Optimization and Coding of a LCLS Control Program

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Introduction

A goal of SLAC besides preforming great scientific research has been to make its facilities accessible to all members of the scientific community. This can be challenging due to the high demand for research time on its facilities such as the Linac Coherent Light Source (LCLS) also known as world's first hard X-ray free-electron laser. This has prompted research into methods of streamlining and optimization of the research process by SLAC employees. This streamlining can involve creating brand new operating systems, user interfaces and system control programs. In this experiment, we are trying to look into the problem of operators who wish to maximize the power output of the LCLS by creating an optimization program. This program would take control of the LCLS undulator hall, modifying it to create the greatest power out from the beam. This should, when implemented correctly, reduce optimization time needed for these kinds of experiments.

Methods

To get the most power out of the system, we first need to explain how the system works. The LCLS generates x-rays by wiggling an electron beam in what is known as an undulator hall. The undulator there has magnets with alternating polarization that generates magnetic fields which cause the electrons to wiggle. This causes the electrons to emit x-rays which is a process known as synchrotron radiation. When the electrons and the x-rays are in phase with one another, they constructively add to the existing x-rays. This rises the lasers power output. The electrons are not traveling at the same speed as the x-rays and because they are radiating they also have a tendency to loose speed. By adjusting the magnetic field in the undulator, we can change the paths these electrons take resyncing them up to the existing x-rays. A simple method for doing this is by reducing the magnetic field as the electrons travel down the hall or tapering it.

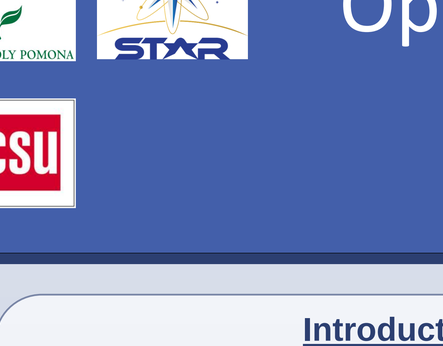

Figure 1: Graph of power vs distance in the undulator for an untapered setup and a tapered setup.

The program takes several steps in the process of optimizing the system. The first step we make is matching the undulators to functional fits.

- · Undulators 1-8 liner fit
- · Undulators 10-15 liner fit / polynomial fit
- · Undulators 17-32 polynomial fit

Next, we go through undulators 17-32 discretely on an individual basis optimizing their power output starting from 17 going to 32. Finally, we perform a backpropagation step where we go through optimizing the values for undulators 17-32 but starting with 32 and going backwards.

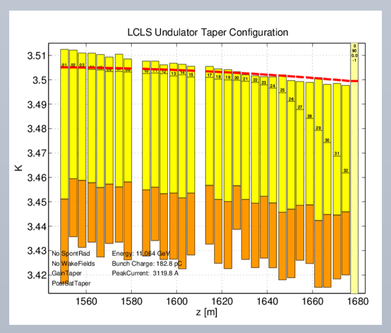

Figure 2: Example of a tapered undulator set up in the undulator hall. There are three distinct regions from 1-8, 10-15, and 17-32.

Results

We got three opportunities to test the program out on the LCLS itself. The first attempt unfortunately didn't work out so well. The bracket was set incorrectly for the experiment which resulted in the program never finding a good solution to the optimization problem. We fixed the bracket and tried the second test. The program to work by the end of the test and were able to get the power to a respectable 3.2 mJ or 32 GW of power output. During the third test we optimized the system with the Ocelot program an existing program used by the control staff. We then ran our program over its solution which resulted in a .5mJ power increase to about 3.7 mJ power output 37 GW.

Figure 3: Gas chamber power reading for the second experiment. Max power output reached 3.2 mJ or 32 GW.

Figure 4: Gas chamber power reading for the third experiment. The experiment was to have our program try and improve power after Ocelot program had already optimize the values. Max power reached 3.7mJ or 37 GW which is a .5mJ increase over the Ocelot program.

Discussion

The experiment highlighted some limitations. The program currently takes too long to optimize the power to be effective alternative over manual optimization. We also, have some concerns that the undulators may be coupled together. This means that as we change one value, we maybe inadvertently change how other undulators effect the system. To gain some insight into this coupling problem, I'm using Genesis a simulator to look at how different undulators respond as their magnetic field changes. I varied undulates 17- 32 through five separate values measuring how the power at each individual undulator changed as a result. The preliminary results can be seen in figures 5, 6 and 7.

