CHARACTERISATION AND REDUCTION OF TRANSVERSE RF KICKS IN THE LCLS LINAC*

F.-J. Decker, R. Akre, K. Bertsche, A. Brachmann, W. Colocho, Y. Ding, D. Dowell, P. J. Emma, J. Frisch, S. Gilevich, G. R. Hays, P. Hering, Z. Huang, R. Iverson, A.K. Krasnykh, H. Loos, H.-D. Nuhn, D. Ratner, H. Smith, J. L. Turner, J. Welch, W. White, J. Wu
SLAC, Menlo Park, CA 94025, U.S.A.

Abstract

The electron beam for the Linac Coherent Light Source (LCLS) at SLAC is accelerated by disk-loaded RF structures over a length of 1 km. The mainly longitudinal field can sometimes exhibit transverse components, which kick the beam in x and/or y. This is normally a stable situation, but when a klystron, which powers some of these structures, has to be switched off and another one switched on, different kicks can lead to quite a different orbit. Some klystrons, configured in an energy and bunch length feedback, caused orbit changes of more than 1 mm, which is about 20 times the sigma beam size. The origins and measurements of these kicks and some efforts (orbit bumps) to reduce them will be discussed.

INTRODUCTION

Transverse RF kicks had caused some grief during the SLC era of the SLAC Linac, prompting beam studies and a beam-based alignment technique [1,2,3]. Emittance blow up due to an early klystron failure either required a 4 hour retuning or 2 hour repair impacting the program during that time. For LCLS these issues are reduced due to lower currents and shorter bunch length, but some impacts have been observed especially with klystrons 24-1 and 24-2 which have been used for energy and bunch length feedback and therefore vary constantly. It was possible to flip the phase configuration of say -90°, +30° to +30°, -90°, inducing an orbit oscillation with more than 1 mm amplitude (Fig. 1).

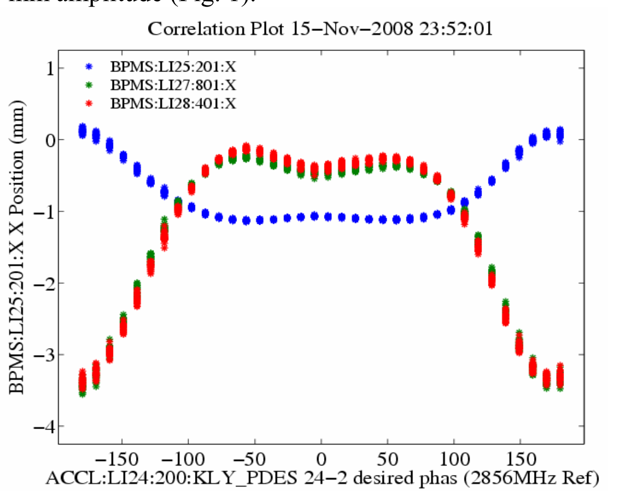

Figure 1: RF kick for 360° phase change of klystron 24-2.

This caused in some cases charge loss on collimators at the end of the linac before an orbit feedback corrected it.

Besides the direct RF kicks, we have to consider dispersive effects too, since the beam energy is changed. These can be linear or even quadratic, as in the case of the BC2 chicane (bunch compressor 2 Fig. 3) [4]. The size of these effects, how they can bias our dispersion tuning procedure, and how we tried to suppress them with dispersive and non-dispersive bumps is discussed.

DISPERSIVE OR RF KICKS

In general it is tricky to distinguish between an RF kick and a dispersive kick due to an energy change. Two examples are given below. In Figure 2 the difference orbit is shown when a klystron early in the linac (22-8) is switched off. The orbit stays flat for two sectors Li23 and Li24 till it hits the BC2 chicane at Li24 801. There the beam gets a kick mainly in x, since some dispersion from BC2 "leaks" out. One reason for that is that the dispersion tuning procedure (see below) uses the energy feedback to set the energy using klystrons 24-1 and 24-2 (from Fig. 1) generating significant RF kicks.

