Analysis Tools for Current Characteristics of Pulse-Forming Networks Driving High-Energy Flash Lamps

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1. Abstract

High-intensity flash lamps are used to excite laser glass amplifiers on the OMEGA and OMEGA EP lasers. These flash lamps are driven by high-energy current pulses created by pulse-forming networks in power-conditioning units (PCUs). The electrical current waveforms directly correlate to the laser output energy and hence can adversely affect the beamline gain. Analyzing and correlating flash-lamp current data can highlight trends that can help locate failures, predict potential failures, and provide information for preventive maintenance. In this work, Python programs were developed to analyze PCU diagnostic current data. The first program – a diagnostic information tool – calculates summary metrics from the current data stored for each laser system shot in the power conditioning database and compiles them into Excel files. With the files created by this program, the second program – a PCU health program – can display useful information for each PCU on a per-shot basis and summary metric trends over time.

2. Introduction

Currently, maintenance on the flash-lamp systems of the OMEGA and the OMEGA EP lasers is done in reaction to part failures. This approach is inefficient and requires extensive labor. This also results in failed laser shots and downtime on the laser. Developing software tools that use available data to predict part failures or determine when parts should be serviced is valuable because such software will decrease the downtime of the laser by indicating when maintenance for the flash-lamp systems is needed. Although most of the data analysis for this project was devoted to the OMEGA EP (extended performance) laser system, similar analysis routines can be easily applied to the OMEGA laser system.

The OMEGA EP laser system produces light pulses of kilojoule energies at picosecond widths, resulting in ultrahigh petawatt (10^{15} W) powers. The Omega EP beam lines consist of neodymium-doped glass excited by xenon flash lamps. The power conditioning system provides the high-energy pulses required to power the flash lamps. This involves converting ac power to high voltage dc, storing the energy in charge-storage capacitor banks, and delivering precisely timed high-current pulses to the flash lamps. The amplified laser beams can be delivered to targets within the OMEGA target chamber as well as an independent chamber within the OMEGA EP target area.[1] Each beamline includes a main amplifier containing 11 laser disk modules (shown in Figure 1) and a booster amplifier containing 7 laser disk modules. Since each laser disk module requires one power-conditioning unit (PCU), each beamline requires 18 PCUs, each of which powers the 36 flash lamps required for one laser disk module.

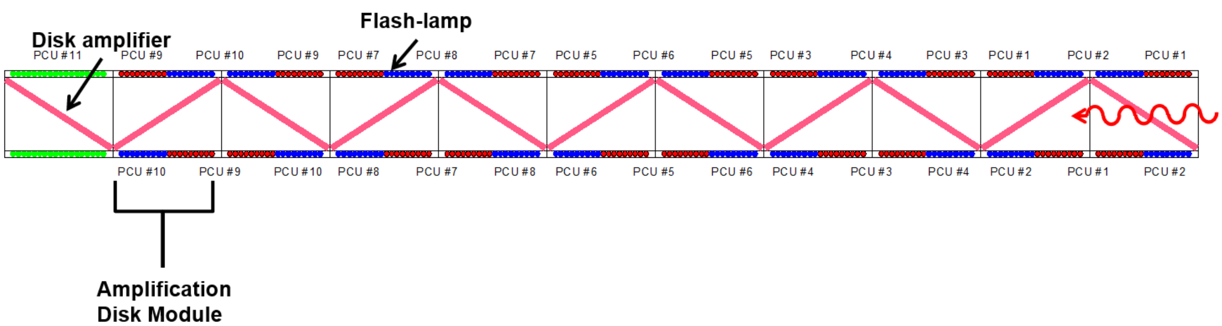

Figure 1: OMEGA EP main-amplifier configuration.

Figure 2 depicts a block diagram of a PCU, including the PCU control module (PCM), the waveform digitizer module (WDM), and charging, trigger, and switching circuits. There are two trigger generator modules: one for the pre–ionization and lamp check (PILC) and another to trigger the main pulse. Each PCU includes 12 pulse-forming networks (PFNs) that create the electrical pulse shape used to drive the flash lamps.

