PREDICTED PULSED-POWER/FLASH-LAMP PERFORMANCE OF THE NIF MAIN AMPLIFIER+

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Abstract

The laser glass for the National Ignition Facility (NIF) Main Amplifier system is pumped by a system of 192 pulsed power/flash lamp assemblies. Each of these 192 assemblies consists of a 1.6 MJ (nominal) capacitor bank working with a Pre-Ionization/Lamp Check (PILC) pulser to drive an array of 40 flash lamps.

This paper describes the predicted performance of these Power Conditioning System (PCS) modules in concert with flashlamp assemblies in NIF. Each flashlamp assembly consists of 20 parallel sets of lamps in series pairs.

The sensitivity of system performance to various design parameters of the PILC pulser and the main capacitor bank is described. Results of circuit models are compared to sub-scale flashlamp tests and to measurements taken in tests of a PCS module driving a flashlamp assembly in the First Article NIF Test Module facility at Sandia National Laboratories. Also included are predictions from a physics-based, semi-empirical amplifier gain code.

I. INTRODUCTION

The National Ignition Facility is presently being built at the Lawrence Livermore National Laboratory (LLNL). The pulsed power system for the Main Amplifier and Power Amplifier has been designed by Sandia National Laboratories, Albuquerque, with support by Maxwell Physics International. A First Article NIF Test Module (FANTM) is under test at Sandia. The design features of the module and results of tests at Sandia are described in a companion paper[1].

The large-aperture amplifier of the National Ignition Facility laser is divided into two systems, the Main Amplifier and the Power Amplifier. The flashlamp assemblies in these amplifiers are driven by 192 Power Conditioning System modules. Each PCS module, shown in Figure 1, can house up to twenty-four 300 µF, 24 kV capacitors. In the baseline configuration, only twenty capacitors will be installed.

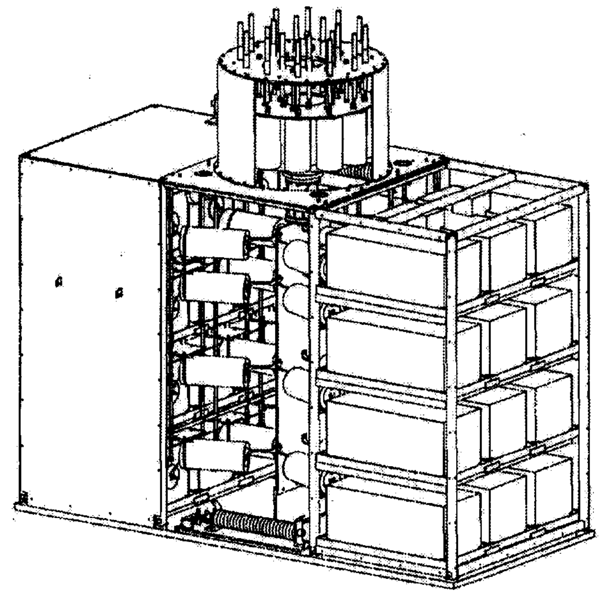

Figure 1. View of uncovered 24 capacitor PCS module.

Each PCS module drives a flashlamp assembly containing twenty series pairs of flashlamps. The lamps are pre-ionized by a pulse from a Pre-Ionization/Lamp Check pulser approximately 300 µs prior to the arrival of the main current pulse from the PCS module. A simplified circuit schematic of the system is shown in Figure 2.

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14. ABSTRACT
The laser glass for the National Ignition Facility (NIF) Main Amplifier system is pumped by a system of 192 pulsed power/flash lamp assemblies. Each of these 192 assemblies consists of a 1.6 MJ (nominal) capacitor bank working with a Pre-Ionization/Lamp Check (PILC) pulser to drive an array of 40 flash lamps. This paper describes the predicted performance of these Power Conditioning System (PCS) modules in concert with flashlamp assemblies in NIF. Each flashlamp assembly consists of 20 parallel sets of lamps in series pairs. The sensitivity of system performance to various design parameters of the PILC pulser and the main capacitor bank is described. Results of circuit models are compared to sub-scale flashlamp tests and to measurements taken in tests of a PCS module driving a flashlamp assembly in the First Article NIF Test Module facility at Sandia National Laboratories. Also included are predictions from a physics-based, semi-empirical amplifier gain code.

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The effective circuit values for the PCS module, including the set of output cables, but not the flashlamps, are:

C = 6.24 mF   R = 5.42 mΩ   L = 2.05 µH

The set of flashlamps provides a critically-damped load for the PCS module.

