SLAC-PUB-5339
September 1990
(A)

Controlling Multi-Bunches by a Fast Phase Switching

F.-J. Decker, R.K. Jobe, N. Merminga, K.A. Thompson

Stanford Linear Accelerator Center, Stanford, California 94309, USA*

Abstract

In linear accelerators with two or more bunches the beam loading of one bunch will influence the energy and energy spread the following bunches. This can be corrected by quickly changing the phase of a travelling wave structure, so that each bunch recieves a slightly different net phase. At the SLAC Linear Collider (SLC) three bunches, two (e^+, e^-) for the high energy collisions and one (e^--scavenger) for producing positrons should sit at different phases, due to their different tasks. The two e^--bunches are extracted from the damping ring at the same cycle time about 60 ns apart. Fast phase switching of the RF to the bunch length compressor in the Ring-To-Linac (RTL) section can produce the necessary advance of the scavenger bunch (about 6° in phase). This allows a low energy spread of this third bunch at the e^+-production region at 2/3 of the linac length, while the other bunches are not influenced. The principles and possible other applications of this fast phase switching as using it for multi-bunches, as well as the experimental layout for the actual RTL compressor are presented.

1 Introduction

In current designs for future linear colliders each RF cycle accelerates several bunches in one pulse train to drop energy costs and to increase the luminosity (Fig. 1). This multi-bunch scheme can be disturbed by longitudinal and transverse wakefields of the high intensity bunches or by different purposes of the bunches, as in the SLC (Fig. 2). Here the two interaction bunches, e^+ and e^-, are followed by a scavenger bunch which produces the positrons for the next cycle at about 2/3 of the linac (Sector 19). At this point the scavenger beam should have a minimum energy spread, while the other two bunches are still decreasing their energy spread.

For the transverse stability of the beams an energy spread is introduced in the beginning of the linac, called BNS-damping or autophasing [1, 2, 3]. At the later part it is decreased so that the energy spread of the bunches is a minimum at the end of the linac. At Sector 19 the beams have about three times the final energy spread. By changing the longitudinal position of only the scavenger bunch by about 6° in phase (1.75 mm) the energy spread can be compensated there. This relative position shift can be either done at the beginning of the linac with a compressor phasing or by a fast phase switching of the RF drive to the linac after the first two bunches have passed through.

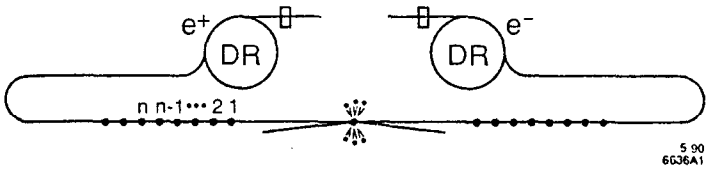

Figure 1: Linear Collider with multi-bunches.
A train of several bunches is extracted from a damping ring (DR) and accelerated. The energy of each bunch should be the same ($E_n = E_{n-1}$) and the energy spread minimized before colliding with the other bunch train.

*Work supported by the Department of Energy, contract DE-AC03-76SF00515.

