SIMULATIONS ON WAKEFIELD EFFECTS IN THE ELECTRON BEAM AT THE 2.5 GeV PLS LINAC

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Abstract

We investigated simulations on the effects of the wakefield on emittance growth at the 2.5 GeV PLS linac. The effects of initial beam offset, bunch charge, misalignments of a accelerating structures and magnets on the emittance growth are considered in the simulation. It is shown that BNS damping effectively reduces emittance growths due to the these causes. Based on the simulation results, maximum possible beam current per bunch for the stable beam operation of linac is estimated to be 3 nC.

INTRODUCTION

Since the October 2002, PLS linac has been served as a 2.5 GeV full energy injector. In the injector linac, a high-intensity, stable single bunched electron beam is required. It is well known that wake fields affect on the emittance growth and energy spread [1]. The longitudinal wake field causes an energy spread within a bunch as well as a decrease in beam energy, depending on the bunch length and the acceleration phase, while the transverse wake field induces an emittance growth related with a beam instability due to injection errors and cavity misalignments [2][3]. Therefore, it is valuable to estimate both the longitudinal and transverse effects of a wake field concerning the 2.5 GeV PLS linac for optimum stable beam operation. Using a simulation code LIAR [4], we estimated the wake field effects on the PLS linac. We also considered the BNS damping to reduce the emittance growths due to the several causes.

PLS LINAC

The 2.5 GeV PLS consists of the storage ring as a 2.5 GeV storage ring and a full energy linear accelerator as an injector. The 160 meter-long linac has a 44 accelerating columns powered by 12 klystrons. A total of 7 quadrupole triplets guide the accelerated electron beam through the linac. The pre-injector, which is the first 100 MeV section of the PLS linac, consists of an thermionic triode electron gun, an S-band prebuncher, an S-band buncher, and two accelerating columns powered by a klystron. The electron beams from the pre-injector are accelerated to 2.5 GeV by 42 accelerating columns powered by 11 klystrons of 200 MW maximum output power. The 3m long accelerating column has a SLAC-type constant gradient structure with $2\pi/3$ operating mode [5].

The main simulation parameters of the 2.5 GeV PLS linac are listed in table 1. We assumed that the initial normalized emittance is 295 mm mrad referring the designed value, and calculated the initial Twiss parameters. Concerning the designed value of the bunch length of 2mm [5], the bunch length in the simulation is varied from 0.5 mm to 6 mm to see the effects of bunch length. In order to estimate the wake field effects, we used the short-range wake function of the SLAC type accelerating structure. The bunch in the simulation was represented with 20 slices having 2 macroparticles per slice.

Table 1: Used parameters in this simulation

E_0	0.1	[GeV]
E_f	2.5	[GeV]
I	1~20	nC
$\gamma\varepsilon_x$, $\gamma\varepsilon_x$	295×10^{-6}	[m rad]
β_x , β_y	8.32	M
α_x , α_y	-0.9	

LONGITUDINAL WAKE FIELD EFFECTS

Figure 1 shows dependence of bunch length on optimum off-crest phase, which is determined by the phase minimizing the final energy spread for the given bunch charge and the bunch length.

The energy spread is estimated as a function of the bunch length, which is shown in Figure 2. In order to obtain the energy spread below 1 %, the bunch length should be below 3 mm. These results well agree with the Ogawa's Gaussian longitudinal wake field model [2].

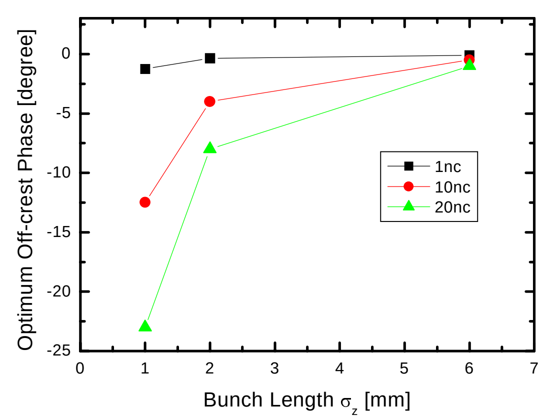

Figure 1: Optimum off-crest phase vs bunch length.