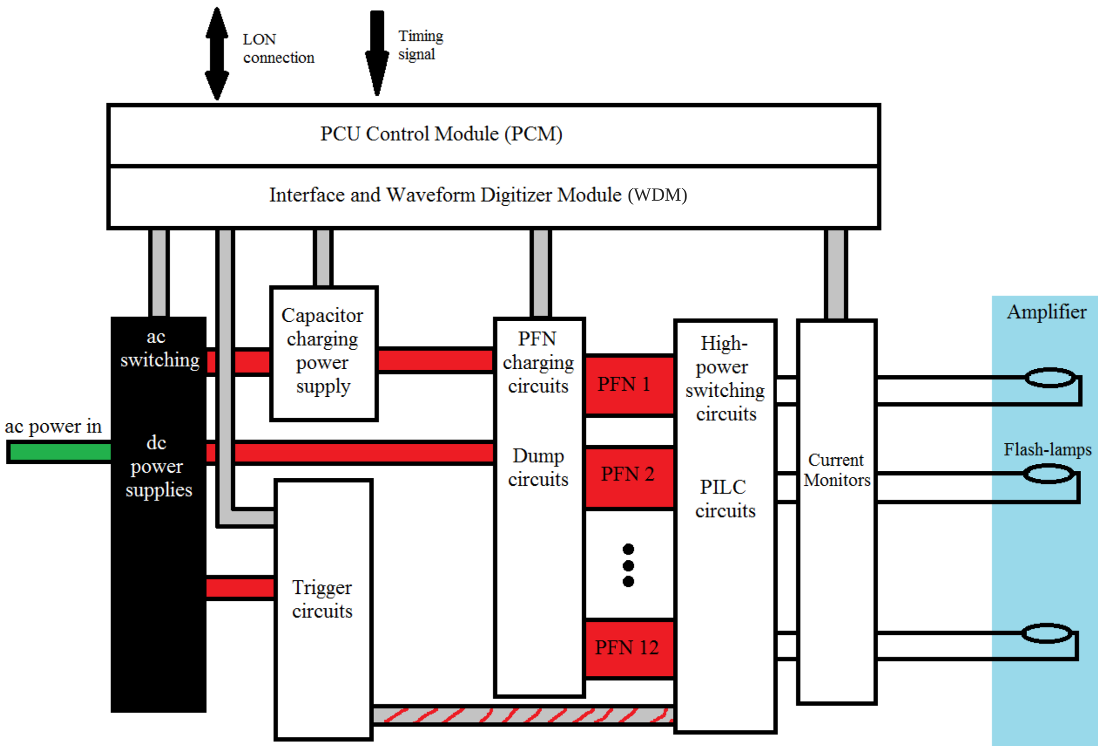

Figure 2: Power-conditioning unit (PCU) block diagram. Red represents power transfer, while grey represents control signals. ac power from the power grid enters the PCU and is converted to high voltage dc power, which charges the capacitors that provide the power for the pulse-forming networks (PFNs) and the trigger circuits used to initiate the pulses. A short time after a timing signal is received from the power control executive, the trigger circuits initiate the PILC (pre-ionization and lamp check) pulse, and then shortly thereafter the main pulse. The current through the PFNs is recorded by current monitors and sent to the Waveform Digitizer Module (WDM) for later analysis.

Once the PFNs are charged and a shot is about to occur, the power conditioning executive sends a timing signal to each PCU's PCM to synchronize their firings. Once the timing signal is received, the pre-ionization and lamp check (PILC) circuits discharge. This low intensity pulse determines if there have been any lamp failures and reduces the mechanical shock of the main pulse and x ray production from the rapid ionization of xenon. Approximately 250 microseconds after the PILC trigger is received, the main PFNs discharge as well. The primary purpose of the WDM is to digitize and store PFN current waveforms during the shot sequence (Figure 3). The WDM records the current for each of 15 assigned channels twice per microsecond. The 16^{th}

channel is reserved as a space for future development. After this, the residual stored energy is discharged through dump circuits, and the current data recorded by the WDM is sent to the power conditioning executive control program and exported to an Excel file. The data quantity per shot per PCU is very large and stored in a spreadsheet format. These large Excel spreadsheets typically comprise 16 columns, one for each of the 12 PFNs, the ground buss bar, and several other diagnostic signals. Each file has 6000 rows, one for each 500 ns spaced sample. The magnitude of these spreadsheets makes analyzing the data by hand an insurmountable task.

