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RADIABEAM/SLAC DECHIRPER AS A PASSIVE DEFLECTOR*

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Abstract

We discuss the possibility of using the RadiaBeam/SLAC dechirper recently installed at LCLS for measuring the length of very short bunches, less than 1 fs and perhaps as short as 100 as. When a bunch travels close to one of the jaws, each particle gets a transverse kick depending on its position in the bunch. The tail particles get more kick. The transverse force also depends nonlinearly on the transverse position. The stretched bunch has been measured at the YAG screen 100 m downstream of the dechirper. The most important aspect of this measurement is that that no synchronization is needed. The Green's function for the transverse kick was evaluated based on precise wake field calculations for the dechirper's corrugated structure. Using this function, we can recover the longitudinal shape of the bunch. This may also help to see if a bunch has any micro-bunch structure. Recent measurement using wire scanners showed that the kick from the dechirper can be strong enough to stretch a short bunch.

INTRODUCTION

The idea of using a passive device like an active device is not new. Usually the passive device is optimized for a single frequency and uses a train of bunches. For example, the excitation of the passive cavity of a klystron by previous bunches establishes the amplitude and a phase of the field acting on subsequent ones. The same principle must work for a single bunch. The fields excited in a dielectric structure by the head of a bunch have been shown to deflect electrons in the tail, and in this way it is possible to perform time-resolved bunch measurements (passive streaking) [1]. A passive structure used as a beam diagnostic is also discussed in Ref. [2]. A new device that may generate substantial wake field power was recently commissioned at SLAC in the LCLS FEL. Since the main goal of this device is to remove energy chirp from a bunch, it is known as the "dechirper" [3].

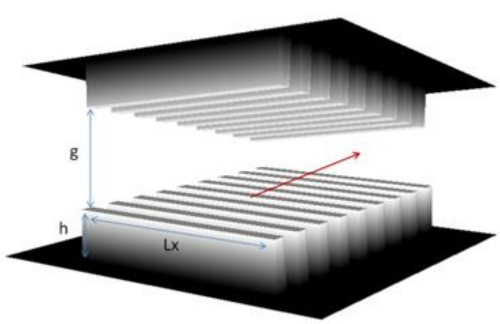

Figure 1: A schematic drawing of a dechirper. The red line shows a bunch trajectory.

WAKE FIELDS IN THE DECHIRPER

As previously proposed, a dechirper takes energy from the beam through the interaction of the bunch electromagnetic field with a metal corrugated structure. The practical design of the dechirper consists of two identical movable parallel plates (jaws) with corrugated walls in the form of a periodic set of planar ridges, as shown schematically in Fig. 1. The period is 0.5 mm; the thickness of a ridge is a half of a period. The transverse sizes of a ridge are: height h=0.5 mm, length L_x = 12 mm. Definitions of the sizes are given in Fig 1. Both jaws can be moved independently to the center, with the gap g between jaws adjustable from 0.1 to 20 mm. Two dechirpers, each with a (longitudinal) length of 2 m, were installed. The vertical dechirper has horizontal jaw faces and moves vertically, as shown in Fig. 1; the horizontal dechirper has vertical jaw faces and moves horizontally. The dechirpers are separated by approximately 1 m.

We propose to insert only one jaw to deflect the beam. Precise calculations of the wake fields for the case when a bunch travels very close to one jaw showed that the kick for a tail particle can be so large that we can resolve the bunch structure at very small time intervals even for high energy beams [4]. An example of a relative kick function along a 50-fs (FWHM) bunch with two horns (due to bunch compression) is shown in Fig. 2. The bunch shape was taken from a measured distribution. The beam's distance to the jaw is 150 µm, the bunch charge is 183 pC, and the beam energy is 13.3 GeV.

