LCLS Physics Requirements Document # 1.2-031	Injector	Revision 0

BUNCH CHARGE FEEDBACK LOOP

Paul Emma Author	Signature	11/30/06 Date
Bill White Author	Signature	11/30/06 Date
Dave Schultz Electron Beam Manager	Signature	11/30/06 Date
Eric Bong System Manager	Signature	11/30/06 Date
Darren Marsh Quality Assurance Manager	Signature	11/30/06 Date
Cecile Limborg Injector Physicist	Signature	11/30/06 Date

Brief Summary:

This specification summarizes physics requirements for the bunch charge feedback loop, including software limits to protect the photocathode from excessive laser energy.

Change History Log:

Rev Number	Revision Date	Sections Affected	Description of Change
000	Nov. 20, 2006	All	Initial Version

Check the LCLS Project website to verify that this is the correct version prior to use.

Bunch Charge Feedback Loop

Introduction

The LCLS electron bunch charge will need to be stabilized with a software feedback loop at the RF gun. This stabilization can be accomplished by maintaining the measured drive-laser energy at the cathode or similarly by maintaining the measured bunch charge immediately after the gun. Ideally the loop would be based on bunch charge, but it is also important to limit the laser pulse energy so as not to damage the photocathode. The method described here uses a combination of measured laser energy and measured bunch charge, adjusting the laser energy using the motorized wave-plate located in the frequency tripler. **Figure 1** shows a schematic of the feedback loop, where the charge measurement (using toroid IM01) is used to control the laser energy loop set-point.

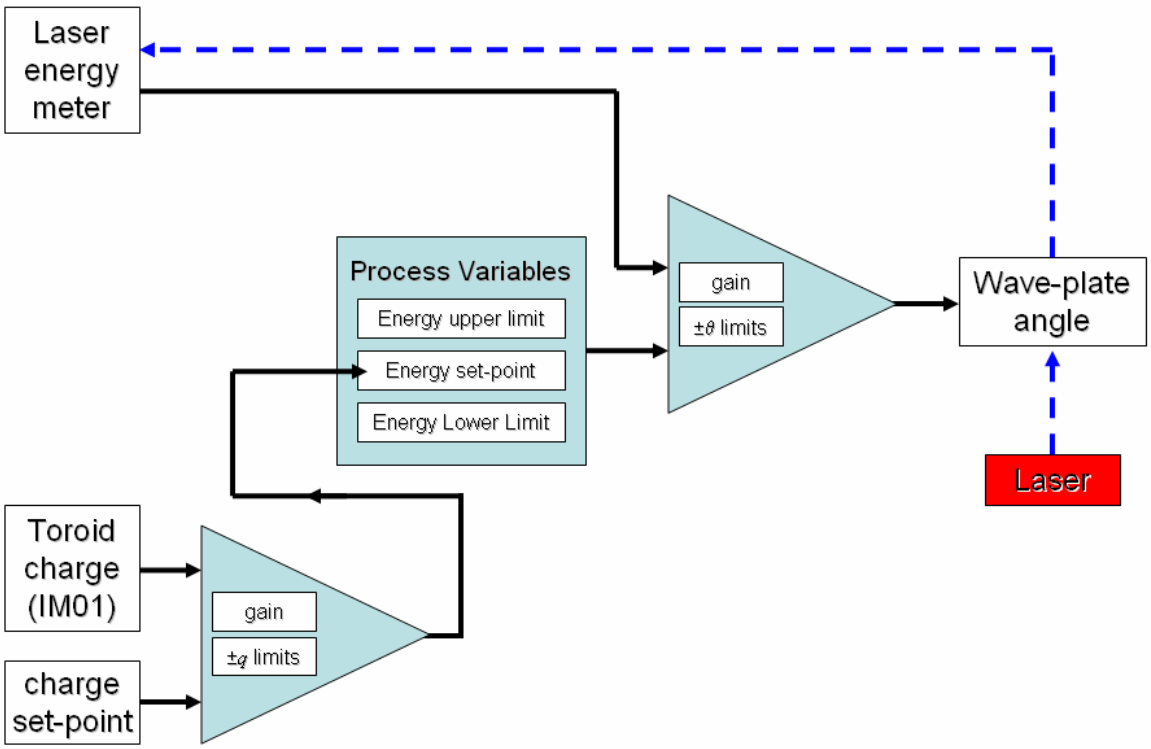

Figure 1. Bunch charge feedback loop controlling the drive-laser energy set-point.