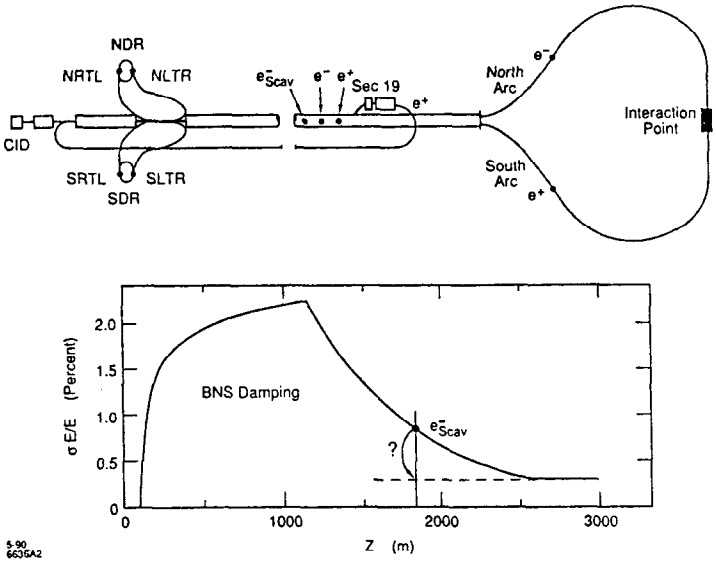

Figure 2: SLC energy profile.
The transverse motion of the particles is stabilized (BNS-damping) by increasing and afterwards decreasing the energy spread within the bunch. But the third bunch (scavenger) would get an intolerable big energy spread at the positron production area, if no fast phase adjustment would be done.

The principle and some details of this fast phase switching are presented first. Then the current set up for the scavenger beam with some experimental data are shown. At the end a possible scenario for a multi-bunch scheme even at the SLC demonstrates how powerful this fast phase switching can be.

2 Fast Phase Switching

A fast phase change introduces a phase gradient in an acceleration structure [4]. The spatially separated bunches can be influenced differently in integrated phase and amplitude.

2.1 Principle

A travelling wave accelerator structure is fed by an RF source which produces a sudden phase change from 0° to 90° (Fig. 3). A bunch of particles just prior to this change will see no difference. It will experience a phase of 0° and amplitude A_1. A second bunch, say the scavenger, arives a time t_b later, which corresponds to the bunch separation. When t_f is the filling time of the whole structure, t_b/t_f of its length is filled with the new phase. (No losses in a constant impedance structure are assumed.) For a 90° phase change the second bunch will see a net phase and amplitude of

$$\varphi_2 = \arctan\left(\frac{t_b}{t_f - t_b}\right), \quad A_2 = A_1 \frac{\sqrt{(t_f - t_b)^2 + t_b^2}}{t_f}.$$

For $t_f = 600$ ns and $t_b = 60$ ns this gives $\varphi_2 = 6.3°$ and $A_2 \approx 0.9A_1$. Figure 3 c) shows the phasors of that change. Zero phase is horizontal, 90° is vertical and the length between the time steps

Presented at the Linear Accelerator Conference, Albuquerque, New Mexico, September 10–14, 1990.

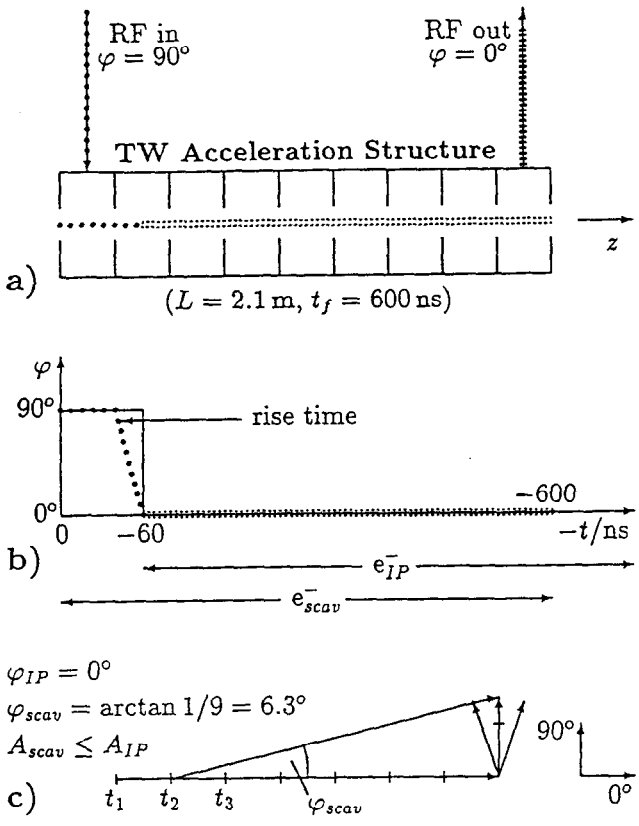

Figure 3: Principle of fast phase switching.

