SIMPLE ESTIMATE, DETAILED COMPUTER SIMULATION AND MEASUREMENT OF THE TRANSVERSE KICK IN THE SLAC ACCELERATING STRUCTURE*

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Abstract

We discuss the result of calculation and measurement of the transverse kick in the SLAC accelerating section in a single and multi-bunch regime. We present a simple estimate, which can be used in practical situations like two-bunch or multi-bunch operation at LCLS.

INTRODUCTION

Wake fields, excited by a very short bunch in an accelerating section may play an important role in the beam dynamics of linear accelerators. They are responsible for the energy loss of a bunch, the energy spread inside the bunch and, consequently, the adiabatic bunch emittance growth in dispersive areas. Other important role of the wake field is the transverse kick when the beam trajectory is not on the axis of the accelerating sections. There are many studies on this subject mainly concentrated on the beam transverse instability [1-2]. While doing longitudinal wake field calculation we found a Green function, which can describe wake potentials for very short bunches [3]. In calculations we use a model of the SLAC constant gradient accelerating structure. The constant accelerating field is obtained by tapering the cross-sectional dimensions of the cells.

The transverse effect of the wake fields becomes important at LCLS for creating two or more bunches [4-7]. After an initial test with two bunches in 2010, many-photon experiments have been carried out using two bunches with separations up to 122.5 ns. We carried several measurements of the transverse kick and we did calculations of the transverse kick in the same way as for longitudinal field using a constant gradient model.

While wake field kicks are the biggest source for separating two bunches for short distances (<50 ns), RF kicks seem to cause most of the transverse separation for longer delays. If the two bunches have different energies (required for some photon experiments) they can be influenced by introducing dispersion and finally overlap them in the undulator. This could be explained by different alignments of the front and back end of the accelerator structure. Some partial alignment measurements have been done and they confirm at least the order of magnitude.

SLAC ACCELERATING SECTION

The SLAC accelerating structure is a quasi-periodic structure, which consists of a sequence of 10 ft long accelerating sections. The accelerating sections repeat each other, but the cells inside each section are different. The geometry of an azimuthally symmetric model of the SLAC accelerating section is shown in Fig. 1.

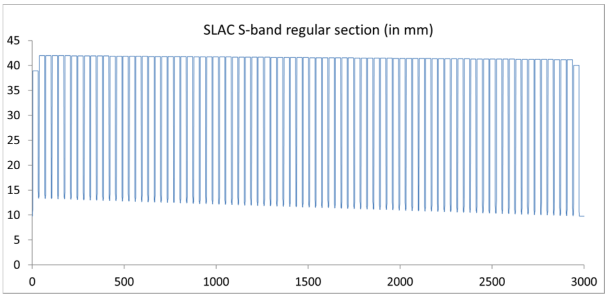

Figure 1: Azimuthally symmetrical SLAC section model.

We use a Table 6–6 of Ref. [1] for the dimensions of a regular 10-ft constant gradient disk-loaded section. The section consists of 86 cells, formed by 85 disks and two coupler flanges. Each disk in a section has a different hole radius starting at 13.11 mm and ending with 9.62 mm (the difference is approximately 36%). Radiuses of the input and the outgoing pipes are the same and equal to 9.55 mm. The transverse cell radius changes from 41.73 mm to 40.91 mm. The coupling cells have radiuses of 38.62 and 39.76 mm. This type of accelerating structure is 2π/3 and has a period of 35 mm.

WAKE FIELDS

The longitudinal shape of an accelerating section disk (or sometimes we call it as iris) can be seen at the plot in Fig. 2.

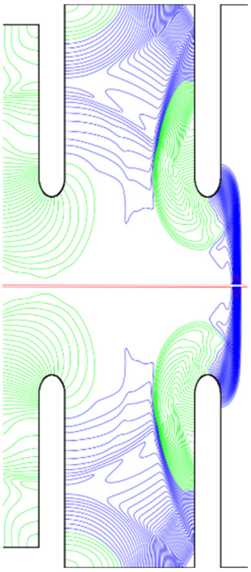

Figure 2: Electric field lines of the wake field excited by a 0.5 mm bunch in a SLAC accelerating section.

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This figure shows a snapshot of the electric field lines of the wake field excited by a 0.5 mm bunch is shown. A bunch has passed the two first disks of a section. The transverse size of the first coupler cell is smaller than the next cell. The blue lines show field lines with the longitudinal projection opposite to the bunch velocity. These lines describe the decelerating forces. The green lines have collinear longitudinal projections with a bunch velocity and describe the accelerating forces. It can be seen that the structure of the fields deflected on iris are moving to the axis and sometime will catch the bunch. We can present the iris as a sum of small azimuthal pieces and study wake fields from one piece. Fig. 3 shows an integrated kick on a bunch coming from a rectangular azimuthal piece. At first the bunch is deflected a little, but then it gets a kick in the direction of the azimuthal peace.

