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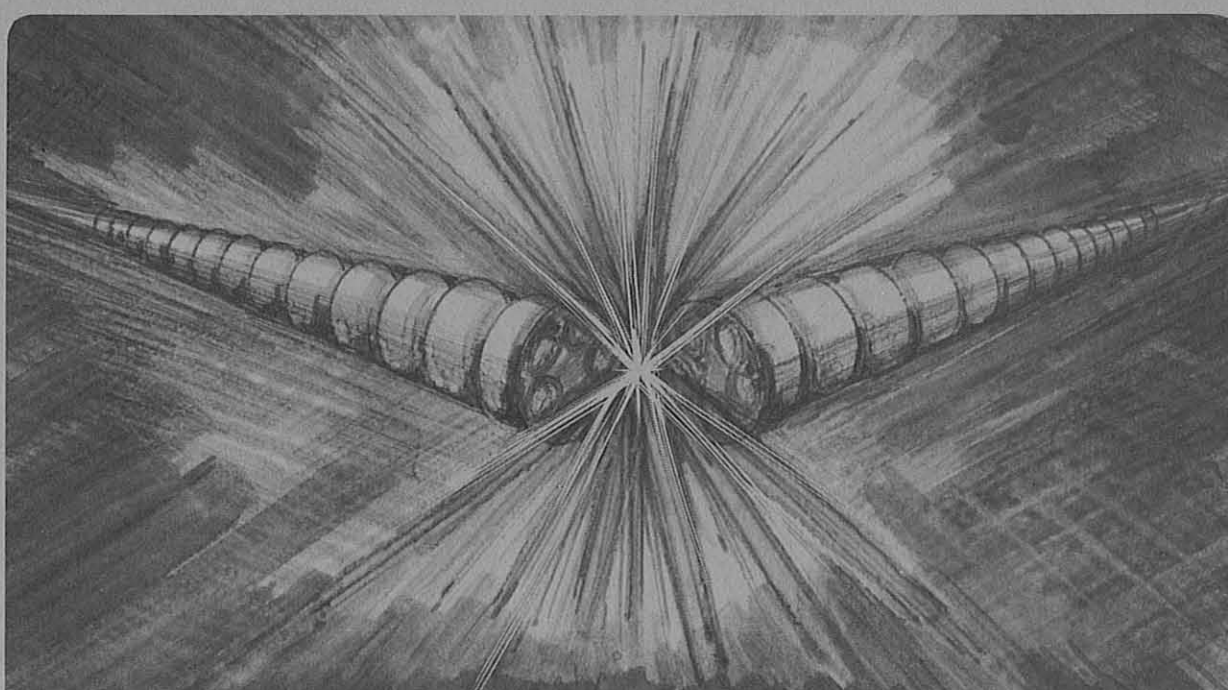

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SIMULATION OF EMITTANCE GROWTH IN THE ALS PRE-INJECTOR*

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Abstract

Transverse and longitudinal beam dynamics in the ALS pre-injector were simulated with a 2 1/2 D code. Strong space-charge forces at low energy and nonlinearities caused emittances to grow. However, careful tuning of the bunching system and the linac reduced emittance growth to an acceptable level. About 1/3 of the gun output are within the required energy spread and the normalized rms emittance is significanly lower than the expected value.

Introduction

The preinjector of the Advanced Light Source now under construction at the Lawrence Berkeley Laboratory consists of a 120 keV 2A electron gun, a bunching system with three bunchers (125, 500, and 3000 MHz), and a 50 MeV disk-loaded traveling-wave linac. It was designed to operate in either a single bunch mode or in a multi-bunch mode at a rap rate of up to 10 Hz. In the single bunch mode, more than 1 nC of electrons with a velocity spread of less than 0.3 % rms must be delivered to the booster synchrotron in order to fill the storage ring in a few minute.

Energy spread is of our main concern because main beam osses will occur at the energy selector located in the linac-to-booster transfer line.Short bunch length in the linac and tuning of the rf phase is essential for a small energy spread. A 2 ns, 4 nC bunch starting at the gun is compressed by a factor of 10 in the two subharmonic bunchers and by another factor of 10 in the S-band buncher [1]. Bunch compression is limited by strong repulsive space charge forces; the beam perveance, $2I/(I_A(\beta\gamma)^3)$, increases rapidly in the bunching system and reaches a maximum value of 6×10^{-2} in the middle of the S-band buncher.

Description of the Pre-injector

Beam elements, their locations, and strength are summarized in Table I below.

Table I. The beam elements and locations used in the simulation.