It is important to note that when a particle in the bunch is kicked by the transverse wake field; it also decelerated by a longitudinal force. Figure 3 shows the particle ener-

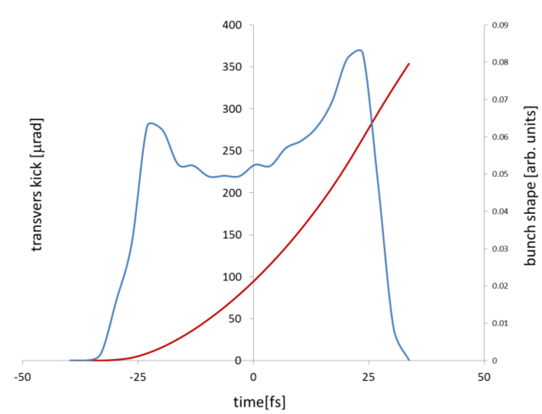

Figure 2: A bunch shape (blue line) and the corresponding transverse kick along the bunch (red line).

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gy loss as a function of the transverse kick. This effect must be taken into account in calculating the beam profile at some distance after the dechirper.

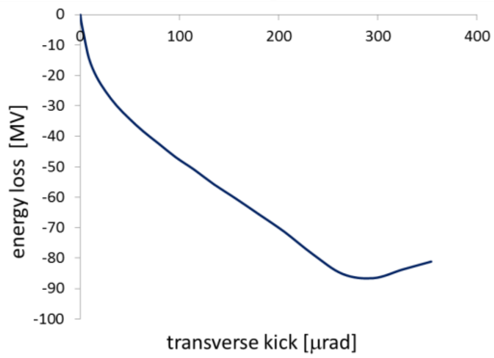

Figure 3: A particle energy loss as a function of the transverse kick acting on this particle. The distance from the bunch to the jaw edge is of 150 micron.

We can describe the horizontal kick $K(s, \Delta, x)$ for the horizontal dechirper as function $K_1(s, \Delta)$ of a longitudinal position s and a distance to the jaw edge Δ and its derivative $K_2(s,\Delta)$ at s:

$$
\begin{aligned}
&K(s,\Delta,x) = K_1(s,\Delta) + K_2(s,\Delta)\times(x-\Delta) \\
&K_1(s,\Delta) = \frac{Q}{P_0}\int_{-\infty}^{s} g_1(s-s',\Delta)\left[\int_{-\infty}^{\infty}\tilde{\rho}_0(s',\tilde{x},y)d\tilde{x}dy\right]ds' \\
&K_2(s,\Delta) = \frac{Q}{P_0}\int_{-\infty}^{s} g_2(s-s',\Delta)\left[\int_{-\infty}^{\infty}\tilde{\rho}_0(s',\tilde{x},y)d\tilde{x}dy\right]ds'
\end{aligned}
\tag{1}
$$

The kick is normalized to the longitudinal momentum P_0. We calculate the Green's functions $g_1(s,\Delta)$ and $g_2(s,\Delta)$ for this dechirper. Q is the total bunch charge, and the bunch density $\rho_0(s,x,y)$ is normalized to unity:

$$
\int_{-\infty}^{\infty}\rho_0(s,x,y)dsdxdy = 1 \tag{2}
$$

We can evaluate the vertical kick from this dechirper in the same way. If the beam is in the vertical center of the

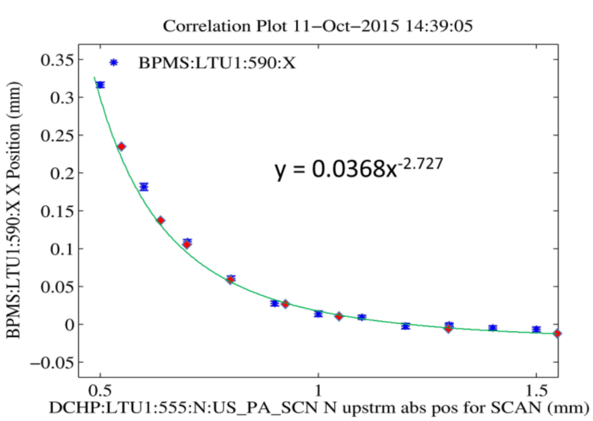

Figure 4: Comparison of the measured kick (blue dots) as a function of a beam distance to a jaw *edge* and the calculated kick (red diamonds). Green line shows a power approximation of the measured kick.

dechirper, we are left with only derivatives, which are same as those for the horizontal but with opposite sign. The beam (mainly the tail of the bunch) is focused vertically by these wake fields.