The current work involved the development of two computer programs. The first, a diagnostic information program, calculates useful summary metrics from the raw data recorded in the database. The second, a PCU health program, displays these metrics in a format that can be used to determine which PCUs or PFNs need servicing.

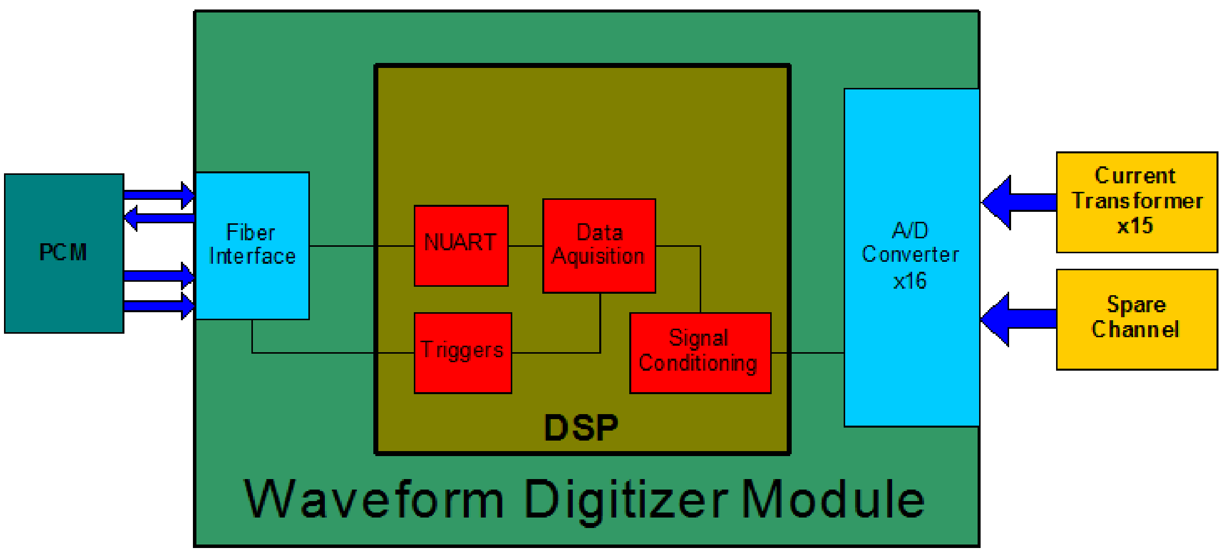

Figure 3: Waveform Digitizer Module (WDM) block diagram. The WDM uses analog-to-digital converters to sample the current from the 12 PFNs and several other parts in the PCU. This information is sent through digital signal processing (DSP) and travels to the PCM through a fiber interface. After each shot, the PCU control module (PCM) communicates the information with the power conditioning executive, and later stores the data acquired in Excel files.

3. Program Development

Python was selected as the primary programming language for its flexible packages and strong data analysis capabilities. The main packages used for data analysis were Pandas, NumPy, and Matplotlib. Pandas is a well-rounded data manipulation package, and interfaces well with the other two packages used for data analysis. NumPy supports large, multidimensional arrays and matrices, and hosts a suite of high-level mathematical functions to operate on these structures. Matplotlib produces quality graphs that are easily embedded in the graphical user interface (GUI). Tkinter was selected for its simplicity and functionality and was used to make the GUIs for the two programs.

4. Data Analysis

Every time a shot is performed on OMEGA or OMEGA EP, the records of all the gathered data are stored in LLE's databases which can then be accessed for analysis. The Excel files produced from the WDMs' data are stored on the LLE network drive Redwood. While these files are typically 16 columns by 6000 rows, their length depends on whether the shot was successful or not. Lamp failures or other circuit components breaking can result in shortened data recording or atypical waveforms. Some shots are PILC only and are used for diagnostics of the systems. These shots also result in atypical pulse shapes. Such shots are ignored by the diagnostic information program. Figure 4 is a plot produced by the PCU health program for a successful shot, showing a typical PFN current waveform with definitions of the summary metrics (the time from the trigger firing to the peak current, the magnitude of the peak current, and the width of the peak when it is at one-third of its maximum current).