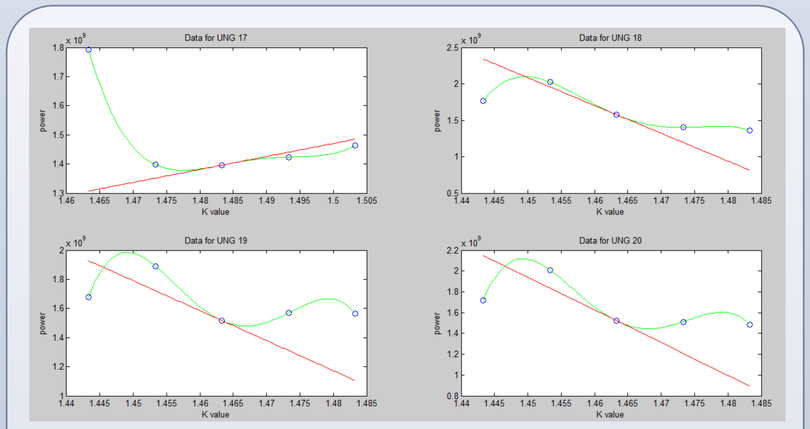

Figure 5: Graphs of how the power at an undulator as it is being changed through five values. The graphs are fitted by a fourth order polynomial. The red line is the tangent line to the third value.

16*16 zeroMat / 1E10

11.28983	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5.70025	0.91625	0	0	0	0	0	0	0	0	0	0	0	0	0
5.8085	6.39025	0.521917	0	0	0	0	0	0	0	0	0	0	0	0
5.8355	6.692	4.929	0.195667	0	0	0	0	0	0	0	0	0	0	0
5.91775	6.7985	5.007	5.5025	0.290083	0	0	0	0	0	0	0	0	0	0
5.99675	6.90825	5.1245	5.6645	5.57875	0.51075	0	0	0	0	0	0	0	0	0
6.12275	7.016	5.19475	5.808	5.72225	5.631	0.11225	0	0	0	0	0	0	0	0
6.21325	7.12075	5.278	5.897	5.841	5.7085	5.85475	0.025417	0	0	0	0	0	0	0
6.313	7.2395	5.3805	6.02225	6.0015	5.8115	5.96825	5.9075	0.27675	0	0	0	0	0	0
6.40275	7.33125	5.48725	6.133	6.19675	5.92325	6.0595	6.0095	6.024	0.097	0	0	0	0	0
6.484	7.407	5.56775	6.21925	6.3195	6.0395	6.12775	6.12525	6.1325	6.10675	0.1925	0	0	0	0
6.64325	7.5565	5.67575	6.29925	6.42075	6.1465	6.23975	6.245	6.296	6.2275	6.362	0.1005	0	0	0
6.7735	7.62	5.7665	6.41675	6.54675	6.2335	6.352	6.4245	6.44975	6.381	6.4855	6.32825	0.061667	0	0
6.8975	7.6835	5.85225	6.50675	6.67725	6.32625	6.485	6.5635	6.545	6.525	6.54125	6.42875	6.389	-0.11217	0
7.02925	7.76325	5.94825	6.60925	6.811	6.408	6.62125	6.72575	6.6235	6.65275	6.6555	6.546	6.4945	6.5655	0.012417
7.0675	7.7285	5.954	6.6115	6.90275	6.43	6.71	6.8095	6.69825	6.7315	6.7245	6.58675	6.54975	6.62225	6.596

Figure 6: 16 X 16 matrix of how the power at individual undulators change as a result of changing the value at other undulators. Represents ΔP / Δk of the system.

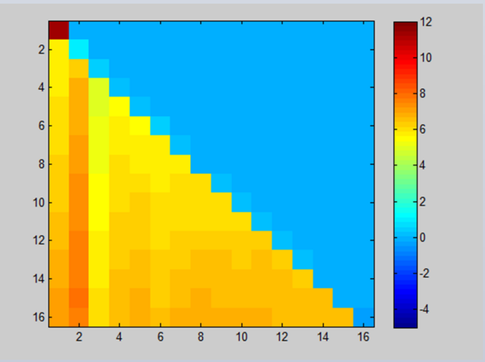

Figure 7: Color map of the 16 x 16 matrix seen in figure 6. Represents ΔP / Δk of the system.

Conclusion

Overall, this program for optimization needs to be further analyzed before it is suitable for use on any regular bases by the control room staff at SLAC. The results do show that some form of system operation could be implemented to lessen the set up time of an accelerator while still achieving a desirable high power output.

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