Multibunch Emittance Growth and Its Corrections in S-Band Linear Collider

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Abstract

Multibunch emittance growths caused by long range wakefields with the misalignments of accelerating structures and quadrupoles in S-Band linear collider are studied. At the end of main linac, emittance corrector (EC) is proposed to be used to reduce further the multibunch emittance. Numerical simulations show that the effect of EC is obvious (multibunch emittance can be reduced about one order of magnitude), and it is believed that this kind of EC will be necessary for future linear colliders.

1 INTRODUCTION

Multibunch emitance growth is a characteristic problem in future linear colliders. In order to get a small multibunch emittance growth accelerating structures should be detuned and damped, beam position monitors have to be installed along the main linac and the electron bunch trajectories have to be corrected by means of "one-to-one", "dispersion free" and "wake free" corrections[1]. In this paper we propose to use an emittance corrector (EC) at the exist of main linac to reduce further the multibunch emittance. S-band linear collider has been taken as an example to demonstrate the effects of this emittance corrector. Numerical simulations are carried out to estimate multibunch emittance growth considering long range wakefields and considering structures, quadrupoles and BPMs misalignment errors. After having corrected the multibunch emittance by one-to-one trajectory correction (dispersion free and wake free corrections have not been used), we use emittance corrector to reduce multibunch emittance further. It is shown that the proposed emittance corrector works well and it can reduce the multibunch emittance by about one order of magnitude.

2 EMITTANCE CORRECTOR (EC)

At the exist of main linac we get definite multibunch emittances (x and y planes) which might be the results of different trajectory correction operations (one-to-one, DF, or WF) along the main linac. Facing to these resultant emittances can we do something more to reduce them further? In this paper Emittance Corrector is proposed to be used at the end of main linac. The idea of making emittance correction at the end of main linac comes out of the results of enormous numerical simulations[2]. It is found out that when the multibunch emittance is about one order of magnitude higher than the required value for a linear collider, the multibunch transverse position (x) distribution and derivative (dx/dz) distribution can be classified as two standard distributions for x and dx/dz, respectively, as shown in Fig. 1 and Fig. 2. In principle the multibunch positions and derivatives in two tanseverse phase spaces can be measured by at least four BMPs located at the exit of main linac. Imagining that all the bunches' transverse positions (x, y) and derivatives ($x' = dx/dz$, $y' = dy/dz$) are corrected to be almost same, one can get multibunch emittances much smaller. In the following we discuss about only one transverse plane since the physics

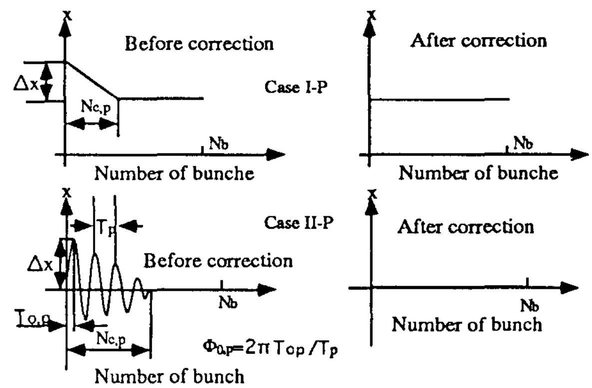

Figure 1: Transverse bunch position distribution.

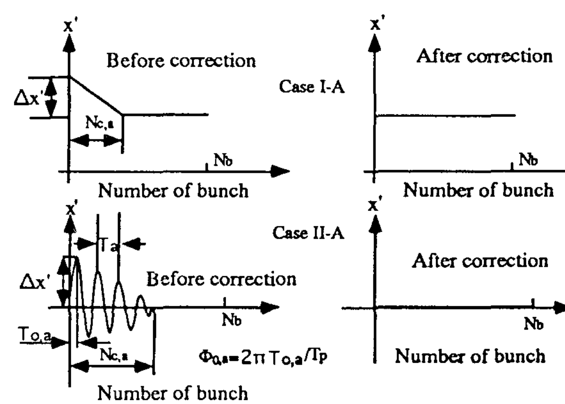

Figure 2: Transverse derivative distribution.

