THE SIMULATION OF THE BEAM DYNAMICS IN THE HIGH CURRENT CORNELL ELECTRON LINAC*

V. S. Aleksandrov, N. Yu. Kazarinov, E. A. Perelstein, M. N. Sazonov
JINR, Dubna, Moscow Region, 141980, Russia

M. G. Billing†, Cornell University, LNS, Ithaca, NY 14583, USA

Abstract

The Cornell Linac is the initial component of the injector for Cornell Electron Storage Ring operating in multibunch regime. Numerous linac multibunch conditions have been studied at Cornell. The simulation of bunch self-fields presented int this paper must complement the experimental efforts to increase the CESR luminosity and promote the further development of beam control systems. The wakefield effects in the Cornell electron linac are studied here including more realistic details for the linac accelerating sections and creating more correct models to allow the comparison of experimental and simulation results. This simulation includes the effects of beam loading, longitudinal and transverse wakefields from both self-fields and from previous bunches.

1 INTRODUCTION

The Cornell Electron Storage Ring (CESR) operates as an electron-positron collider with 9 trains of 2 to 5 [1] closely spaced bunches per train per beam. The Cornell Linac is the first component of the injector for CESR and it must provide multibunch trains of electrons and positrons at high injection rates for CESR.

In the previous report [2] we have studied the effects of operating of the Cornell Linac at high multibunch currents needed for the production of trains of positron bunches. Results included the effect of longitudinal wakefields induced by the beam in the linac injector s prebuncher cavities and a method for partial compensation of the effect of these wakefields, the effect of transverse wakefields in the SLAC type linac accelerator sections in the electron linac preceding the positron target and the effect on positron capture from the increase of the accelerating gradient in the positron linac.

Here we are studying the beam dynamics in the electron linac which consists of the 150 keV electron gun, two prebuncher cavities and four accelerating sections AS#1...AS#4. In the case of positron production the accelerated electron bunches with an energy ~150 MeV hit the converter target where positrons are created. For effective positron production the radius of electron beam s cross section on the target should be less than 1 mm [3]. The space charge effects have been simulated here for a single train consisting of 6 bunches with a charge 16 nC per a bunch and 14 ns of bunch spacing. This simulation includes the real details of the electron linac magnetic optics and accelerating sections.

*This work has been carried out under NFS contract No. PHY-99809799-SUB-U-82-8400

†mgb@cesr10.lns.cornell.edu

2 BEAM DYNAMICS SIMULATION

The beam dynamics is simulated for two initial conditions of the beam at the gun. The first condition is that a beam has an initial displacement from the axis of the accelerator, x = 1 mm, dx/ds = 0. The second one is that a beam has initial angle to the accelerator axis, i.e x = 0, dx/ds = 1 mrad.

The motion of single bunch through two prebunchers is simulated by the Parmela code [4]. The final results are the beam conditions at the entrance into the first accelerating section. Thus, the Parmela simulation yields the following beam conditions for the centroid of the injected bunches: x=0.076 mm, dx/ds=11.6 mrad, y=-0.22 mm, dy/ds=26.3 mrad for the initial beam displacement at the gun and x=-0.034 mm, dx/ds=4.5 mrad, y=0.056 mm, dy/ds=3.9 mrad for the initial angle at the gun. The prebunchers and first accelerating section have uniform solenoid focusing with a longitudinal magnetic field B_z = 0.2 T. It is assumed that all bunches are ideally captured into the linac for further simulations.

2.1 Beam loading

According to Wang[5] the accelerating electrical field $E_z(s,t)$ in the constant gradient structure loaded by beam satisfies the following equation:

$$\frac{\partial E_z}{\partial s} + \frac{1}{v_g(s)}\frac{\partial E_z}{\partial t} = -\frac{\pi f R}{Q v_g(s)} i(s,t), \qquad (1)$$

where v_g is group velocity, f is the frequency of the accelerating wave, R is the shunt impedance per unit length, Q is the quality factor, i is the beam current. The solution of this equation with boundary condition $E_z(0,t)$ = E_0 for $t \geq 0$ has the following form:

$$E(s,t)=E_0\theta[t-\tau(s)]-\frac{\pi fR}{Q}\int_0^{\tau(s)} i[s(\tau'),t+\tau'-\tau]d\tau' \quad (2)$$

where $\theta(x)$ is the Heavyside step function, $\tau(s)=\int_0^s \frac{dz'}{v_g(z')}$ is propagation time of the RF power from 0 to s. For an ultrarelativistic short bunch the current $i(s,t)=q\delta(t-s/c)$, q is the bunch charge, c is the speed of light. The amplitude of the induced field at the fixed point z in accordance with formula (2) is equal to $\Delta E=-\frac{\pi fR}{Q}q$, if $s/c\le t\le \tau(s)$ and $\Delta E=0$ for all other moments of time. For the multibunch beam the amplitude of the induced field acting on the bunch is found by summing the amplitudes of the field from all previouse bunches. The results of the simulation of beam loading in accelerating sections are shown in Figure 1.