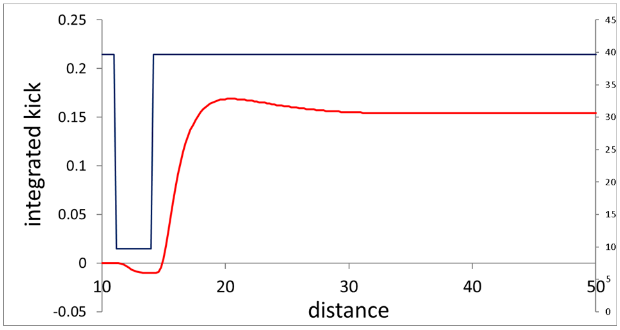

Figure 3: A kick from an azimuthal iris piece.

The final kick strongly depends upon the distance δ between the edge of the iris piece and the beam and naturally depends upon the bunch charge Q. We can estimate by a formula [8-9]

$$g_{av} = \frac{Q}{8\pi\varepsilon_0}\frac{1}{\delta} \qquad (1)$$

In the azimuthal symmetrical structure, the fields coming from different azimuthal parts of the iris meet together on the axis and there will be no a transverse kick on the bunch, as the kicks from different azimuthal parts are compensated. However, if the bunch trajectory is not on the axis then the field coming from the closer part of the iris may kick the beam, after that the field coming from other parts will kick the beam in the opposite direction but with a smaller amplitude. As the kicks are different, the final kick on the beam will be in the direction of the closer azimuthal part of the iris. We may estimate this kick by a formula for a dipole kick.

$$g_{av} \approx \frac{Q}{4\pi\varepsilon_0}\frac{\Delta x}{a^2} \quad \Delta x << a \qquad (2)$$

Δx is a small beam trajectory displacement, a is a hole radius of the iris.

Accurate numerical calculations for the kick in the SLAC accelerating section were done for a short range and long-range wake fields. As an example, Fig. 4 shows a wake potential for a kick for a 1 mm bunch. We can see the kick rising almost linear along the bunch and reach maximum far behind the bunch somewhere at 6 mm distance after the center of the bunch. The averaged kick on a bunch, somewhere near the bunch center is noticeably smaller than the maximum kick.

Plots for long range wake fields will be shown later together with the measurement results.

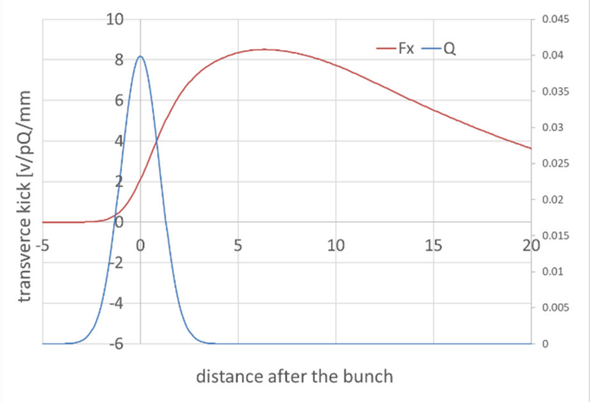

Figure 4: Wake field kick for a 1 mm bunch.

MEASUREMENT WITH TWO BUNCHES

Measurements were done at the 1 km part of the SLAC room temperature linear accelerator used for LCLS. To provide two bunch operation was necessary to determine how the wake field kick may change the trajectory and parameters of the second bunch and how it is possible compensate this effect. For measurement a transverse bump was developed in the first part of the LCLS linac. Due to the wake field kick the beam gets transverse oscillations in the following part of the linac. The amplitude of oscillations can be measured by beam position monitors (BPMs), situated at the end of the linac in the undulator section.

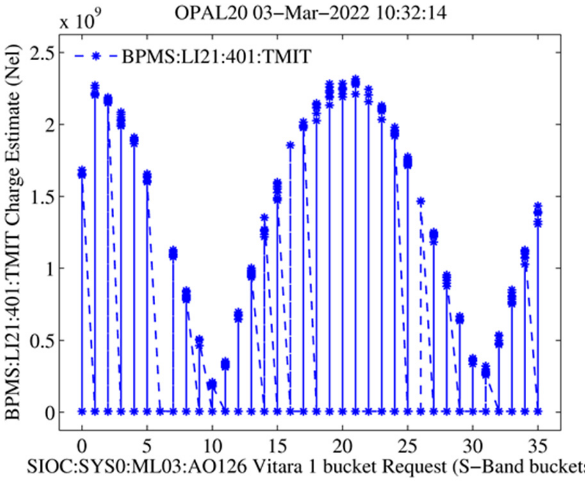

Figure 5: How a BPMs shows the bunch charge of two bunches.

A long separation of two bunches has a complicated beam diagnostic. Beam diagnostics BPMs signals used for tuning. They show the trajectory of the beam through the accelerator, the undulator and finally to the dump. For two bunches the normal BPM system shows a vector sum, so a special deconvolution software was developed. In the dispersive regions BPMs used to measure the beam energy. Feedback use the BPMs to keep the beam stable. For two bunches the average position is measured, and the charge is a vector addition resulting typically in a lower charge This has some consequential influence wherever the charge is used. For instance, the peak current measurement is "normalized" to charge and then shows twice the normal value when the "measured" charge is half. This peak current is used for a small correction of the reported photon energy derived from electron energy resulting in an overcorrection. BPMs of the RF type are used in the undulator region.