System Description

This feedback system is effectively two nested feedback loops. The inner loop (loop-1, with faster response) controls the wave-plate angle, and therefore the laser pulse energy, by measuring the laser pulse energy on a Joule meter near the cathode and comparing this to an energy software set-point. This set-point is entered by the operator during initial setup, or when altering operating parameters.

The outer loop (loop-2, with slower response) measures the bunch charge with respect to the charge software set-point, also entered by the operator during initial setup. This outer loop controls the energy set-point of the inner (laser energy) loop.

All parameters will require software limits so that the feedback loops are only active within a reasonable operating range as described below:

Laser Energy (Inner) Loop-1:

- The wave-plate angle will have upper and lower software limits (*e.g.*, ±20% of the initial wave-plate angle). If the wave-plate angle is commanded to run outside of these limits the energy-feedback software will raise an "out-of-limits" alarm and suspend any further loop-1 action while outside of the limits. This should also suspend loop-2. These software limits should be asymmetric, allowing a lower limit different than the upper.
- The laser energy meter will have upper and lower reasonability software limits (*e.g.*, ±20% of the energy set-point). If the laser energy measurement is outside of these limits the energy-feedback software will raise an "out-of-limits" alarm and ignore the measurement, suspending any further action while outside of the limits. This should also suspend loop-2. These software limits should be asymmetric, allowing a lower limit different than the upper.

Bunch Charge (Outer) Loop-2:

- The bunch charge toroid will have upper and lower reasonability software limits (*e.g.*, ±20% of the charge set-point). If the charge measurement is outside of these limits the charge-feedback software will raise an "out-of-limits" alarm and suspend any further loop-2 action while outside of the limits. In this case, loop-1 (laser energy) should continue to run, based on the last value of the energy set-point. Only loop-2 (bunch charge) should be inhibited from updating the energy set-point. These bunch charge reasonability software limits should be asymmetric, allowing a lower limit different than the upper.
- The laser energy set-point will have upper and lower software limits (*e.g.*, ±20% of the laser energy set-point). If the laser energy is commanded to run outside of these limits the charge-feedback software will raise an "out-of-limits" alarm and suspend any further loop-2 action while outside of the limits. In this case, loop-1 (laser energy) should continue to run. These software limits should be asymmetric, allowing a lower limit different than the upper.

The wave-plate angle, θ, controls the laser energy through an intrinsically non-linear response as sketched in **Fig. 2**. The software limits on angle control and energy measurement validity should keep the feedback loop operating in the 'linear' region, away from the roll-over point where the energy drops again with increasing angle.

The feedback correction command, however, will simply be linearly scaled with the error signal (for both the energy and charge loops). The non-linear energy response to wave-plate angle is intrinsic to the hardware, but will not be used in the software to command the wave-plate. The wave-plate angle change command ($\Delta\theta_i$ for each beam pulse i) will be based on a simple linear scaling of the laser energy error signal, such as

$$\Delta\theta_i = g_1 C_1 (E_i - E_s), \tag{1}$$

where $\Delta\theta_i$ is the wave-plate angle *change* correction command, g_1 is the loop-1 gain ($0 < g_1 \leq 1$), C_1 is the loop-1 coefficient converting a desired laser energy change to a needed wave-plate angle change (*i.e.*, approximately the slope in **Fig. 2** at the "operating point"), E_i is the measured laser energy of the ith beam pulse, and E_s is the laser energy set-point. The loop-1 gain, g_1, and the loop conversion coefficient, C_1, should be conveniently entered by the operator, as should be the set-point, to allow manual user optimization of loop performance.