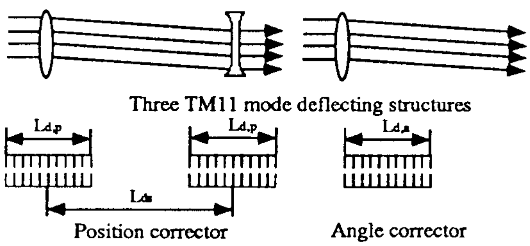

Figure 3: Proposed emittance corrector (position corrector + angle corrector)

is same for the other plane. The proposed emittance corrector is composed of a pair of travelling wave deflecting structure working on TM_{11} mode and seperated by a drift space as shown in Fig. 3 which is used to correct multibunch transverse position spread (position corrector), and a single travelling wave deflecting structure of the same type as shown in Fig. 3 which is used to correct the multibunch derivative spread (angle corrector). In the following we will discuss position correction firstly and then angle correction.

The transverse momentum gains from the two deflecting structures of position corrector are opposite in sign and equal in magnitude for each bunch, therefore, the effect of this pair of deflecting structures is just changing the transverse position of passing bunches. The final multibunch transverse distributions is shown in Fig. 1 (Case I-P and Case II-P, where P denotes position correction). In reality the continous line in Fig. 1 should be replaced by discret points which represent the multibunch locations. The principle of position correction corresponding to the two cases are described here:

Case I-P:

The phase velocity of the em field in the structure is chosen the same as that of light, and the synchronous rf phase is chosen at the crest of rf wave (for example). The structure is filled with rf power within length $L_{d,p}$ before the first bunch enters and the input rf power is just stopped at the moment when the first bunch enters the structure. The length filled with rf power satisfies the following relation:

$$L_{d,p} = \frac{v_{g,p}\tau_b N_{c,p}}{N_b} \tag{1}$$

where the subscript p denotes position correction, $v_{g,p}$ is the gropu velocity of the deflecting structure, N_b is the bunch number in a bunch train, τ_b is the time duration of the bunch train, $L_{d,p}$ is the length filled with rf power and $N_{c,p}$ is shown in Fig. 1. The synchronous magnetic field strength is

$$B_p = \frac{\Delta x W_f}{ecL_{d,p}L_{ds}} \tag{2}$$

where Δx is shown in Fig. 1, W_f is the final beam energy, L_{ds} is the length of the drift space between the two deflectors and c is the velocity of light. In practice the physical length of the deflecting structure can be longer than $L_{d,p}$ in order to adapt to different situations.

Case II-P:

The phase velocity of the em field in the structure is set different from that of light by shifting rf power frequency from f_0 to f_{rf} (where f_{rf} is the rf source frequency, f_0 is the structure characteristic frequency at which the phase velocity of the structure is equal to that of light), and the rf phase of the first bunch is chosen to be $\Phi_{0,p}$. Powering the structure in the same way as in Case I-P, we have

$$L_{d,p} = \frac{V_{g,p}\tau_b N_{c,p}}{N_b} \tag{3}$$

The magnetic field felt by the nth bunch is

$$B_{n,p} = B_p F_{n,p} sin(2\pi(f_{rf,p} - f_0)(n-1)\frac{\tau_n}{N_b} + \Phi_{0,p}) \tag{4}$$

where

$$B_p = \frac{\Delta x W_f}{ecL_{d,p}L_{ds}} \tag{5}$$

if $n \leq N_{c,p}$

$$F_{n,p} = \frac{N_{c,p} - n}{N_{c,p} - 1} \tag{6}$$

if $n > N_{c,p}$

$$F_{n,p} = 0 \tag{7}$$

The frequency shift is

$$f_{rf,p} - f_0 = \frac{1}{T_p} \tag{8}$$

After making the so-called position correction, one can make angle correction also if necessary. The derivative $x' = dx/dz$ for each bunch can be determined by two BPMs seperated by a definite distance. Similar to multibunch transverse position distribution, multibunch transverse derivative distributions at the exit of main linac are shown in Fig. 2 (Case I-A and Case II-A, where A denotes angle correction). The structure is filled with rf power within length $L_{d,a}$ before the first bunch enters and the input rf power is just stopped at the moment when the first bunch enters the structure. The deflecting structure's parameters corresponding to the two cases are given here:

Case I-A:

The phase velocity of the em field in the structure is chosen the same as that of light, and the synchronous rf phase is chosen at the crest of rf wave. The length filled with rf power $L_{d,a}$ satisfies the following relation:

$$L_{d,a} = \frac{V_{g,a}\tau_b N_{c,a}}{N_b} \tag{9}$$

where the subscript a denotes position correction, $V_{g,a}$ is the structure group velocity and $N_{c,a}$ is shown in Fig. 2. The synchronous magnetic field strength is

$$B_a = \frac{\Delta x' W_f}{ecL_{d,a}} \tag{10}$$

where Δx and $L_{d,a}$ are shown in Fig. 2.