WAKE FIELD KICK

Usually, it is easy to measure the kick for the same and the second bucket, there are a lot of additional effects influenced on the beam position, however we believe in measurement for longer separation. The results for measured and calculated wake field kick are show in Fig. 6. The time scale is shifted to compensate initial phase error. We can see good enough agreement in the range of 3 ns.

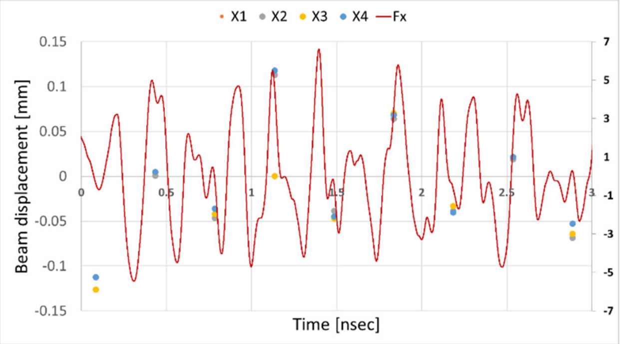

Figure 6: Comparison of the 4 measurements of the beam displacement with wake field calculations.

For the long range we can describe a kick by only one sinus function with frequency *f*, *c* is the speed of light.

$$g(t)_{[V/pQ/mm]} = 4\sin\left(\frac{2\pi f}{c}t\right) \qquad (3)$$

It means that that there is one outstanding deflecting mode in the SLAC accelerating section. We found that the frequency of this mode is *f*=4.1708 GHz. The comparison of measured and sinus function with this frequency is shown in Fig. 7.

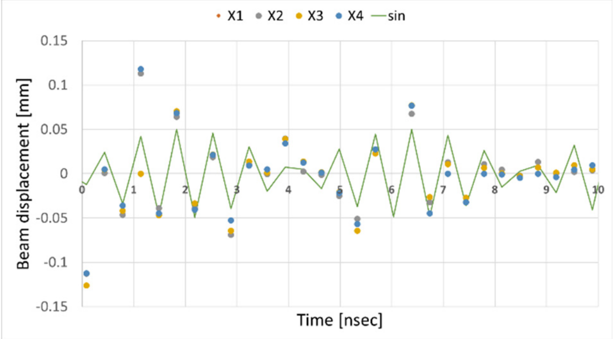

Figure 7: Approximation by simple sinus function.

We can see from the plot that agreement is very good, however for longer separation we may be needed to include the decay of the mode. There is a difference in frequencies of 30 MHz for the mode determined in the "Blue Book", Ref. [1]. Needs more study.

The results for last measurement with the attempt to reduce wake fields are shown in Fig. 8 for the X-direction and Fig. 9 for Y-direction.

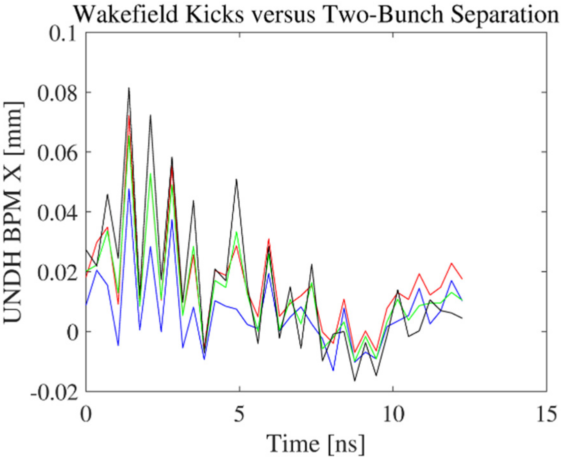

Figure 8: Wake field kick in X-direction versus bunch separation.

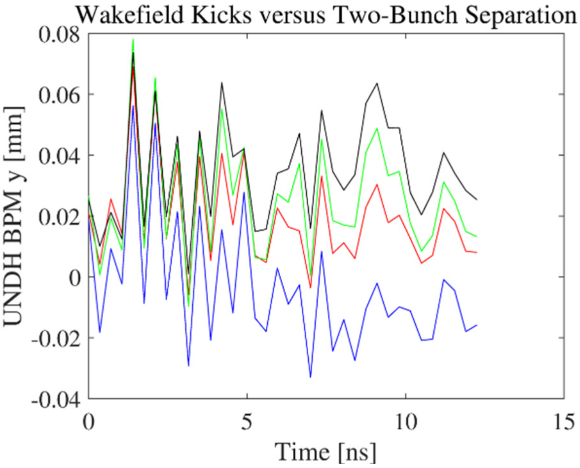

Figure 9: Wake field kick in Y-direction versus bunch separation.

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