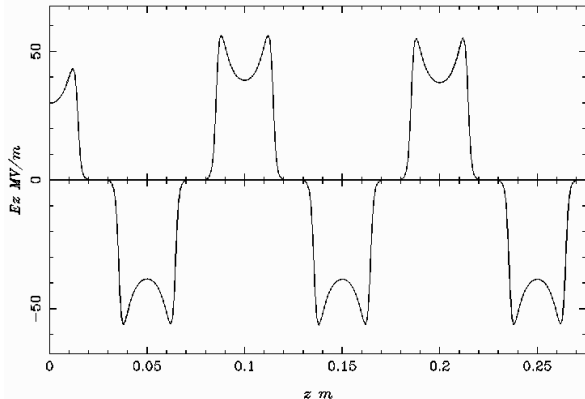


Figure 2: Longitudinal electric field.

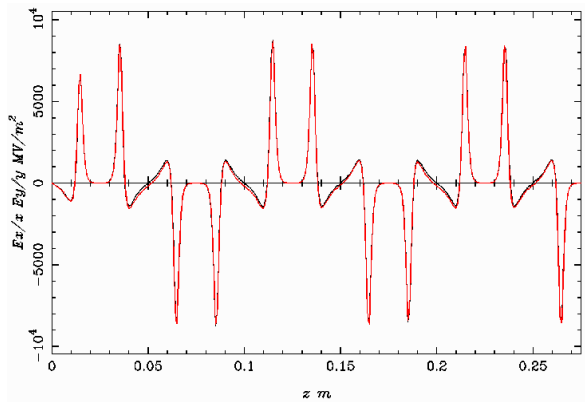


Figure 3: Transverse electric field (red: vertical, black: horizontal).

For simulations, we have defined 30000 macro particles in uniform distribution in longitudinal direction and Gaussian distribution in transverse direction as input beam for ASTRA code.

The mean energy of the particles injected in the tube is 30 keV and 4 mm vertical and horizontal beam size according to the cathode diameter is determined. Initial beam specification are shown in Table 2.

Table 2: Input beam

Beam Parameter	Value
Vertical beam size	4 mm
Horizontal beam size	4 mm
Energy	30 keV
Energy spread	3 keV
Longitudinal emittance	300 mm
Vertical emittance	0.47 pi-mm-mrad
Horizontal emittance	0.47 pi-mm-mrad

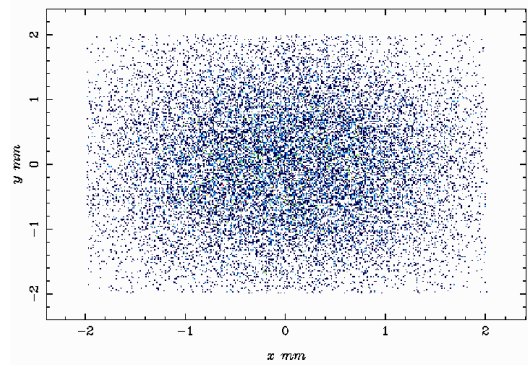


Figure 4: Beam size of input beam.

In Figure 4, Beam size of input beam is shown in the transverse plane and Figure 5 shows the Input beam divergence.

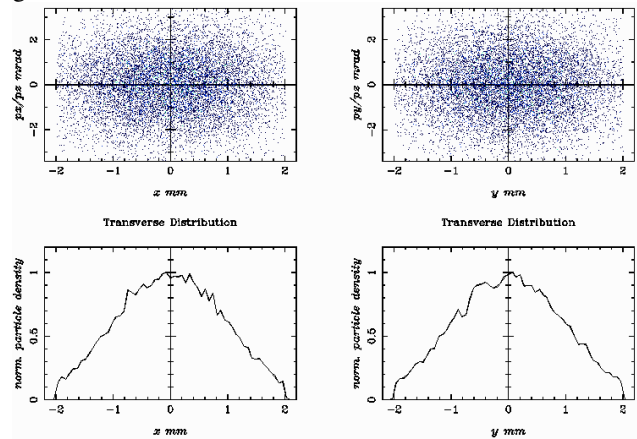


Figure 5: Input beam divergence.

RESULTS

By considering the effect of space charge, 30000 macro particles have been tracked and about 45 percent of particles reach the end of the tube. Figure 6 shows final energy of the beam against initial phase, in the initial phase between -100° and 35° have been reached to 6 MeV that equal to more than 37.5 percent capture efficiency.

Computed results of capture efficiency prove that it is suitable comparing with the reported standing wave tubes [8,9].

