BEAM DYNAMICS SIMULATIONS OF THE VELOCITY BUNCHING IN A SUPERCONDUCTING LINAC

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Abstract

The velocity bunching is a hot topic in normal conducting photoinjectors to generate high-brightness beams instead of using magnetic chicanes in the low energy region. We apply this technique to the superconducting photoinjectors. The linac considered here consists of several 9-cell TESLA cavities, and a normal conducting 1.6-cell RF gun at L-band. In the case of 1 nC with mild compression, the peak current increases to 300 A and the 1.8 mm.mrad of the emittance. With 1 pC bunch, 2.5 A and 0.062 mm.mrad are obtained. Compared with the emittance in non-bunching case, 1.3 and 0.061 mm.mrad, for 1 nC and 1 pC, respectively, the emittance degradation was smaller in the latter case. This is because the thermal emittance dominant beam in the low charge case.

INTRODUCTION

The superconducting linacs are adopted as high power light sources in many places. For the applications, the electron beams must be compressed to obtain a high gain of the light production. To make the bunches compressed, there are two methods: the magnetic compression and the ballistic compression. The magnetic compression uses the chicane magnets and the difference of the pass length due to the energy makes the bunch short. The ballistic compression is achieved by the difference of the speed of the particles. We are interested in the latter one.

The ballistic bunching in electron photoinjectors are called "velocity bunching" and investigated in the normal conducting accelerators [1,2]. There is also the study for a superconducting linac [3]. These studies surveyed the bunch with the charge of about 1 nC and suffers the emittance degradation from the strong space charge force of the bunched beam. If the emittance degradation comes from the space charge force, the smaller charge can be more applicable for the scheme. We discuss the small charge case of 1 pC bunch as well as 1 nC case.

BEAMLINE AND FIELD

We consider an L-band standing wave linac with a 1.6-cell RF gun with an emittance compensation solenoid as shown in Figure 1. The RF gun is assumed normal conducting and its design is made by scaling an S-band one (Figure 2). The emittance compensation solenoid is also scaled one. The standing wave structures of the linac are TESLA cavities [4]. Every two structures is supposed to be driven by one klystron, and there are five pairs in the linac.

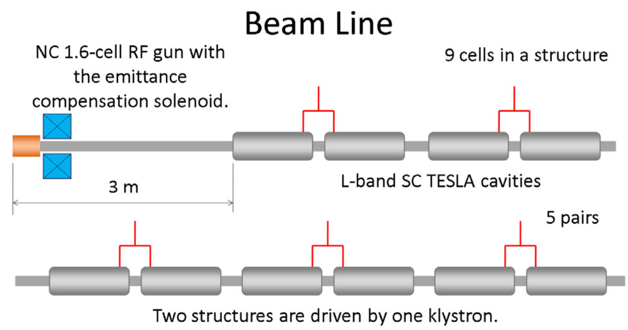

Figure 1: The layout of the beamline for the simulation.

The peak field strength in the gun is 55 MV/m and the acceleration in the TESLA cavities is 11 MV/m. The solenoid field strength is 1100 - 1200 Gauss. The first linac locates at 3 m from the cathode for the normal emittance compensation scheme.

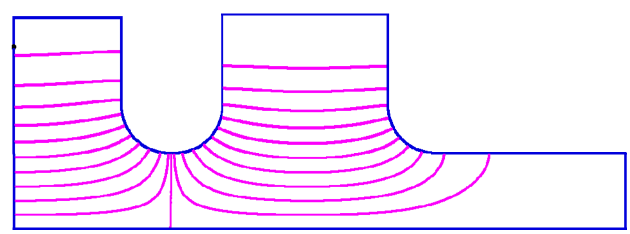

Figure 2: The shape of the 1.6-cell RF gun.

SIMULATION RESULTS

PARMELA [5] is used to simulate the beam dynamics. We simulated two charge cases, 1 nC and 1 pC, to compare the charge effect.

At first we optimized the emittance at the first linac's phase where the bunch enters 90 deg ahead of maximum acceleration point and set it '0 deg'.