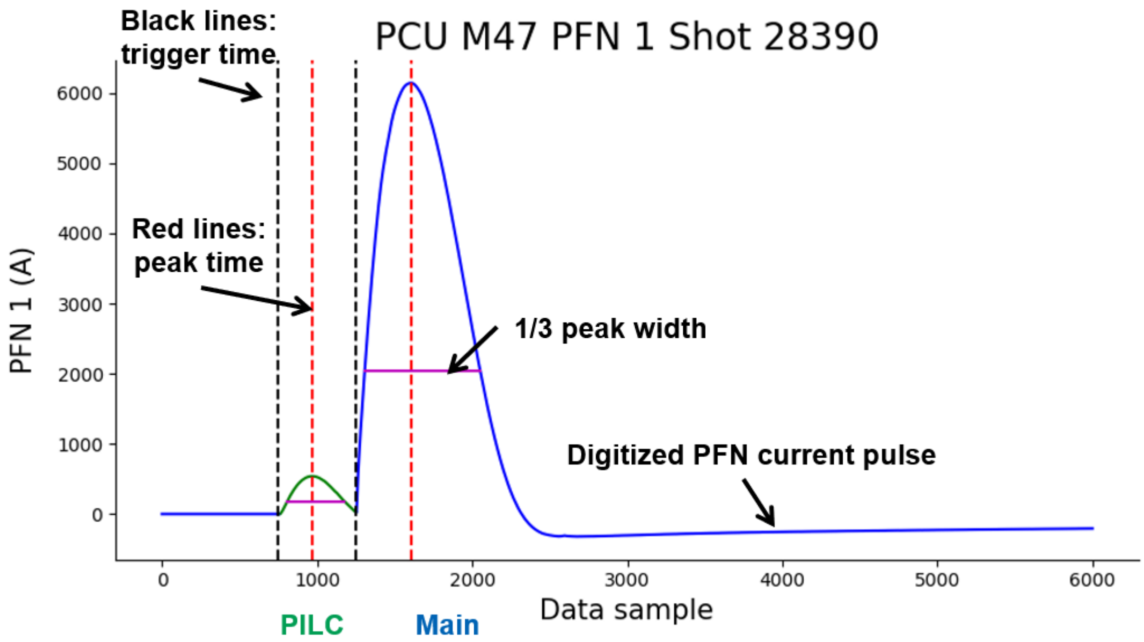

Figure 4: Typical shot waveform. The small green peak is the PILC (pre-ionization and lamp check) pulse, while the large blue one is the main pulse. The two dotted black lines show the times of the triggers for the PILC and the main pulse, while the two dotted red lines show the time of the peaks for each pulse. The time to peak is the distance between these two values for each pulse. The peak current is the highest value for each pulse. The solid horizontal purple lines show the 1/3 width measurement, which is the width of the curve at 1/3 of its peak current.

5. Programs developed

When launched, the diagnostic information program GUI prompts the user to select the PCUs to calculate summary metrics for. The diagnostic information program then retrieves the requested data from the Redwood database and calculates the summary metrics for every successful shot in that PCU. The calculated metrics are stored in an Excel file, which contains the peak current, time from the trigger to the peak, and width of the curve at a third of its peak current for each PFN. Failed shots are left out of the final output and are reported in an error log text file.

When launched, the PCU health program prompts the user to input the Redwood folder (for single-shot information), and the folder containing the files produced by the diagnostic information program (for long-term trends). The single-shot metrics page allows the user to see waveforms and summary metrics for specific shots, and to see how each PFN performed compared to the PCU's average (Figure 5). This comparison is useful because the most underperforming PFN is likely the one that needs servicing. While the single-shot page can graph failed or PILC-only shots as well, it does not enable metrics to be calculated for those shots.

Figure 5: Single shot metrics. The user inputs the PCU, shot number, and PFN number, and the program graphs the waveform. For the selected shot, it also displays each PFN's percent deviation from the PCU's average peak current.

The PCU health program also features long-term trend plotting to show how pulse metrics are changing over time for PCUs or PFNs. As shown in Figure 6, using the summary metrics calculated by the diagnostic information program, the GUI can display trends in any of the three summary metrics for either specific PFNs or PCU averages. This information can be plotted over any date range or shot number range the user selects and can be used to give a good overview of how PFN health is changing over time. This can be used to help technicians choose when to perform maintenance on PCUs and trends can be studied to mitigate future degradation.