We compared these calculations with the measured transverse positions of a bunch at the first downstream beam-position monitor (BPM), 16.2 m after the horizontal dechirper, for a bunch charge of 150 pC and a beam energy of 6.6 GeV. With no focusing elements between the dechirper and BPM, the comparisons of Fig. 4 directly track the kick and show close agreement. Blue dots give the measured horizontal displacement at the BPM. Red diamonds show the calculated horizontal bunch position at the BPM. The green line is a power-law approximation to the measured points. The kick increases strongly when the beam approaches the jaw face.

TRANSVERSE BEAM PROFILE

With the wakefield deflection, a bunch takes a special shape: streaked in one direction and focused in the other. We can calculate the bunch distribution on a screen after the dechirper using a simple linear lattice:

$$
\begin{aligned}
&\rho_{scr}(x_{scr},\Delta) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\rho_0(s,x,x')dx'_{\mathrm{scr}}ds \\
&\begin{pmatrix} x \\ x' \end{pmatrix} = \begin{pmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{pmatrix}\begin{pmatrix} x_{\mathrm{scr}} \\ x'_{\mathrm{scr}} \end{pmatrix} - \begin{pmatrix} 0 \\ K(s,\Delta,x) \end{pmatrix}
\end{aligned}
\tag{3}
$$

Here x' is the relative particle horizontal momentum and $m_{ik} = a_{ik}^{-1}$ is an element of the inverse transfer matrix from the dechirper to the screen:

$$
\begin{aligned}
&\begin{pmatrix} x_{\mathrm{scr}} \\ x'_{\mathrm{scr}} \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix}\begin{pmatrix} x \\ x' \end{pmatrix} \\
&\begin{pmatrix} x \\ x' \end{pmatrix} = \begin{pmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{pmatrix}\begin{pmatrix} x_{\mathrm{scr}} \\ x'_{\mathrm{scr}} \end{pmatrix}
\end{aligned}
\tag{4}
$$

Integration over x' can be done only after determining the matrix elements. The lattice is optimal when $\alpha_{\mathrm{dech}} = 0$ at the dechirper and the phase advance to the screen $\Delta\psi = 90°$, and so we get:

$$
(a_{ik}) = \begin{pmatrix} 0 & \sqrt{\beta_{dech}\beta_{scr}} \\ -\dfrac{1}{\sqrt{\beta_{dech}\beta_{scr}}} & -\alpha_{scr}\sqrt{\dfrac{\beta_{dech}}{\beta_{scr}}} \end{pmatrix} \tag{5}
$$

and

$$
(m_{ik}) = \begin{pmatrix} -\alpha_{scr}\sqrt{\dfrac{\beta_{dech}}{\beta_{scr}}} & -\sqrt{\beta_{dech}\beta_{scr}} \\ \dfrac{1}{\sqrt{\beta_{dech}\beta_{scr}}} & 0 \end{pmatrix} \tag{6}
$$

We may assume that the distribution in x and x' has a Gaussian shape. In this case we can integrate over x' analytically. The bunch size at the screen without deflection will be determined by the bunch emittance:

$$\sigma_{scr}^2 = \frac{\left\langle x'_{dech} \right\rangle^2}{m_{21}^2} = \left\langle x'_{dech} \right\rangle^2 \beta_{dech}\beta_{scr} = \varepsilon\beta_{scr} \quad (7)$$

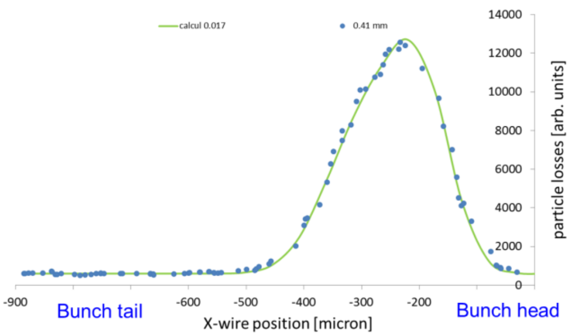

Figure 5: Beam profile measured by a wire scanner (blue dots). A green line shows an analytical profile derived from Eq. (3).