Emittance and Beam Envelope

Figure 3 and Figure 4 shows the horizontal normalized emittance and the beam envelope along z for 1 nC and 1 pC, respectively. The beam envelope evolves in the same way in both cases, while the emittance doesn't. In the low charge regime, the space charge is no longer strong enough to harm the emittance, and it becomes thermal emittance dominant.

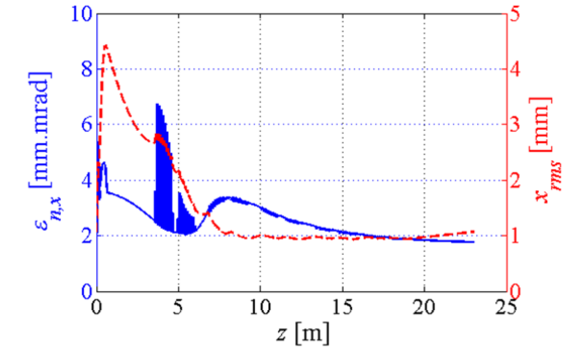

Figure 3: The horizontal normalized emittance (blue, solid line) and beam envelope (red, dashed line) along z for 1 nC bunch with mild compression.

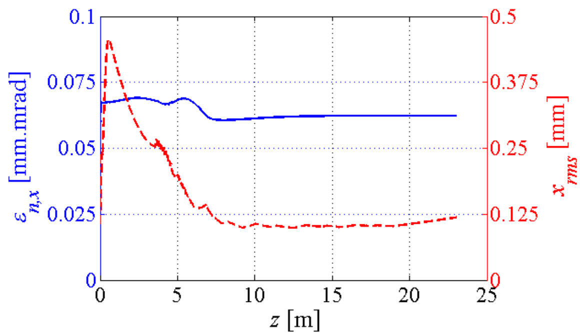

Figure 4: The horizontal normalized emittance (blue, solid line) and beam envelope (red, dashed line) along z for 1 pC bunch.

RMS Bunch Length and Beam Energy

As you see in Figure 5 and 6, the rms bunch length and beam energy does not differ in both cases. The difference of the emittance scheme does not affect longitudinal dynamics at this phase.

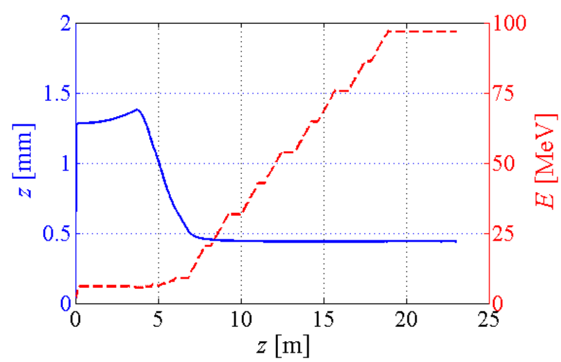

Figure 5: The rms of bunch length (blue, solid line) and the energy (red, dashed line) along z for 1 nC bunch with mild compression.

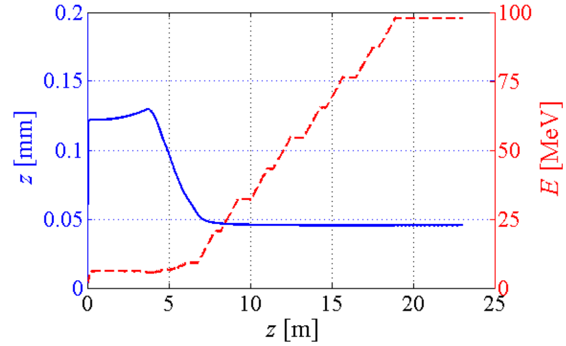

Figure 6: The rms of bunch length (blue, solid line) and the energy (red, dashed line) along z for 1 PC bunch with mild compression.

Phase Scan

The emittance and peak current are scanned by changing the phase of the first linac. Other parameters, such as solenoid field strength, stay the same as before. Moving the phase ahead results in stronger bunching force.