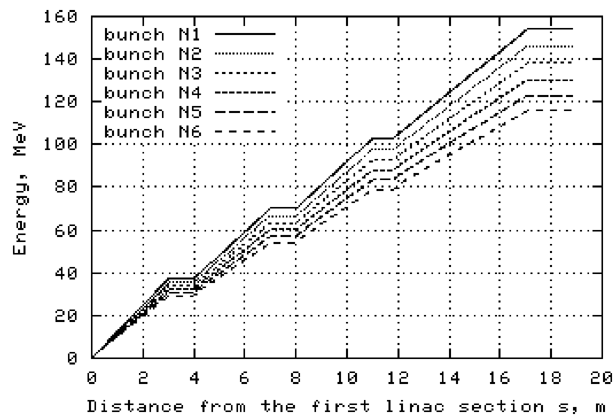

Figure 1: Dependences of the bunch energy on the length along the linac.

2.2 Transverse Wake Field Model

The bunches excite wakefields in accelerating sections of the linac. The bunch to bunch longitudinal fields define the beam loading while the transverse fields produce an additional transverse kick on the bunches.

The transverse fields at the lowest frequency are the main cause of bunch instability. Indeed, the group velocity of these synchronous waves is negligible compared to bunch arrival time. Thus the accelerating section can be presented as set of uncoupled cavities. The section AS#1, 2, 3 have 86 cells each and section AS#4 has 150 cells.

All accelerating sections have been assumed to be constant gradient. The first section AS#1 is a SLAC-type, second AS#2 and third AS3# are CEA-types and fourth section AS#4 is CU-type[6]. They have slightly different geometric dimensions and the URMEL [7] simulation of first dipole mode displays the following frequency detuning for first and last cells in the sections: AS#1 from 4150 to 4370 MHz, AS#2,3 from 4200 to 4370 MHz and AS#4 from 4050 to 4270 MHz. The attenuation of this mode is negligible for our bunch train since the quality factor is about 12000. The loss factors are almost the same for all sections 0.56 — 0.4 V/pC at the iris radius for the first and last cells of sections, respectively.

To simulate the bunch head-tail effects, the charge density of every bunch is modelled as a set of delta function microbunches. Thus the wakefields excited by the first delta microbunches cause additional transverse kicks on subsequent microbunches in the same bunch.

2.2 Bunch motion in linac

The transverse beam dynamics in the linac is defined by the following system of equations in acceleration sections:

$$\begin{cases} x''(s)=\frac{eB_z}{P_z}y'-\frac{P_z'}{P_z}x'+\frac{F_x(t)}{P_z v_z} \\ y''(s)=-\frac{eB_z}{P_z}x'-\frac{P_z'}{P_z}y'+\frac{F_y(t)}{P_z v_z} \end{cases}, \quad (3)$$

where (x, y) is the transverse beam position, e is the electron charge, P_z and v_z are the longitudinal bunch momentum and velocity, B_z is the longitudinal magnetic field, $F_{x,y}$ is the resulting wake force from the previous bunches.

Solving these differential equations for the initial beam condition, one obtains the beam trajectory from cell to cell in an accelerating section. Applying the linac optics matrices between the sections one can get the beam trajectory along the whole linac. The resulting trajectories of bunch centroids for an initial beam angle at the gun are shown in Figure 2.

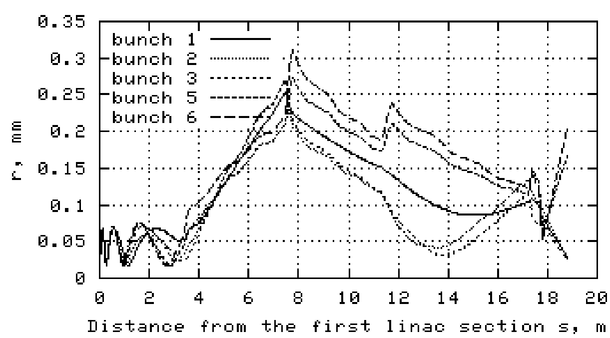

Figure 2: Trajectories of bunches along the linac via initial beam angle on the gun.

All intensity dependant effects described above are taken into account. For the second gun conditions (when beam has an initial displacement) the bunch trajectories are shown in Figure 3. The line called no wakes displays the trajectory for the first bunch with no self-wakefields. An example of resulting transverse wake potential found at the center of last (sixth) bunch is shown in Figure 4.

The transverse bunch distribution on the positron converter is presented in Figure 5. The charge density is scaled there and every point corresponds to a delta function microbunch. It should be noted that the head-tail effect has been investigated for the first dipole mode only.