The phase of the RF to the input of a travelling wave structure is changed quickly (a), so a second bunch 60 ns later (b) will see a different net phase of about 6° (c).

corresponds to the amplitude of the averaged seen RF field. By changing the input phase a little bit around 90° the amplitude A_2 can be varied while the phase keeps mainly constant.

In general it is possible to change the phase φ_i and amplitude A_i for a bunch number i by a certain amount by changing the timing and the amount of the phase change.

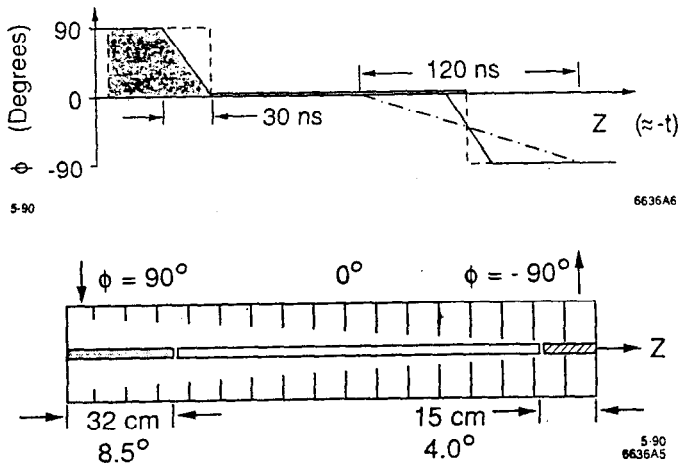

Figure 4: Phase changes in a constant gradient structure.

Due to the different group velocities at the input and output, about 32 cm or 15 cm can be filled with different phases within 60 ns. A finite risetime of the pulse decreases this value.

2.2 Actual RF Set Up

Two phase steps, which act at the input and the output, can provide twice the phase change. In the constant gradient structure of the SLC compressor the higher group velocity at the input rather than at the output changes the possible phase variation in 60 ns to about 8.5° (in) and 4.0° (out), see Fig. 4.

The risetime or transition time from one phase to the other is finite. This and the dispersion within the acceleration structure decreases the amount of a fast phase switching. For the input it is about 25 % less in 60 ns (Fig. 5).

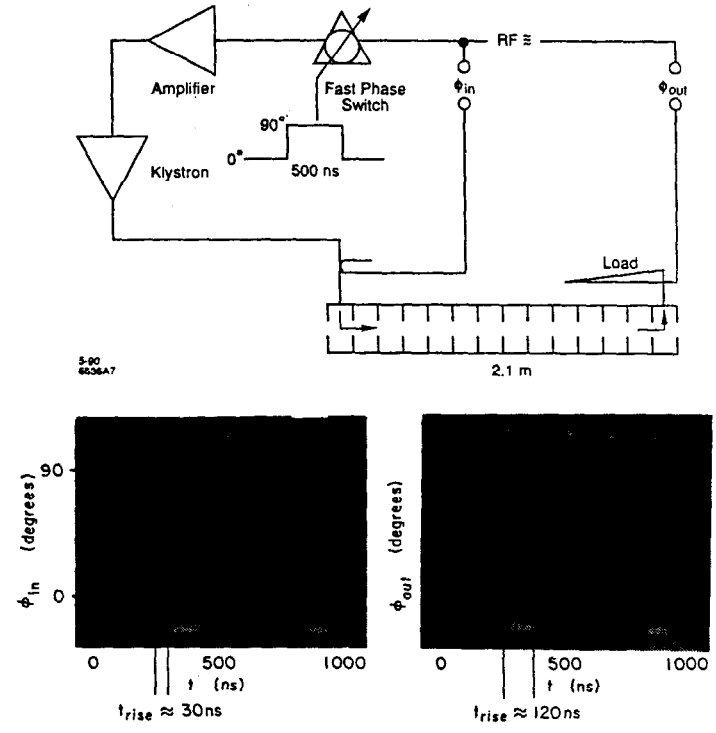

Figure 5: Set up of the fast phase switch.