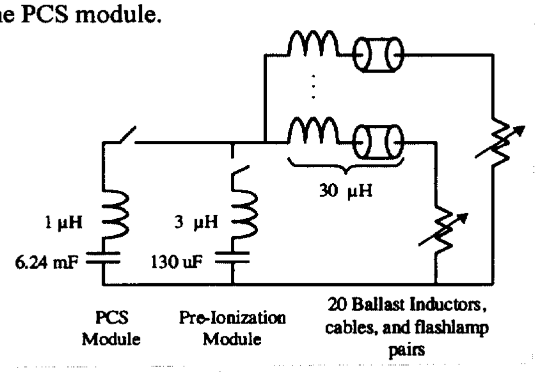

Figure 2. Simplified Circuit showing a PCS Module and PILC driving flashlamp loads, for the 20-capacitor PCS.

II. SYSTEM REQUIREMENTS

Performance requirements for the PCS module and the PILC pulsers are derived from performance requirements for the Main Amplifer and Power Amplifier modules given in Table 1. These requirements flow down into the PCS module pulsed power requirements given in Table 2.

Table 1. Amplifier performance requirements that drive the PCS and PILC requirements

Average Gain Coefficient (AGC)	≥ 5.0%/cm at ≤ 24 kV charge
Shot-to-shot variability	≤ ±1% in peak current (into reproducible load)
Cable-to-cable variability	≤ ± 3% in peak current (into reproducible load)

Table 2. PCS module pulsed power requirements

Module peak power to lamp set	≥ 300 MW
Power pulse width (10% points)	≤ 390 µs
Peak current (total)	≥ 490 kA
Peak current per lamp pair	≥ 24.5 kA
Energy per lamp pair	≥ 70 kJ
Shot-to-shot peak current variability	≤ ± 1%
Cable-to-cable peak current variability	≤ ± 3%
Pulse-to-pulse &unit-to-unit jitter	≤ 1 µs

III. PREDICTED PERFORMANCE

Performance of the PCS modules in concert with the flashlamp assemblies has been predicted by a combination of computer modeling and prototype tests. The models were baselined against pre-prototype systems and predictions were compared to the performance of the FANTM system operating with a flashlamp load. The only significant departure of measured FANTM performance from the model is in the dynamic resistance profile of the flashlamps.

A. Flashlamp Resistance

Measured flashlamp resistance shows a significant hysteresis that has not been included in the load resistance model. This hysteresis reduces the peak current and prolongs the time to peak current. However, it does not significantly alter the energy delivered to the lamps. From a circuit performance standpoint, it behaves very much like an additional series inductance of 12 µH per lamp set.

A comparison between the predictions of a detailed PSpice model and measurements on the FANTM facility are shown in Figures 4 through 6 and Table 3. In this circuit model, 12 µH has been added to the physical inductance of each channel, to simulate the hysteresis of the lamps. When the system is used to drive a simple resistive load, a very good match is achieved without the added inductance.

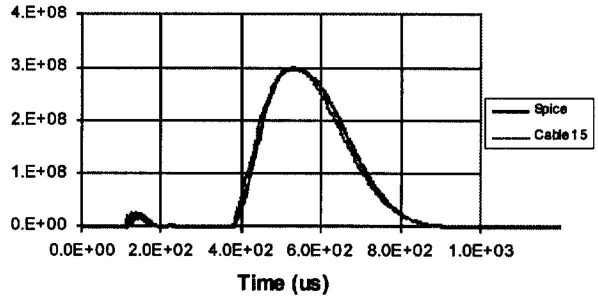

Figure 4. Modeled and measured power pulses

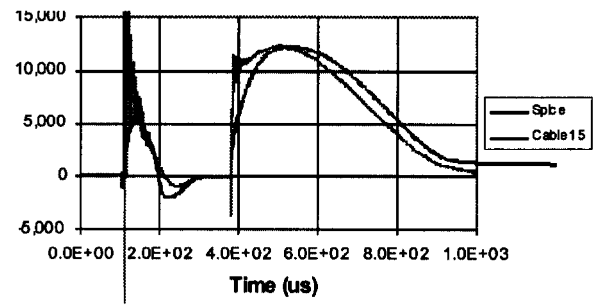

Figure 5. Modeled and measured voltage pulses

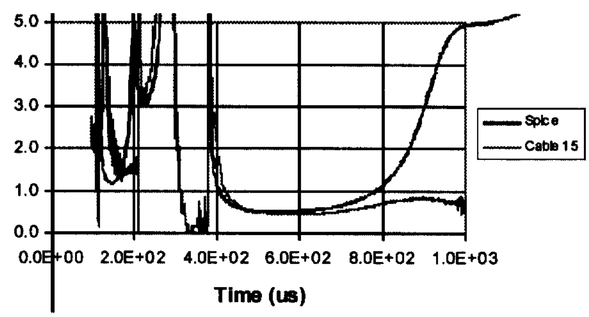

Figure 6. Modeled and measured flashlamp resistance

Measured flashlamp resistance departs significantly from the Spice model late in time. The current-dependent resistance of a series pair of lamps is modeled as