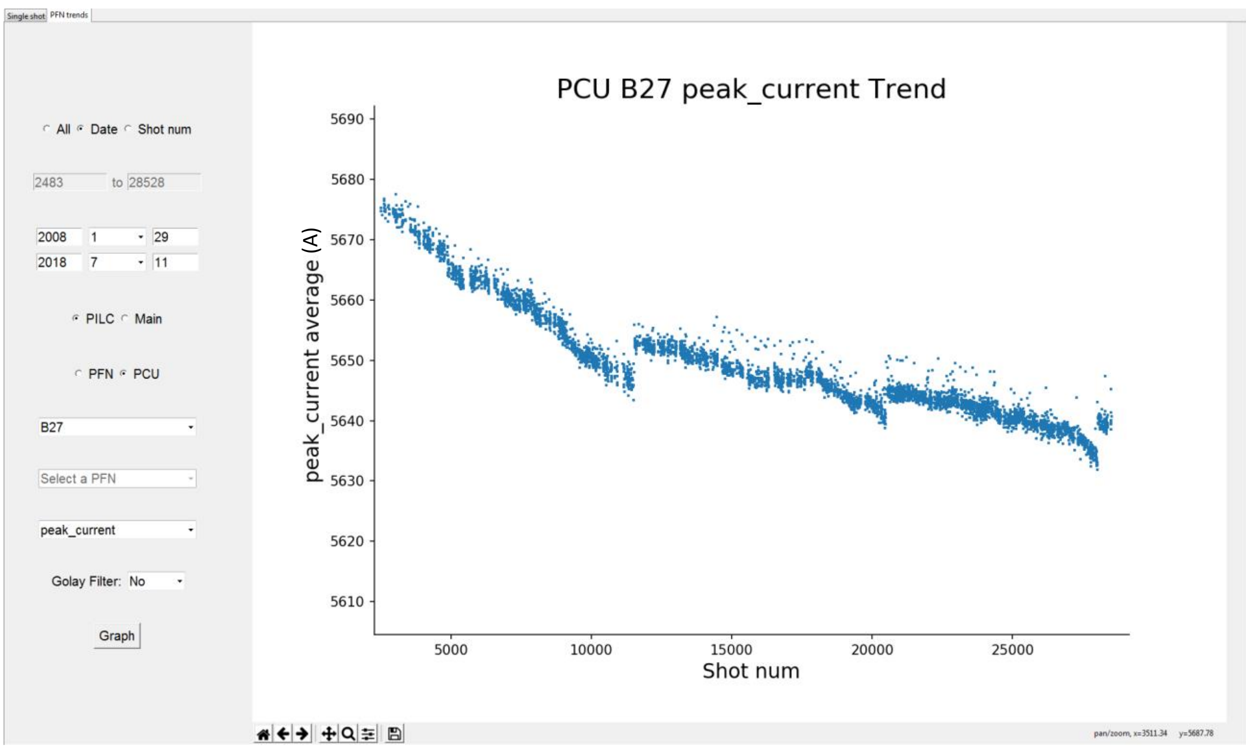

Figure 6: Long-term trend panel. The graph is interactive, and can be plotted for different PFNs, PCUs, date ranges, and statistics.

6. Conclusion

Python programs were developed that analyze PCU diagnostic data to help technicians determine when preventative maintenance is required. Using the current data stored after each shot in the power conditioning database, the diagnostic information program calculates summary metrics and compiles them into Excel files. The PCU health program reads these files and displays useful information on a per-shot basis and summary metric trends for multiple shots over time. Its easy-to-use GUI can help technicians decide which PFNs need to be serviced. Future development could expand on this functionality by allowing the program to automatically predict when critical failures could occur. With more diagnostic information and further development, such programs could replace the current reactive maintenance approach with a predictive preventative maintenance approach that would greatly increase the operational efficiency of the laser system.

7. Acknowledgements

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8. References

[1] University of Rochester - Laboratory for Laser Energetics. OMEGA Power Conditioning - Laboratory for Laser Energetics, www.lle.rochester.edu/omega_facility/omega_ep/.