Advanced Methods of Klystron Phasing

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Introduction

The LCLS is powered, almost exclusively, by klystrons. In order to transfer the maximum amount of energy from the klystron's RF output to a beam pulse in the linac, klystrons must be at their optimal phases. Phasing klystrons is crucial to maintaining proper beam energy, yet the current method of doing so is time-consuming and tedious. Two alternative methods, extremum seeking and running fast phase scans, are analyzed and empirically shown to greatly reduce the time required to phase, to improve accuracy of collected phase-data, to be run noninvasively, and to phase multiple stations at once. One or both of these methods should provide invaluable applications for both LCLS I and LCLS II.

Keywords: LCLS, klystron, phase, extremum seeking, fast phase scans
Figure to the left: individual klystron; figure to the right: LCLS Klystron Gallery

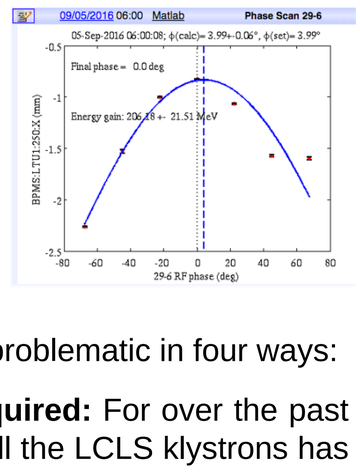
Background

The goal of research is to identify issues with the current phase-scanning method and to formulate new, applicable methods which negate those issues and improve performance.

Phasing klystrons involves trial and error: the phase shifter is manipulated to move the klystron's phase and then the phase value which provides the most energy to the beam is observed. Since the RF amplitude is a sine function, by moving the phase around, the energy downstream of the klystron will increase and decrease sinusoidally.

The figure to the right is an example of plotted data collected from a regular phase scan:

After the phase is set incrementally, there is a pause where multiple data points are collected and averaged corresponding to each data point. A line of best fit is then applied to determine maximum which corresponds to the phase providing maximum energy gain.



The current method is problematic in four ways:

1. Amount of time required: For over the past seven years, phasing all the LCLS klystrons has required approximately seven hours.
2. Lack of robustness and accuracy of data: Averaging data points and applying a line of best fit can be oversimplifying and misleading.
3. Invasive to the beam: During the scanning process, the phases of the klystrons are altered in such a way that the total beam energy is too far changed for experiments to simultaneously be running.
4. Tedious: Only one klystron can be scanned at a time.

Method 1: Extremum- Seeking

This process is noninvasive and modifies the phases of multiple klystrons at once using extremum seeking methods.

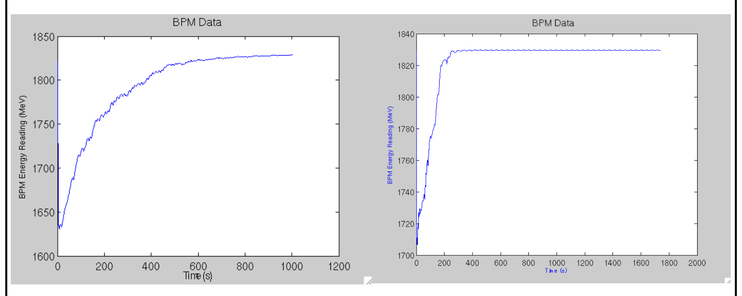
- Created EPICS simulations of each individual klystron and its beam energy contribution and of the total beam energy gain calculated by summing all klystrons' contributions.
- Created a MATLAB program implements the Update Law, as shown below, in order to iteratively modify the phases of each klystron simultaneously until the total beam energy is maximized.

The Update Law:

$$p_i(n+1) = p_i(n) + \delta_t \alpha_i \sqrt{\omega_i}\ \cos(\omega_i n \delta_t - k_i C(n)).$$

*p_i correspond to the phase of each klystron and C(n) is the value which is maximized (total beam energy), while the other parameters determine the quality (speed, noise, etc.) of convergence.
*Further discussion of can be found in Alexander Scheinker's *Nuclear Instruments and Methods in Physics Research A*

Results:



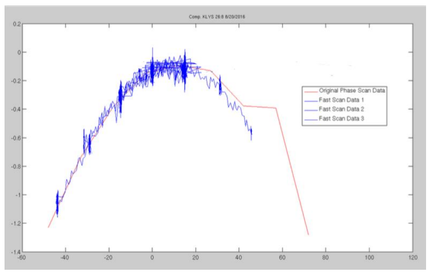
- Program assumes random initial phases with each run; the two plots correspond to two different program runs.
- Data converges consistently with each run in an average of ten minutes.

Method 2: Fast- Phase Scans

This process uses a MATLAB program to collect numerous and robust data points instantaneously as the phase shifter moves.

- Modified and analyzed fast phase scan MATLAB program.
- Ran program to scan phases for multiple klystrons.
- Compared phase data to original scans to determine accuracy.

Results:



- Above is one of the comparison plots of one klystron's fast and slow phase data
- New data includes numerous data points, is more robust, and is consistent and accurate
- New data does not include the same inconsistencies as original scan
- New data does include data bunches which indicate a pause in hardware. Such phenomena requires further exploration into the marriage of hardware and software. Eliminating the hardware pauses will allow scans to run in 23 seconds.

Problem Solving: Method Comparison

Solution	Method 1	Method 2
Amount of time to run phase klystrons is minimized	✓ Time was minimized to 10 minutes on average.	✓ Although further research is required, time can be minimized to 18 minutes without hardware pauses
Method is robust to noise, with a larger range of data	✓ Extremely robust to measurement noise, accuracy is high, data converges to a maximum consistently, and a large range of data is not required.	✓ More robust data collection, large range of data
Method is not invasive	✓ Gentle phase changes, noninvasive	Invasive
Multiple klystrons can be phased at once	✓ Multiple klystrons can be phased at once, an increase of klystrons being phased doesn't affect time to phase	Phases one klystron at a time

Conclusion

Both methods 1 and 2 offer significant improvements in klystron phasing. Overall, method 1, extremum seeking, is the most successful of the methods as it supplies a solution for each problem involving the original phase method. This method is especially applicable for LCLS II because increasing the number of parameters (phase data information per klystron) does not affect phasing speed. Future work for this project includes further research and documentation of the hardware behind the phase shifters of both LCLS I and LCLSII and creating MATLAB GUI(s) in order to make these methods more applicable and user-friendly.

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