Case II-A:

The phase velocity of the em field in the structure is set different from that of light by shifting rf power frequency from f_0 to f_{rf} , and the rf phase of the first bunch is chosen to be $\Phi_{0,a}$ shown in Fig. 2. Powering the structure in the same way as in Case I-P, we have the length filled with rf power $L_{d,a}$ satisfing the following relation:

$$L_{d,a} = \frac{V_{g,a}\tau_b N_{c,a}}{N_b} \tag{11}$$

The magnetic field felt by the nth bunch is

$$B_{n,a} = B_a F_{n,a} sin(2\pi(f_{rf,a} - f_0)(n-1)\frac{\tau_n}{N_b} + \Phi_{0,a}) \tag{12}$$

where

$$B_a = \frac{\Delta x' W_f}{ecL_{d,a}} \tag{13}$$

if $n \leq N_{c,a}$

$$F_{n,a} = \frac{N_{c,a} - n}{N_{c,a} - 1} \tag{14}$$

if $n > N_{c,a}$

$$F_{n,a} = 0 \tag{15}$$

The frequency shift is

$$f_{rf,a} - f_0 = \frac{1}{T_a} \tag{16}$$

where $f_{rf,a}$ is the rf source frequency.

In practice there should be two sets emittance correctors, one for x direction and another for y direction. In the following we will take SBLC[3] as an example to calculate multibunch emittance growth due to long range wakefields, and finally, we will demonstrate the effectiveness of the proposed emittance corrector.

The accelerating structure is $6m$ long detuned+damped structure (180 cells are different from each other). Now taking $Q = 3000$, rms structure misalignment error $\sigma_s = 20\mu m$, rms quadrupole misalignment error $\sigma_q = 20\mu m$ and rms BPM misalignment error $\sigma_b = 10\mu m$, we find at the end of main linac normalized multibunch emittance $\varepsilon_{n,rms} = 1.9 \times 10^{-7}(mrad)$ before position correction which corresponds to 40% emittance growth compared with the total emittance at the exit of damping ring. After position correction, however, we find $\varepsilon_{n,rms} = 2.5 \times 10^{-8}(mrad)$ which corresponds to an acceptable emittance growth, 5%. Fig. 4 shows the simulation results.

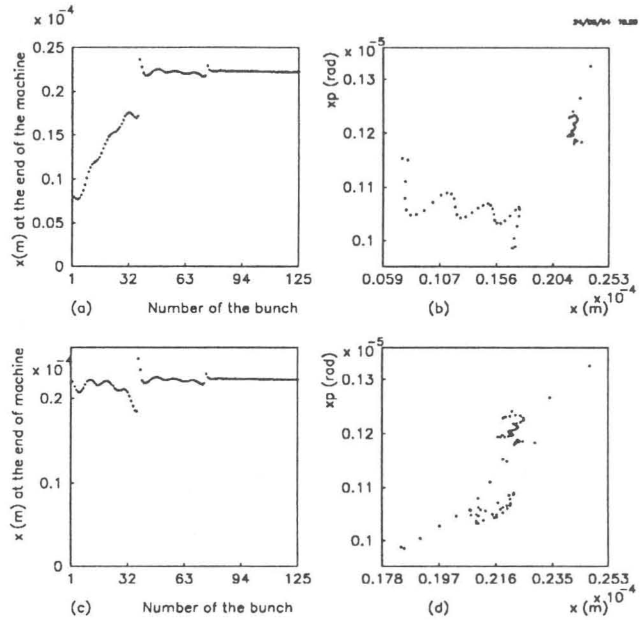

Figure 4: At the exit of the main linac (a) multibunch transverse position distribution before position correction; (b) multibunch phase space before position correction, $\varepsilon_{n,rms} = 1.9 \times 10^{-7}(mrad)$; (c) multibunch transverse position distribution after position correction; (d) multibunch phase space after position correction, $\varepsilon_{n,rms} = 2.5 \times 10^{-8}(mrad)$.

3 CONCLUSION

The emittance corrector proposed in this paper works well and can be used in other types of linear colliders where the multibunch emittances have to be reduced. The misalignment tolerances given above are little bit tight since DF and WF trajectory correction techniques are not used in this paper.

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