Another example is shown in Fig. 4, where the klystron 25-7 was switched off and the kick occurs right there. If there is no dispersion generated right there, which can be check by switching off another klystron earlier in the linac and observing no additional kick, the induced oscillation can be attributed to an RF kick, in this case -0.4 mm from klystron 25-7.

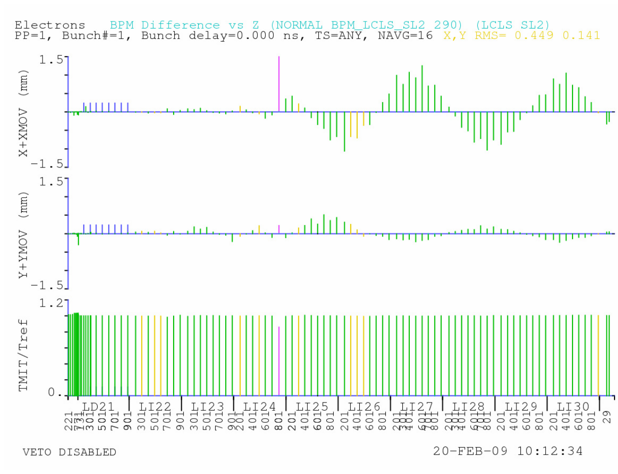

Figure 2: Difference orbit is plotted with the klystron 22-8 off (minus on). An oscillation starts later around Li24 801 indicating a dispersive kick there.

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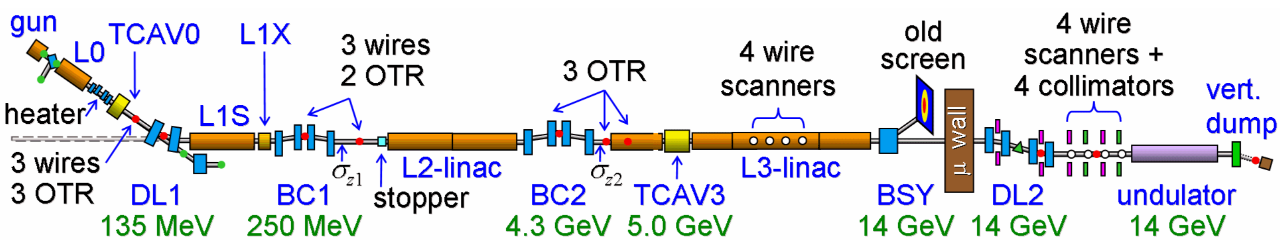

Figure 3: LCLS schematic layout of the Linac sections (L0, L1, L2, and L3) with the two bunch compressors (BC), followed by a dog leg (DL2) and some collimation before reaching the undulator and dump.

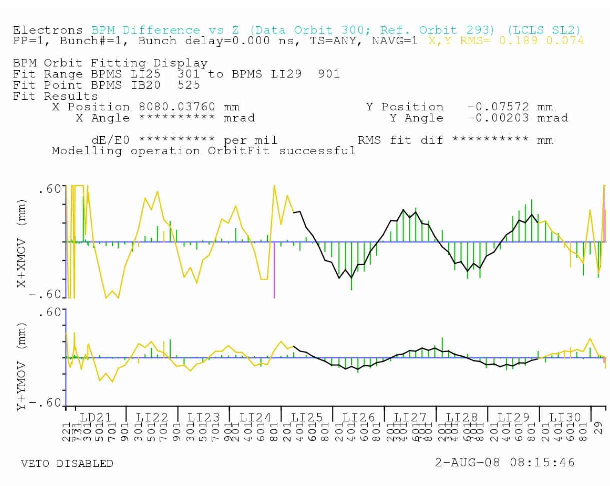

Figure 4: Difference orbit is plotted with the klystron 25-7 off (minus on). An oscillation starts right there indicating an RF kick. The signed “amplitude” is -0.4 mm in x.

The amplitude of the orbits due to some klystron kicks is summarized in Tab. 1.