$$R = 78.7/I^{1/2}$$

This accurately predicts the minimum resistance value and the general profile, until the current begins to fall after the main pulse. The actual lamp resistance remains low for a considerable time, as the temperature and ionization of the gas in the lamp are still quite high.

B. Amplifier Gain

The key performance parameter in the system is, of course, amplifier gain. Amplifier gain is being predicted through the use of a computer code developed by LLNL[2]. The code uses the flashlamp power pulse to predict the "Average Gain Coefficient" or AGC. The AGC predicts the gain coefficient averaged over the set of flashlamps and the laser glass of the amplifier segment driven by a single PCS module, and includes such laser effects as Amplified Spontaneous Emission, which reduces gain when the power pulse is prolonged. The code has been benchmarked against the performance of several systems at LLNL, including the Beamlet Amplifier and AmpLab.

Since the measured power pulse at FANTM matches well with the PSpice model results (after the added inductance to model the hysteresis), it should be no surprise that the AGC inferred from FANTM tests matches well with the predicted results, as shown in Table 3.

Table 3. Modeled and measured performance

	Model	FANTM
Module peak power	299 MW	300 MW
Power pulse (10% points)	392 µs	390 µs
Peak current per lamp pair	24.4 kA	24.6 kA
Energy per Lamp Pair	74.6	73 kJ
Average Gain Coefficient	5.05 %/cm	5.02 %/cm

C. Reproducibility and Reliability

Shot-to-shot reproducibility of the peak current is well within the ± 1% requirement, as shown in Figure 7. The early "drop outs" and the shift near shot 500 were produced by modifications of the PILC circuit. From shot 500 through shot 1200, all parameters were held constant, resulting in very good reproducibility.

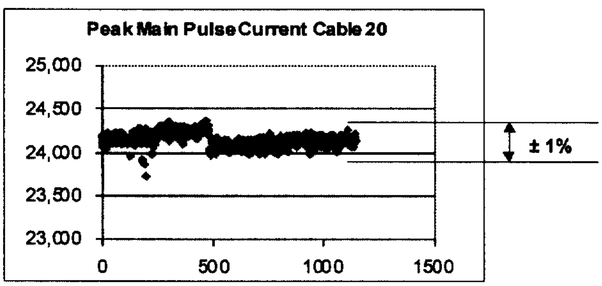

Figure 7. Pulse current reproducibility meets specifications.

Measured cable-to-cable reproducibility was ± 3.1%, slightly poorer than the specified ± 3%. However, more than half the variability was due to variability in the lamp resistance profiles. An example of the resistance profile variability is shown in Figure 8.

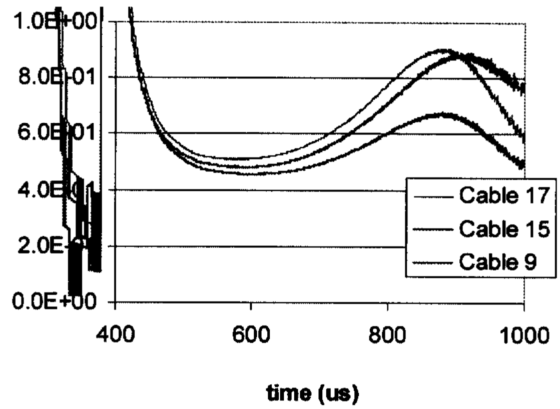

Figure 8. Variations in the resistance profiles for three lamp pairs.

IV. SENSITIVITY TO DESIGN PARAMETERS

A. PCS Module Energy and Series Resistance

In the parameter range of interest, system gain is nearly linearly proportional to energy delivered to the flashlamps, and is weakly dependent on peak power, with gain being slowly reduced as pulses get longer. Flashlamp energy is, of course, dependent on the energy stored in the PCS module and that lost in series resistance.

Figure 9 shows AGC inferred from power pulse measurements on FANTM, with 20, 21, 22, 23, and 24 capacitors at a range of voltages.