To recover the initial longitudinal bunch distribution

$$\rho(s) = \int_{-\infty}^{\infty} \rho_0(s', \tilde{x}) d\tilde{x} \quad (8)$$

using the image on the screen, we need to solve the integral equation:

$$\rho_{scr}(x_{scr}, \Delta) = \int_{-\infty}^{\infty} \tilde{\rho}_0(s, x) ds \quad (9)$$

which is possible using an iteration algorithm.

FIRST EXPERIMENTAL RESULTS

At first we used wire scanners to see the profile of the beam deflected by the wake fields excited in the horizontal dechirper. Figure 5 shows the beam profile when the distance between the beam trajectory and dechirper jaw edge is 410 μm. Blue dots are measured points, and a green line shows an analytical solution from Eq. (3). The amplitude of the profile and some lattice parameters were adjusted to optimize the fit, but were then fixed and used for other profiles.

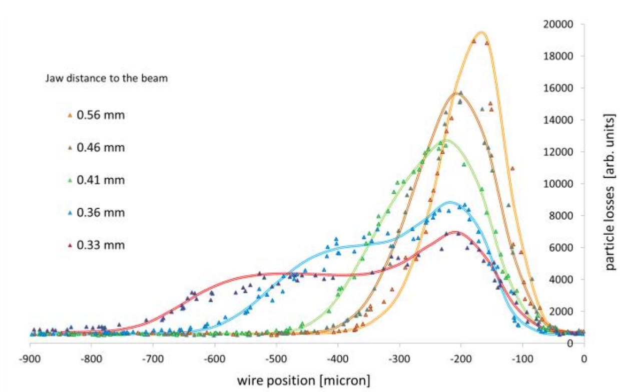

Figure 6: Measured beam profile at different distances between the beam and the dechirper edge, and the corresponding analytical profiles.

Figure 6 shows the change in the beam profile at the screen as the distance between the beam and the dechirper jaw edge becomes smaller: the screen distribution increasingly approaches the shape of the initial distribution of the bunch (compare the red line of Fig. 6 to the blue line of Fig. 2).

A 50-fs bunch stretches to a length of 0.6 mm at the wire scanner when the distance from the beam to the dechirper face is 330 μm. We can increase the kick more than 60 times by putting the jaw 50 μm from the beam, resulting in a resolution of less than 1 fs.

We also made initial measurements of the beam at the YAG screen. Fig. 7 shows a typical beam profile. We can see a strong focusing in the vertical direction. We plan to install a smaller YAG screen to get adequate screen resolution for measurements of very short bunches.

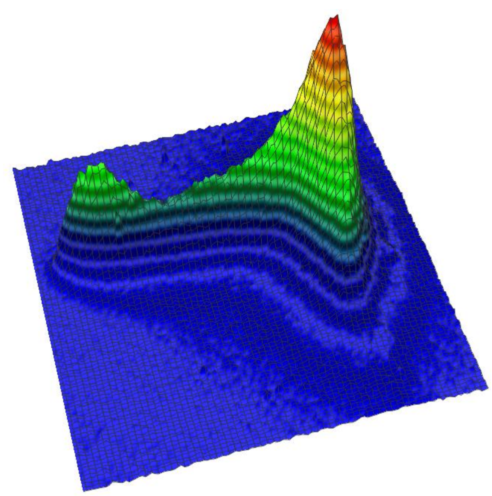

Figure 7: Measured beam profile at the YAG screen.

REFERENCES

[1] S. Bettoni, P. Craievich, A. A. Lutman and M. Perozi, “Temporal profile measurements of relativistic electron bunch based on wakefield generation,” Phys. Rev. Accel. Beams 19, 021304 (2016)

[2] V. Dolgashev *et al.*, “Attosecond Diagnostics of Multi-GeV Electron Beams Using W-Band Deflectors,” 2015, URL http://www.feis-2.org, proceeding of FEIS-2: Femtosecond Electron Imaging and Spectroscopy, East Lansing, Michigan.

[3] M. Guetg *et al.*, “Commissioning of the Radiabeam/SLAC dechirper”, these proceedings.

[4] A. Novokhatski, “Wakefield potentials of corrugated structures,” Phys. Rev. ST Accel. Beams 18, 104402 (2015).