Table 1: Orbit Offset in μm Caused by RF Kicks

Klystron	*x*	*y*		Klystron	*x*	*y*
25-1	200	-250				
25-2	100	0				
25-3	100	200		21-3	900	400
25-4	-100	150		21-4	200	-900
25-5	-200	0		21-5	-200	200
25-6	100	0		21-6	600	-200
25-7	-400	-150		21-7	-600	500
25-8	0	0		21-8	100	-600

DISPERSION MEASUREMENT

The chicanes of the bunch compressors have high dispersion by design, as an example η_x = -366 mm for BC2. This has to be reduced to very low numbers after the chicane to avoid emittance growth. For that we have a GUI (Graphical User Interface) driven computer program which changes the energy, measures the dispersion, and calculates the correction in x by using two weak quadrupoles. Besides the dispersion numbers in x and y it gives also the resulting emittance growth if not corrected (Fig. 5). There is also some second order dispersion visible at the top of the figure.

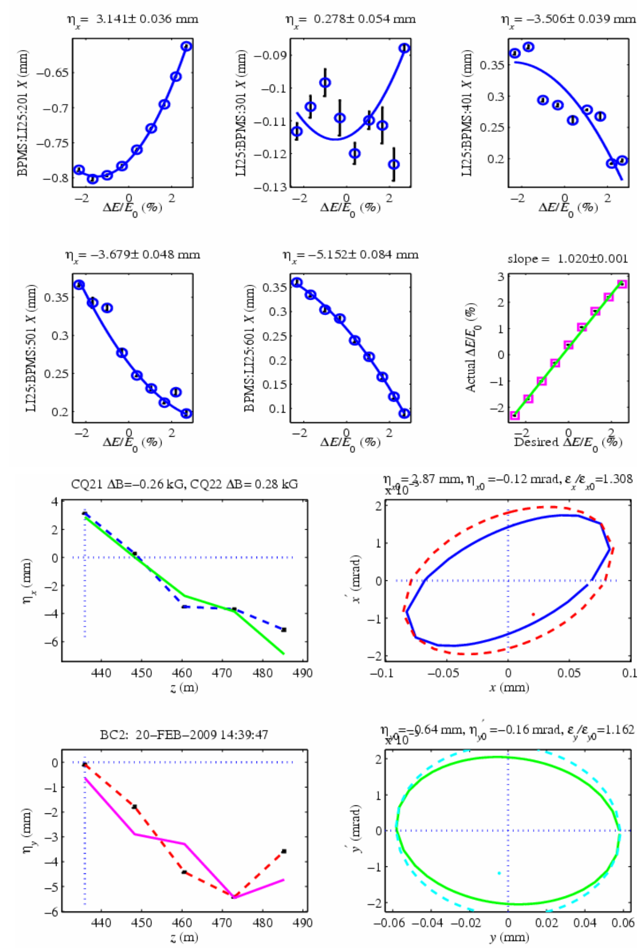

Figure 5: Results of a dispersion measurement at BC2.

There are a few problems with this tuning procedure. Since it uses the 24-1 and 24-2 klystrons of the energy feedback, it gets fooled by their RF kicks resulting in a solution which leaves some residual dispersion leaking out when the energy is change by a different method (compare Fig. 2). Depending on a different klystron complements even with similar RF phases for the 24-1 and 24-2 klystrons, the predicted horizontal emittance growth due to dispersion varied from 0 to 30% due to the confusion generated by RF kicks. Dispersion happens in the vertical plane as well. Instead of having a weak correction quadrupole of say 0.1 kG strength at a dispersion of say 100 mm in a chicane, you achieve the same effect by having a weak dispersion say 1 mm at a normal strength quadrupole say 10 kG. A three corrector bump of 1 mm creates 4 mm dispersion, if the correctors are at the high betatron points in a 90° lattice.

RF KICK CORRECTION METHOD

The first method for reducing the observed RF kicks depended on the following assumption. The RF structures fed by a certain klystron are tilted, let's say in x, so the beam gets not only a longitudinal boost, but also a transverse kick. The kick observed from 24-2 resulted in an equivalent misalignment of ±1mm at its ends of the four 3 m RF structures, which is in the range of the typical 0.3 mm rms alignment error of these structures.