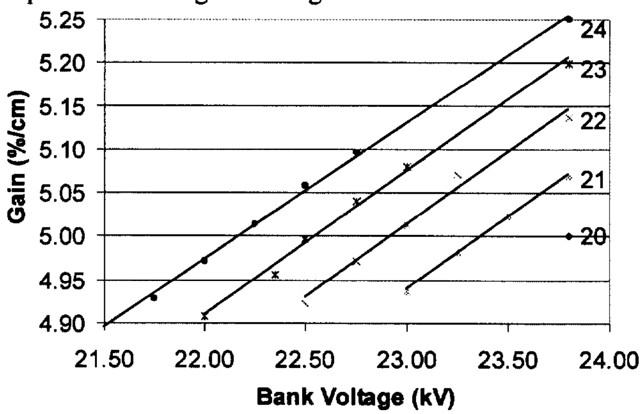

Figure 9. Gain scaling with PCS bank voltage, for a range of charge voltages and from 20 to 24 capacitors.

B. PILC Timing and Energy

The PILC energy was held constant while the delay between the pre-ionization pulse and the main trigger was swept from 100 µs to 600 µs. The sweep was repeated at two different pre-ionization energies: 25 kV DC charge, giving ≈533 J/lamp; and 28.5 kV DC charge, giving ≈648 J/lamp. The optimum delay is 300 µs – 400 µs. Note that with more pre-ionization energy/power that the fluorescence remains closer to its peak value for a greater range of delays.

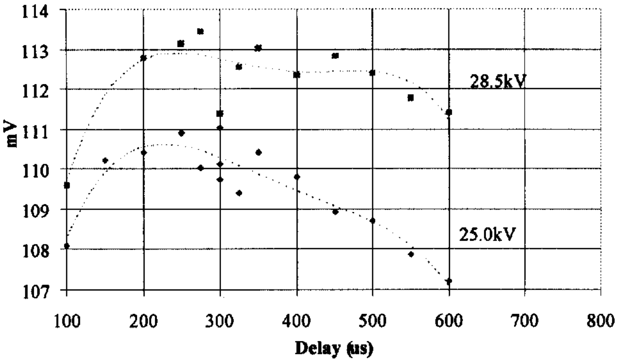

Figure 10. Fluorescence vs PILC delay for two PILC charge voltages.

In a separate test, the pre-ionization pulse to main trigger timing was held constant while the DC charge voltage on the PILC bank was swept from 20.2 kV to 30 kV. This is a range of 390 to 700 Joules per lamp. The sweep was repeated at two different pre-ionization to main trigger delays; 300 µs and 400 µs. Fluorescence increases rapidly with PILC energy/power up to a charge voltage of 25 kV, at which point there is very little improvement in performance. This equates to a minimum acceptable PILC bank energy of about 550 J. The preferred operating point would appear to be about 28.5 kV or about 650 J. This would provide some margin for variations in pre-ionization energies.

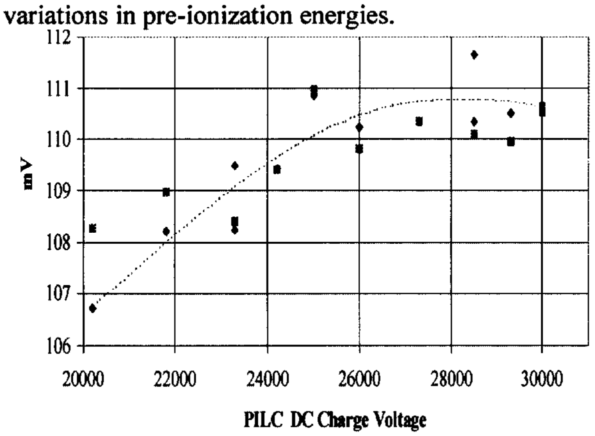

Figure 11. Fluorescence vs PILC charge voltage

V. SUMMARY

Measurements made during tests of the FANTM module have confirmed the basic predictions of the NIF performance models, and have allowed a further refinement of the models, particularly in the area of the hysteresis of the flashlamp resistance profile. Based on the modeling and FANTM tests, we are confident that the planned Power Conditioning System will meet its requirements, and will thus assure that the NIF large-aperture amplifier will meet all requirements.

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VII. REFERENCES

[1] David L. Smith, et. al., "FANTM: The First Article NIF Test Module for the Laser Power Conditioning System" in the proceedings of the 12th IEEE Pulsed Power Conference, 1999.

[2] H. T. Powell, A. C. Erlandson, K. S. Jancaitis and J. E. Murray, "Flashlamp Pumping of ND:Glass Disk Amplifiers," SPIE 1277, p103 (1990)