Between the RF-source and the klystron, which feeds the compressor section, a fast phase switch has been installed. At the input coupler a fast phase risetime (30 ns) has been observed, while at the output the dispersion in the structure has strongly decreased the slope.

3 Experimental Result at the SLC

Figure 6 shows an experimental result with a beam. The bunch phase is normally set to the zero crossing of the compressor RF. A fast phase change of the RF provides a different mean energy of the beam and therefore an offset Δx in the high dispersion region of the RTL. So the second bunch will arrive earlier (or later) in the linac. The measured amount is in good agreement with the expected value of 3/4 of 8.5°. A more detailed discussion is given in [4], which can be summarized in the following way: Controlling the timing and also the amplitude of the RF phase change, changes the effective phase and amplitude for the second bunch in the compressor, which determinds the phase and bunch length in the linac resulting to a certain energy and energy spread at the end.

With the implementation of the fast phase switch the every day operation is simplified by the possible separate adjustment of the energy spread of the scavenger beam.

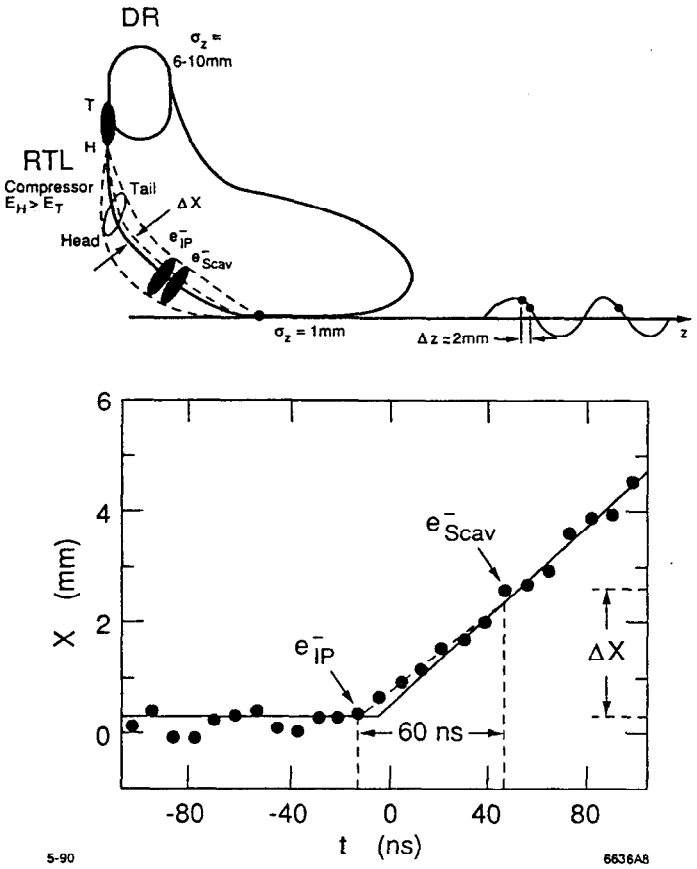

Figure 6: Beam respond to the phase switch.
The long bunches of the damping ring (DR) are compressed in the Ring-To-Linac (RTL) section. A fast phase change provides that the second bunch, about 60 ns *later than the first one, is separated up to* $\Delta x =$ 2.2 mm *in the RTL, which corresponds to a phase variation of* 6.8° *or to* $\Delta z =$ 2 mm *earlier in the Linac.*