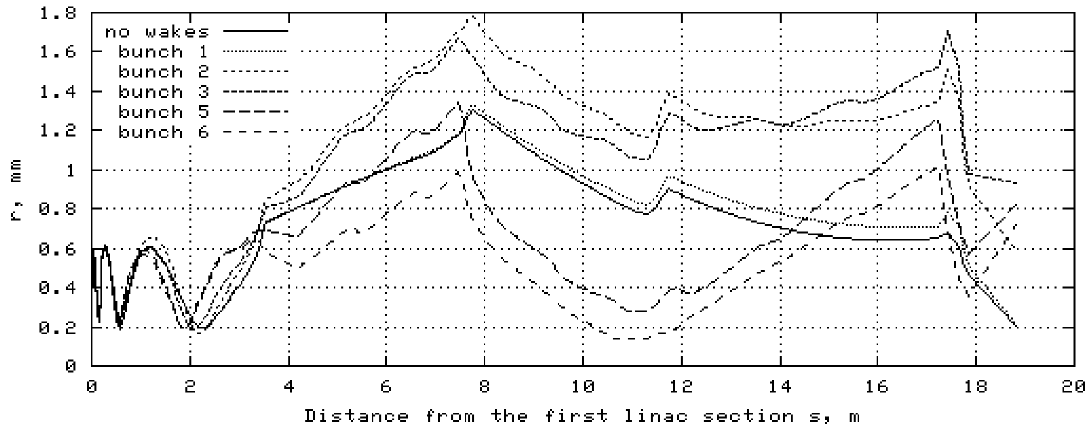

Figure 3: Trajectories of bunches along the linac caused by an initial beam displacement at the gun.

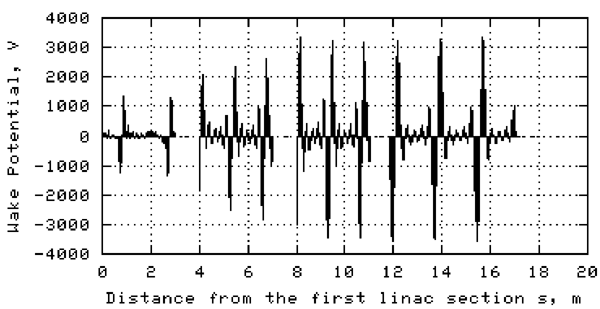

Figure 4: Transverse wake potentials seen by bunch #6.

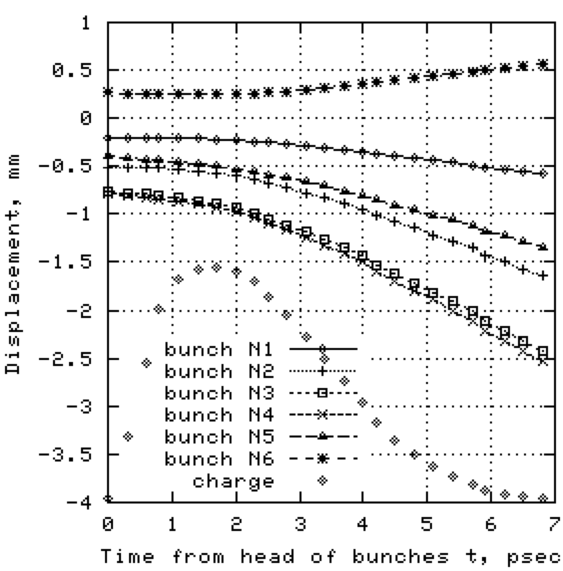

Figure 5: Charge density and bunch distribution at the converter target.

3 CONCLUSIONS

The dynamics of a beam consisting of 6 bunches with 14 ns bunch spacing and charge 16nC per bunch is studied in the high current Cornell electron Linac taking into account intensity dependant effects. The effect of beam loading dominates the bunches motion as compared with the transverse wake fields. The transverse wakefields in the first accelerating section is significantly smaller in a magnitude than in subsequent sections. In the last section the transverse wake potential becomes nearly 3kV per cell for bunch #6. An initial displacement of 1 mm of the beam centroid at the gun produces an increase of the beam spot radius about of 0.8 mm at converter target. In the case of an initial beam angle at the gun of 1 mrad, this increase in the spot size is about of 0.1 mm.

4 ACKNOWLEDGEMENTS

The authors are grateful to Dr V.Kazacha for useful assistance.

5 REFERENCES

[1] D. Rise, Proc. of EPAC96, Barcelona, 1996, p.17.

[2] V. S. Alexandrov, A. P. Ivanov, N. Yu. Kazarinov et. al., Study of the operation of the Cornell linac for positron at high multibunch currents, Proceedings of 1999 Particle Accelerator Conference (PAC'99), New York, 1999, p.˚3501.

[3] M. Billing, N. Kazarinov, "The possibility of increasing the positron production for CESR injection", CBN 93-05, Cornell LNS notes.

[4] B. Mouton, The PARMELA program, Report LAL-SERA 93-455, Laboratoire de l'Accelerateur Lineare, Orsay, France (1993).

[5] J. W. Wang, RF properties of periodic accelerating structures for linear colliders, SLAC-336, 1989.

[6] R. Cuttler, M. Gianella, Private communication, "Linac study", LNS, Cornell, 1996-1997.

[7] U. Laustroer, U. van Rienen, T. Weiland, "URMEL and URMEL-T user guide", DESY M-87-03, 1987.