Dispersive Bumps

An angle bump was created, which should line up the beam orbit to the tilt of the structures, but twice a kick was observed. A sign error or flawed assumption might be the cause, but the opposite bump reduced the kick significantly. The same was done for 24-1 and the resulting kick were reduced by more than a factor of five (see Fig. 6). This was enough to mitigate the urgency of the problem. There were also efforts to reduce the likelihood of the phase flipping of the two feedback klystrons to happen, and finally the klystrons are now used only for energy feedback and not for bunch length which reduces their phase excursions.

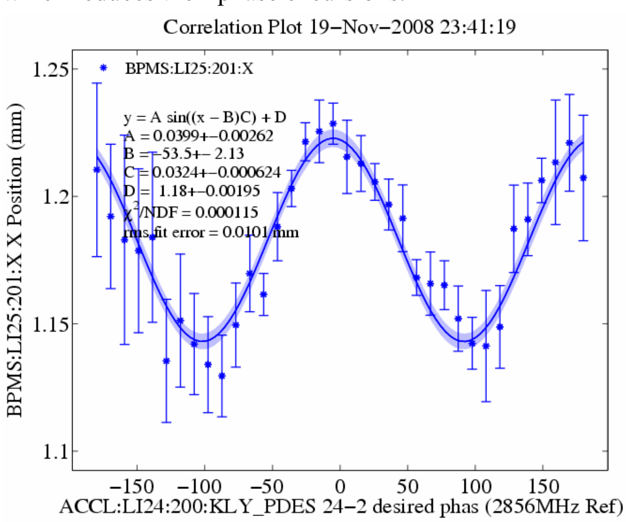

Figure 6: RF kick for 360° phase change of klystron 24-2 after an orbit bumps around the structure reduced the kick.

Non-Dispersive Bumps

It was recognized later that the bumps just described were dispersive, meaning that an energy change upstream of 24-1 and 24-2 was creating a kink in the orbit at the beginning of Sector 24. So the RF kick was at least partly compensated by a dispersive kick. A non-dispersive bump consists of 5 correctors, one corrector creating the bump and two close the orbit: x and x', while two more close the dispersion: η_x and η_x'. We have actually a bump maker, which can make bumps equivalent to this bump; it closed the orbit for electrons and positrons at the same time (Fig. 7). With these bumps it is expected to have a dispersion-free effect on all upstream energy changes while the local dispersion cancels the RF kick.

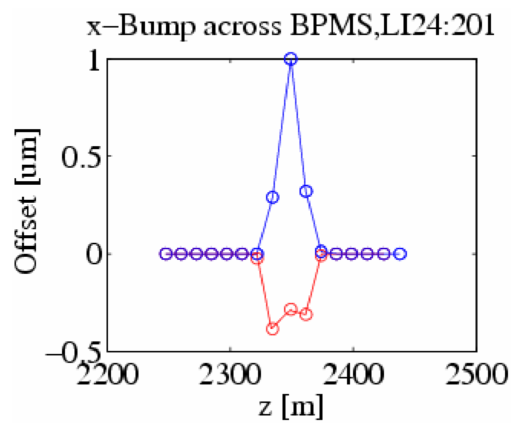

Figure 7: Five correctors bump closed for all energies.

Besides the klystrons which are used for energy feedback it might be prudent to compensate the RF kick for the earlier klystrons of L2 (Sector 21). They are quite big (compare Tab. 1, right side) since the energy added by each klystron is still a large percentage of the beam energy (90%, 45%, 30%, 23% …). Here the procedure might be also different, since the big change will require that the quadrupole magnets need to be scaled and only the resultant kick be compensated.

SUMMARY

Transverse RF kicks creating an orbit distortion of up to a few mm where observed, either looking at the difference orbit with a klystron on and off, or scanning the phase 360°. By applying closed orbit bumps these kicks where reduced by more than a factor of five, but some dispersion was created. This required looking into a dispersion-free version of a bump using 5 correctors.

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