Elements	z (cm)	Strength
Eceltron Gun	0 - 0	
125 MHz Buncher	99 - 99	50 kV peak to peak
500 MHz Buncher	246 - 246	50 kV peak to peak
S-band Buncher	279 - 289	3.5 MV/m
Linac, Section I	291 - 492	15 MV/m
Quadrupole Triplet	535 - 582	143 , -260, 143 Gaus/m
Linac, Section II	612 - 812	15 MV/m

The electron gun is similar to the one used by SLC; it will be capable of producing 2-4 A of peak current at a nominal energy of 120 keV with a normalized rms emittance of 8 π mm-mrad. The gun current can be pulsed for a minimum duration of 2.5 ns, at the maximum rate of 125 MHz. We plan to use at most 18 consecutive micro-pulses (<150 ns) at a time. This is suitable for single-turn injection into the booster. A drift region of 100 cm between the gun and the 125 MHz subharmonic buncher is necessary for beam instrumentation and for bucking the solenoidal focusing field at the gun.

The 125 and 500 MHz subharmonic buncher is a reentrant resonant cavity excited in the TEM mode. The S-band buncher is a 4 cavity traveling wave structure with a wave velocity, $\beta_w = 0.75c$. Wave velocity in the linac is assumed to be 1.003 c. Solenoidal focusing is used up to linac section I and a triplet for linac section II.

Simulation

A modified version of PARMELA[1] was used. The simulation includes space charge forces, and effects of image charges on the vacuum chamber wall. Linac is modeled with three spatial harmonics. Beam loading[2] in the linac and wake field effects may be significant in the multi-bunch mode, but not included in the present simulation.

Results

A particle is considered lost if either it touches the vacuum chamber wall or the velocity becomes less then zero. The number of surviving particles in the simulation is shown in figure (1) as a function of the distance along the linac. Most particle losses (4.2 %) occurred in the first 25 cm of the linac section I. Total lost particles in the pre-injector was 5.8 % in this simulation.

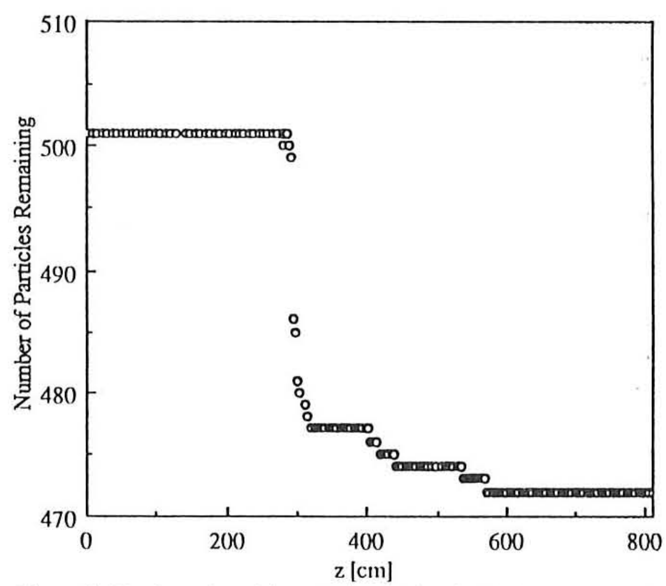

Figure 1. Number of particles remaing in the simulation versus z

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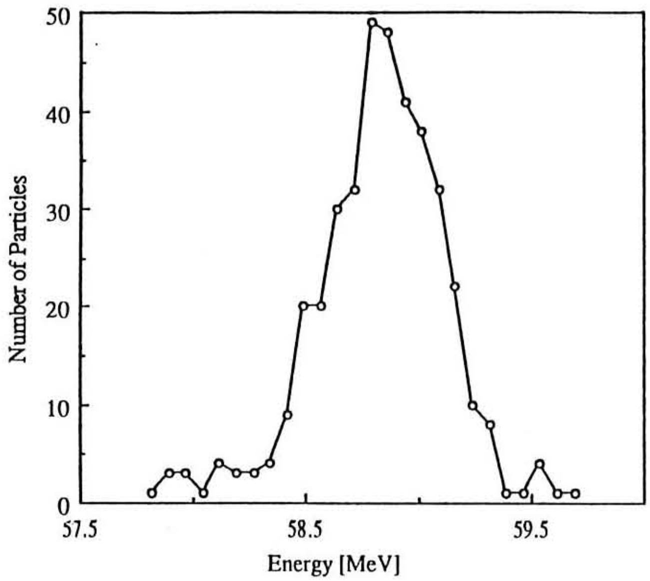

Figure 2. Energy distribution of the 472 surviving particles at the end of the linac

Energy distribution of the particles at the end of the linac is shown in figure 2. Out of 472 "all" particles which are able to make their way to the end of the linac, 322 particles are within the required rms energy spread of 0.3 %. These "core" particles have energies between 58.5 MeV and 59.2 MeV and will be selected for injection into the booster. Transverse (horizontal) emittances of all and core particles at the end of linac are shown in figure 3. The core emittance is significantly smaller than the value we used for our early design studies (110 π mm-mrad).