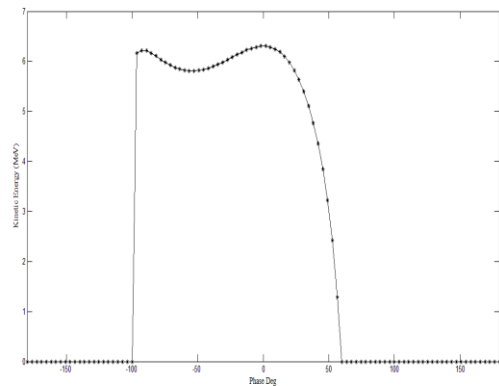


Figure 6: Output energy against initial phases.

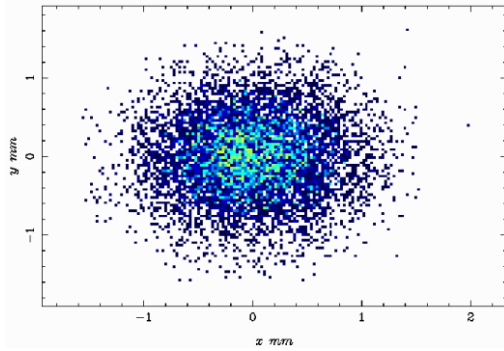


Figure 7: Beam size of output beam.

Figure 7 shows Beam size of output beam at the end of tube in the transverse plane. The results show the vertical and horizontal beam size reduce to 2.24 mm.

The longitudinal phase space of electron bunch is shown in Figure 8.

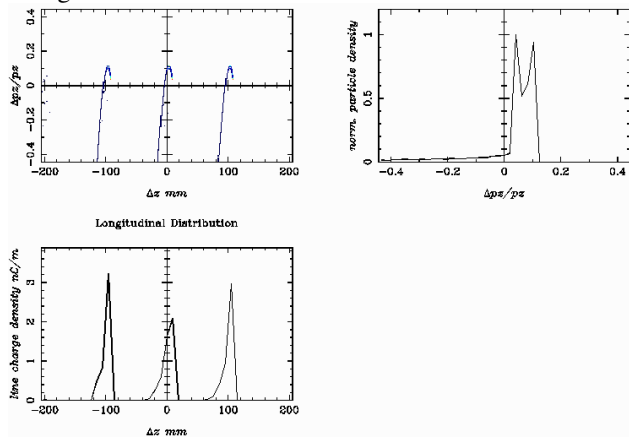


Figure 8: Longitudinal phase space of electron bunches.

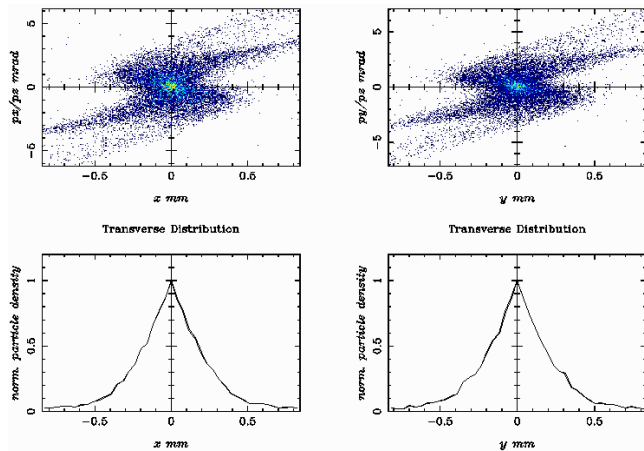


Figure 9: Output beam divergence.

Table 3: Output beam specification

Beam Parameter	value
Vertical beam size	2.24 mm
Horizontal beam size	2.24 mm
Energy	6 MeV
Energy spread	1079 keV
Vertical emittance	6.78 pi-mm-mrad
Horizontal emittance	6.82 pi-mm-mrad

By the beam tracking simulation in the 3D electromagnetic field, at the end of the tube the output beam divergence is about 4 mrad in transverse plane as shown in Figure 9. At the end of the tube, emittance in the vertical direction is 6.78 pi-mm-mrad and in the horizontal direction is 6.82 pi-mm-mrad. Characteristics of the output beam at the end of tube are presented in Table 3.

CONCLUSION

A simulation for beam dynamics of a 6 MeV linac has been carried out in this article. In beam dynamics studies, 30000 macro particles in uniform distribution in longitudinal direction and Gaussian distribution in transverse direction have been defined as input beam. In the simulation, the effects of the space charge and 3D electromagnetic fields have been considered. We conclude from these beam dynamics studies in ASTRA code, horizontal and vertical emittance, horizontal and vertical output beam size and energy spread of the output beam are obtained 6.82 pi-mm-mrad , 6.78 pi-mm-mrad , 2.24 mm , 2.24 mm and 1079 keV respectively.

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