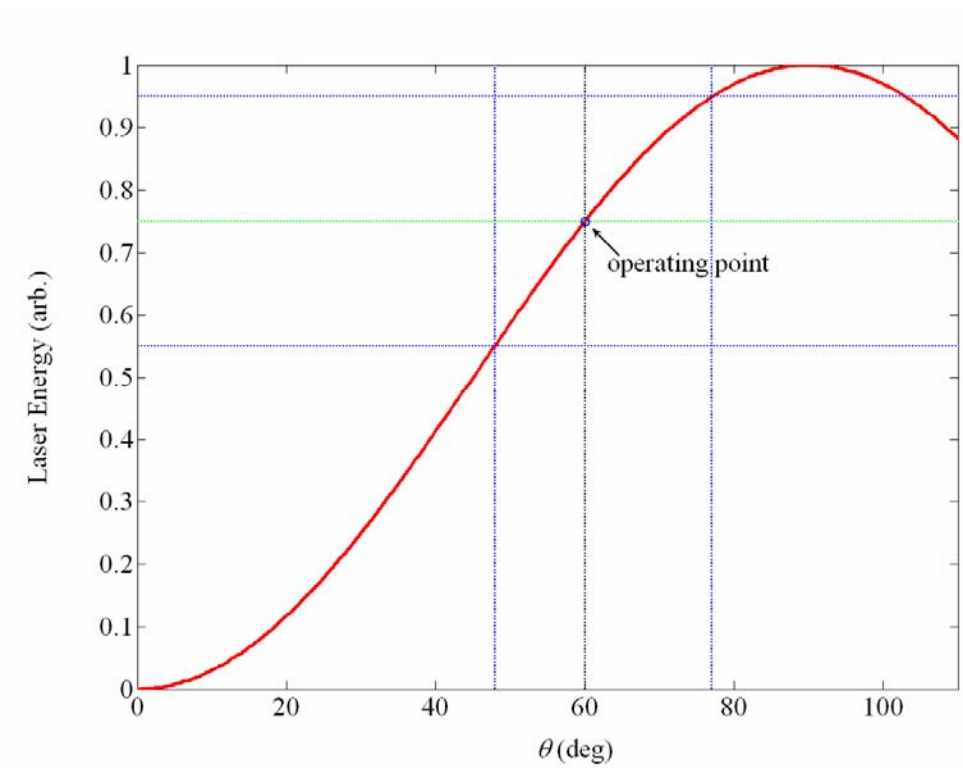

Figure 2. Laser pulse energy (arbitrary vertical scale) as a function of the wave-plate angle, θ. The software limits on angle control and energy measurement validity should keep the feedback loop in the 'linear' region, away from the roll-over point where the energy drops again with increasing angle.

The outer loop will behave in a similar fashion,

$$\Delta E_{s_i} = g_2 C_2 (q_i - q_s), \tag{2}$$

where ΔE_{si} is the laser energy set-point *change* command, g_2 is the loop-2 gain ($0 < g_2 \leq 1$), C_2 is the loop-2 coefficient converting a desired bunch charge change to a necessary laser energy set-point change, q_i is the measured bunch charge of the ith beam pulse, and q_s is the bunch charge set-point. The loop-2 gain, g_2, and conversion coefficient, C_2, should be conveniently entered by the operator, as should be the set-point, to allow manual user optimization of loop performance.

Time Constants and Loop Rate

The measured variables in this feedback loop (laser energy and bunch charge) should be read at the maximum accelerator operating rate (up to 120 Hz), but should also function properly at lower rates, including zero. An option should be included to use a running average of the measured laser energy and bunch charge. For this option, the software should provide two separate user-entered parameters, N_1 and N_2, as the number of pulses to average for each loop. If, for example, $N_1 = 5$ and $N_2 = 25$, the measured laser energy, E_i, should actually be the average of the last 5 laser energy measurements, while the measured charge, q_i, should actually be the average of the last 25 bunch charge measurements. In addition, the charge loop should only update the energy set-point every N_2/N_1 pulses (*e.g.*, every 5th pulse in this case). With this arrangement, typically we would desire the relation: $N_2 > N_1$. This inequality should be forced by the software at the data entry level.