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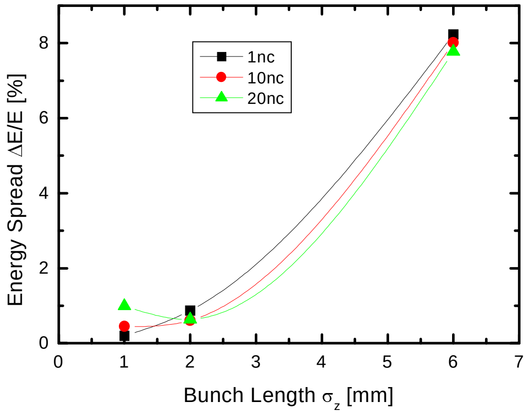

Figure 2: Dependence of bunch length dependence on the energy spread.

TRANSVERSE WAKE FIELD EFFECTS

Initial offset of the injected beam or beam defections along the linac causes emittance growth from the transverse wake field, as shown in figure 3. It is well known that the single bunch instability caused by a short-range transverse wake field can be cured effectively by BNS damping[6]. The BNS damping is done with a position-correlated energy spread in the bunch, that is, $\Delta E/E>0$ in the head and $\Delta E/E<0$ in the tail, which makes the quadrupole lattices focus the tail particles, and hence compensates the defocusing wake field force by the head particles [7]. The energy spread is generated by creating a slope on the accelerating gradient over the bunch length through adjusting the rf phase with respect to the bunch. At the high-energy end, the klystron phase are shifted to make the bunch arrive early for final correction of the longitudinal energy spread.

Figure 4 shows that when BNS damping is applied, the energy spread increases at the low energy position of the 2.5 GeV PLS linac, but that decreases at the high-energy region. We empirically found the BNS configuration for PLS linac satisfying final beam energy spread of ~ 0.9%.

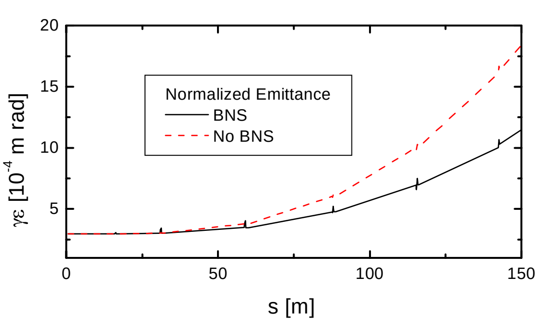

Figure 3: Typical normalized emittance profile.

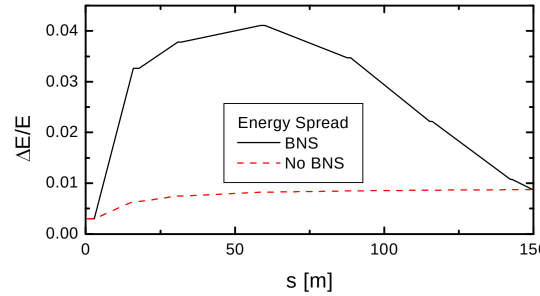

Figure 4: Typical energy spread profile.

Figure 5 shows the emittance growths due to initial beam offsets. The BNS damping effectively reduces the emittance growths due to the initial beam offset effects, depending on the RF phase configurations. The RF settings for the BNS I and the BNS II are shown in Table 2.

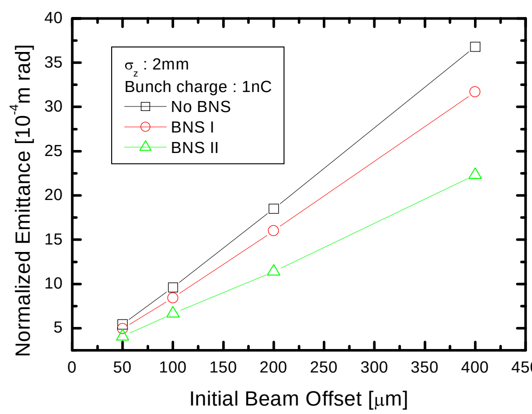

Figure 5: Dependence of initial beam offset on the $\gamma\varepsilon$.