The current increases as the linac phase goes ahead. But the emittance gets worse simultaneously. In the vicinity of the maximum compression, the mixing of the beam slices occurs while the beam is under the emittance compensation. That makes emittance worse, so it is recommended to avoid maximum compression.

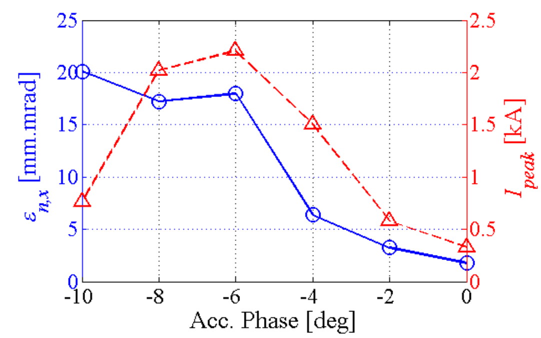

Figure 7: The horizontal normalized emittance (blue, solid line and circle markers) and the peak current (red, dashed line and triangle markers) with the phase in the first linac for 1 nC bunch.

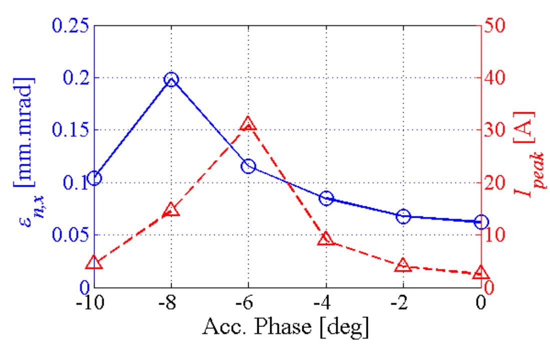

Figure 8: The horizontal normalized emittance (blue, solid line and circle markers) and the peak current (red, dashed line and triangle markers) with the phase in the first linac for 1 pC bunch.

Bunching and Emittance Degradation

The emittance and the peak current in the non-bunching case and the mild bunching case (bunching at 0 deg) are summarized in Table 1. The emittance degradation in 1 nC case is large, while it stays almost the same in 1 pC case.

Table 1: The emittance and the peak current. The numbers in parenthesis are the ratio of the mild compression case to the non-bunching case.

	Emittance [mm.mrad]		**I peak** [A]	
	1 nC	**1 pC**	**1 nC**	**1 pC**
Non-bunching	1.3	0.061	76	0.75
Mild compression (0 deg)	1.8 (1.38)	0.062 (1.02)	330 (4.3)	2.5 (3.3)

DISCUSSION

The damage on the emittance by the velocity bunching is smaller in 1 pC case than 1 nC case. This is because the thermal emittance becomes dominant in the low charge case. Then velocity bunching suits to the emittance dominant beam.

The maximum compression should be avoided because the slice mixing prevents the beam from the emittance compensation. Even in the low charge case, this can exceeds the thermal emittance.

SUMMARY

The velocity bunching in the superconducting linac with the normal conducting 1.6-cell gun is examined by using PARMELA simulation. 1 nC and 1 pC bunch are compared. The emittance degradation by velocity bunching was smaller in the low charge case due to the thermal emittance. The velocity bunching is good for thermal emittance dominant beams.

REFERENCES

[1] L. Serafini and M. Ferrario, "Velocity bunching in photoinjectors", in the Proceedings of AIP conference 581, 87 (2001).

[2] S. G. Anderson et al., "Velocity bunching of high-brightness electron beams", PRST-AB 8, 014401 (2005).

[3] B. Beutner et al., "Velocity Bunching at FLASH", EPAC'08, Genoa, Italy, MOPC019, p. 112 (2008); http://www.JACoW.org.

[4] B. Aune et al., "Superconducting TESLA cavities", PRST-AB 3, 092001 (2000).

[5] Los Alamos Accelerator Code Group; http://laacg1.lanl.gov/laacg/services/serv_codes.phtml.