Behavior of "all" particles and "core" particles are investigated in the subsequent studies using post-processors for post-mortem analysis. Separate analysis of all and core particles turned out to be a

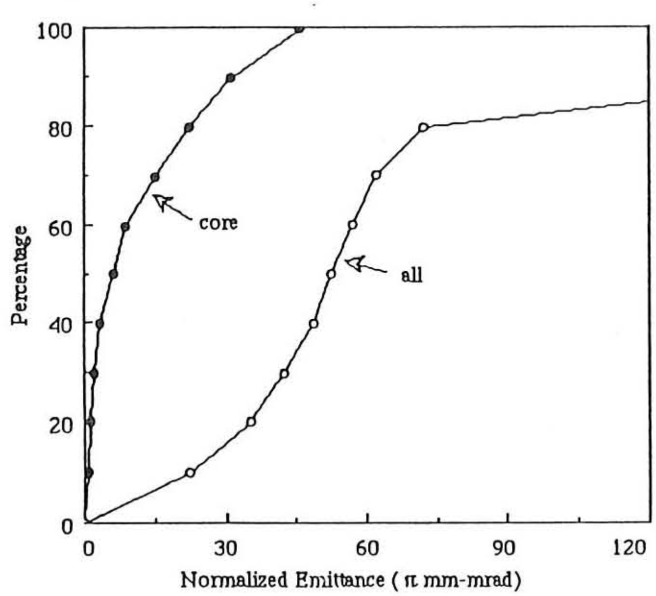

Figure 3. Transverse emittance distribution at the end of the linac for all and core particles.

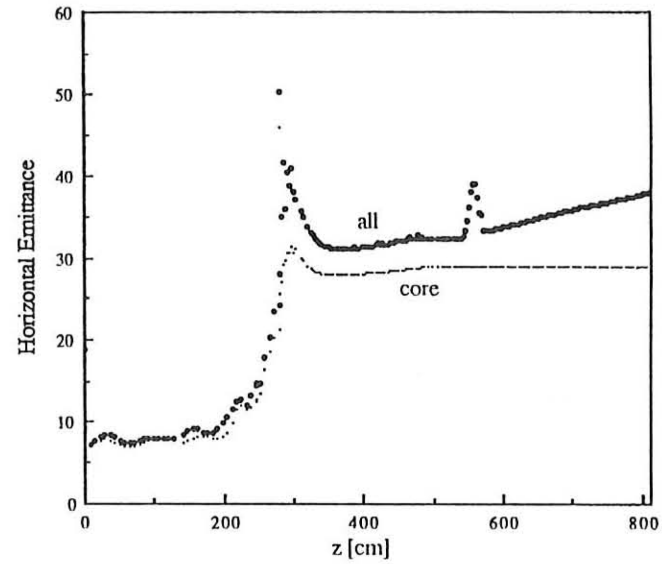

Figure 4. Transverse rms emittance (π mm-mrad) versus z for all and core particles. Transverse emittance grows rapidly in the S-band buncher and in the first few cavities of the linac.

useful tool for future optimization of the core particle performances.

Figure 4 shows growth of the transverse emittances along the pre-injector. Rapid emittance growth in the bunching system was previously reported[1] and the growth mechanism is identified as the one proposed in reference 3, i.e., the time dependent radial rf field. Figure 4 shows that the core particles are behaving in the same way and there are not any more significant emittance growth in the linac.

Pulse durations shown in figure 5 indicate that the repulsive space charge forces are limitting pulse compression (for all particles) at the end of the 500 MHz buncher but do not affect the core particles. The sharp dip of the pulse duration in the S-band buncher