Table 2: Several BNS damping conditions for PLS linac.

	1st phase	1st sw	2nd phase	2nd sw	3rd phase
BNS I	**20°**	**Accel. 24**	**-10°**	**Accel. 40**	**-60°**
BNS II	**20°**	**Accel. 24**	**-10°**	**Accel. 40**	**-110°**

Figure 6 and 7 show the emittance growths caused by the misalignments of accelerating structures and quadrupoles, respectively. They show that the cavity misalignments cause larger emittance growth than the quadrupoles' case. It is also shown that the corrections well cured these emittance growths. BNS damping also reduced the emittance growth induced by the quadrupole misalignments.

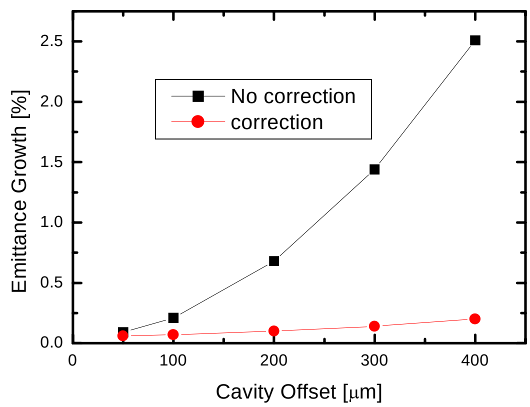

Figure 6: Dependence of cavity misalignment on $\Delta(\gamma\varepsilon)/(\gamma\varepsilon)$.

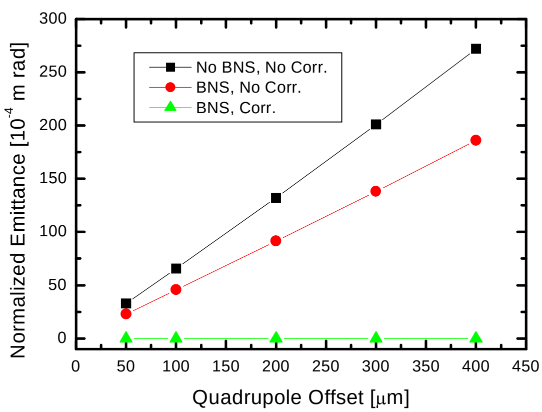

Figure 7: Dependence of quadrupole misalignment on $\gamma\varepsilon$.

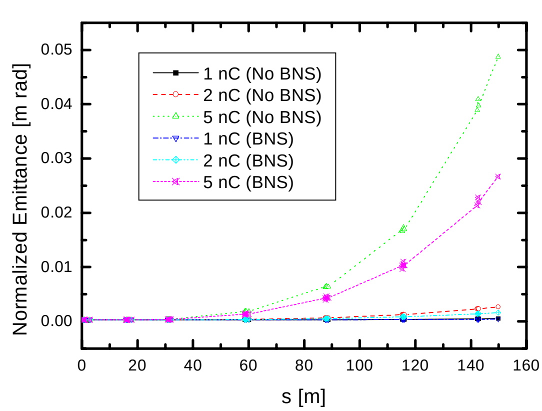

Figure 8: Dependence of bunch charge on $\gamma\varepsilon$.

The emittance growths that are caused by an initial beam offset of 50 μm for the different bunch charges are shown in Figure 8. When the bunch charge is 5 nC/bunch, emittance grows over 500 mm mrad resulting to the beam breakup.

DISCUSSIONS AND CONCLUSION

We simulated the effects of the wake field on the emittance growth and energy spread in the 2.5 GeV PLS linac. Initial beam offsets, accelerating structure offsets and quadrupole misalignments induce severe emittance growth. However, it was shown that the corrections for misalignments and the BNS damping method could cure sufficiently the emittance growth. In order to obtain low emittance and low energy spread electron beam, the bunch length and the bunch current act as crucial beam parameters. The simulation indicated that it is possible to operate the linac up to 3 nC/bunch without showing the emittance growth. The simulation results show that longer bunch length than 2mm induces larger energy spread than 1%, which invokes the chromatic effects.

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