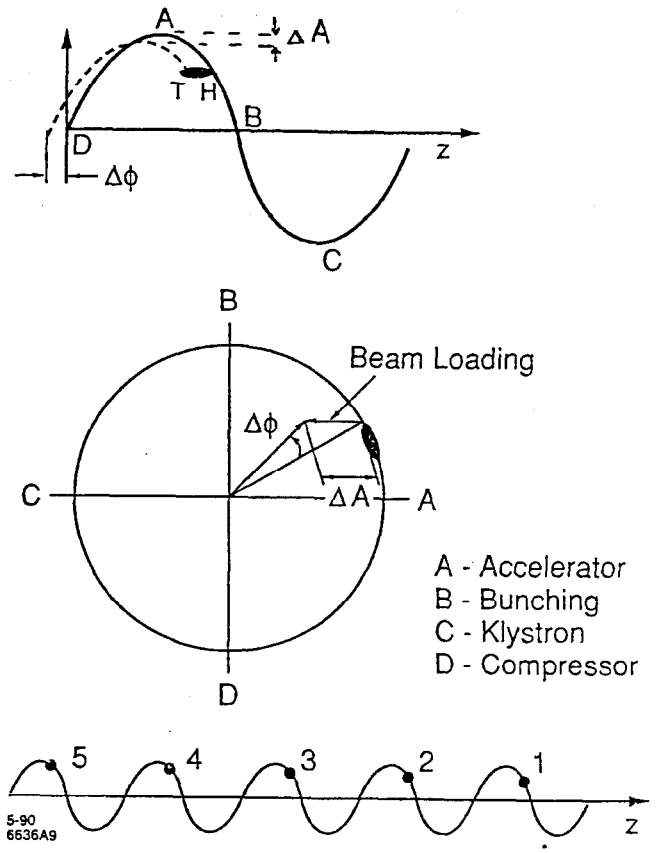

Figure 7: Compensating beam loading by different bunch phases.
In general the beam loading of one bunch introduces an amplitude and phase change (ΔA *and* $\Delta\phi$) *to the next bunch. By putting the bunches to different phases, e.g. bunch 5 later than bunch 4 later . . . than bunch 1, the beam loading can be compensated. Besides a compensating amplitude variation, a fast phase switching helps, especially for the compensation of the* $\Delta\phi$ *beam loading in a compressor region.*

4 Multi-Bunches

In a multi-bunch scheme with high currents the energy of each bunch would be different, if no compensation is used. Changing the amplitude of the RF by partially filling the structure for the first bunch [5], provides a good compensation, especially if the bunch is riding on the crest. Because of BNS-damping or longitudinal wakefield compensation, the beam sits off the crest. So beside the amplitude, a phase change is also necessary. Even a pure phase variation could adjust the invividual energies, if the bunch length from bunch to bunch is varied in an appropriate way (see Fig. 7).

The numerical evaluation of the effect shows [4], that even at the SLC three times five bunches of $5 \cdot 10^{10}$ particles could be controlled by a fast phase switching.

5 Summary

The fast phase switching has become an operational tool at the SLC. By varying the time and phase amount of the phase change the energy and energy spread of a bunch could be controlled. Beside the possibility of a multi-bunch scheme at the SLC, a fast phase switch has to compensate the big phase beam loading in a compressor region of future colliders.

Acknowledgement

We would like to thank K.L. Bane, M. Sands, J.T. Seeman and M. Ross for the inital discussions of the problem, J. Judkins for his personal eagerness during the test set up and the RF- and Electronic group for the final implementation.

References

[1] V. Balakin, A. Novokhatsky, V. Smirnov, *VLEPP: Tranverse Beam Dynamics* , Procedings of the 12th Int. Conf. on High Energy Accelerators, Fermilab, 1983, p. 119.

[2] Karl L. F. Bane, *Wakefield Effects in a Linear Collider*, SLAC-PUB-4169, December 1986.

[3] J.T. Seeman, N. Merminga, *Mutual Compensation of Wakefield and Chromatic Effects of Intense Linac Bunches*, SLAC-PUB-5220, April 1990.

[4] F.-J. Decker, R.K. Jobe, *Phase Gradients in Acceleration Structures*, 2nd European Accelerator Conference, Nice, France, June 12-16, 1990 or SLAC-PUB-5271, May 1990.

[5] R.D. Ruth, *Multi-Bunch Energy Compensation*, Workshop on Physics of Linear Collider, Capri, Italy, 1988.