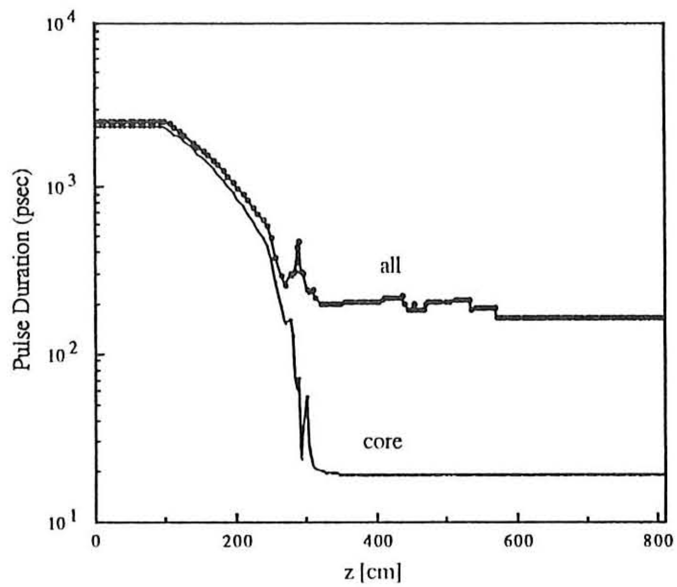

Figure 5. Pulse duration (4 rms) versus z

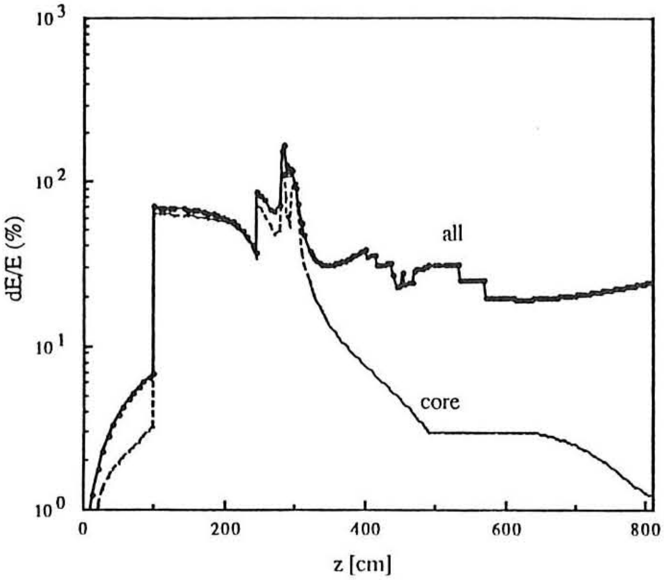

Figure 6. Energy spread (4 rms) versus z

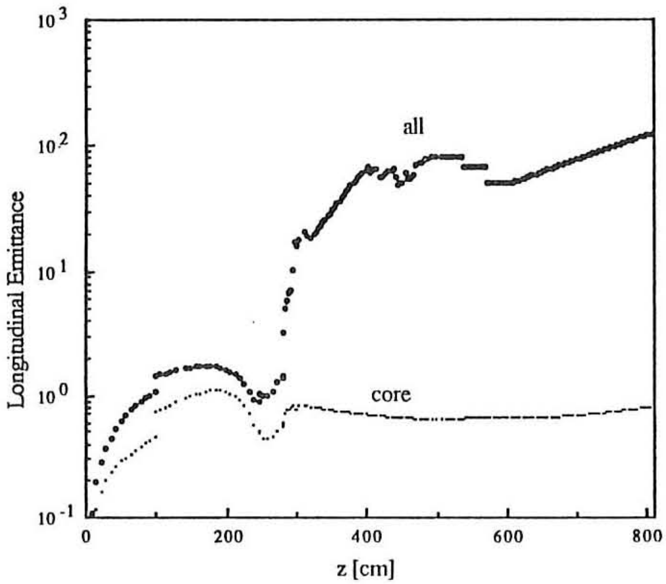

Figure 7. Longitudinal rms emittances (π MeV-deg) versus z for the core and all particles.

indicates that core particles are over bunched. It is difficult to avoid overbunching in the present design

For a single bunch mode of operation it is important that no electrons spill into the neiboring booster rf buckets which correspond to 6 linac rf buckets. In the present simulation 1 out of the 322 core particles was found in one of the nearest neighbor linac rf bucket; This particle was left out in the pulse-duration calculation in figure 5. For all-particle group, 3 were found in one of the nearest linac rf buckets. No particles were found in any other buckets.

The energy spread and the longitudinal emittance of the core particles behaved quite differently from those of the all particles as shown in figures 6 and 7. The rf phases of the two linac sections had to be tuned carefully such that the core population is maximized.

Conclusions

The present simulation showed that in a single bunch mode the ALS pre-injector can deliver about 2.5 nC of 50 MeV electrons in a single rf bucket with an rms energy spread of 0.3 % and normalized rms emittance of 30 π mm-mrad to the ALS booster injection area. Beam loading in the linac and effects of the wake fields are not included and may alter the conclusion, specially for the multi-bunch mode.

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References

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2. F. Selph, in these proceedings.
3. K.-J. Kim and Y.J.Chen in these proceedings.