UCRL-JC-124376
PREPRINT

CONF-9610225--2

Power Conditioning Development for the National Ignition Facility

M. A. Newton, D. W. Larson
Lawrence Livermore National Laboratory

J. M. Wilson, H. C. Harjes, M. E. Savage
Sandia National Laboratory

R. L. Anderson
American Controls Engineering

This paper was prepared for submittal to
Solid State Lasers for Application to Inertial Confinement Fusion (ICF)
2nd Annual International Conference
October 22-25, 1996
Paris, France

October 18, 1996

Lawrence Livermore National Laboratory

DISCLAIMER

Power Conditioning Development for the National Ignition Facility

M.A. Newton, D.W. Larson
Lawrence Livermore National Laboratory
Livermore, California 94550

J.M. Wilson, H.C. Harjes, M.E. Savage
Sandia National Laboratory
Albuquerque, New Mexico, 87185

R. L. Anderson
American Controls Engineering
San Diego, California, 92126

ABSTRACT

The National Ignition Facility (NIF) is a high energy glass laser system and target chamber that will be used for research in inertial confinement fusion. The 192 beams of the NIF laser system are pumped by over 8600 Xenon flashlamps. The power conditioning system for NIF must deliver nearly 300 MJ of energy to the flashlamps in a cost effective and reliable manner. The present system design has over 200 capacitive energy storage modules that store approximately 1.7 MJ each and deliver that energy through a single switch assembly to 20 parallel sets of two series flashlamps. Although there are many possible system designs, few will meet the aggressive cost goals necessary to make the system affordable.

Sandia National Laboratory (SNL) and Lawrence Livermore National Laboratory (LLNL) are developing the system and component technologies that will be required to build the power conditioning system for the National Ignition Facility. This paper will descibe the ongoing development activities for the NIF power conditioning system.

Keywords: National Ignition Facility, NIF, power conditioning, capacitors, energy storage, high power switches, laser

1. DESCRIPTION OF POWER CONDITIONING SYSTEM

The NIF power conditioning system supplies the electrical energy that drives the 8640 flashlamps that pump the neodymium glass in the NIF laser. The power conditioning system must perform a number of functions to insure reliable and efficient operation of the flashlamps including triggering and pre-ionization of flashlamps, delivery of equal current to parallel flashlamp circuits and protection of system in the event of a catastrophic flashlamp failure. Each flashlamp requires nominally 34 kilojoules of energy to be delivered in a 360 μsec pulse. Approximately 100 μs prior to this main pulse, a pre-ionization pulse of 500 joules per flashlamp must be delivered to the flashlamps.

The main pulse energy is initially stored in 216, 1.7 MJ capacitor modules that operate simultaneously but independently of each other. A block diagram of an individual module is shown in figure 1. The energy of each module is switched into 20 coaxial cables that deliver the module energy to 20 series pairs of flashlamps. The specifications for a single NIF module are shown in table 1.

*Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

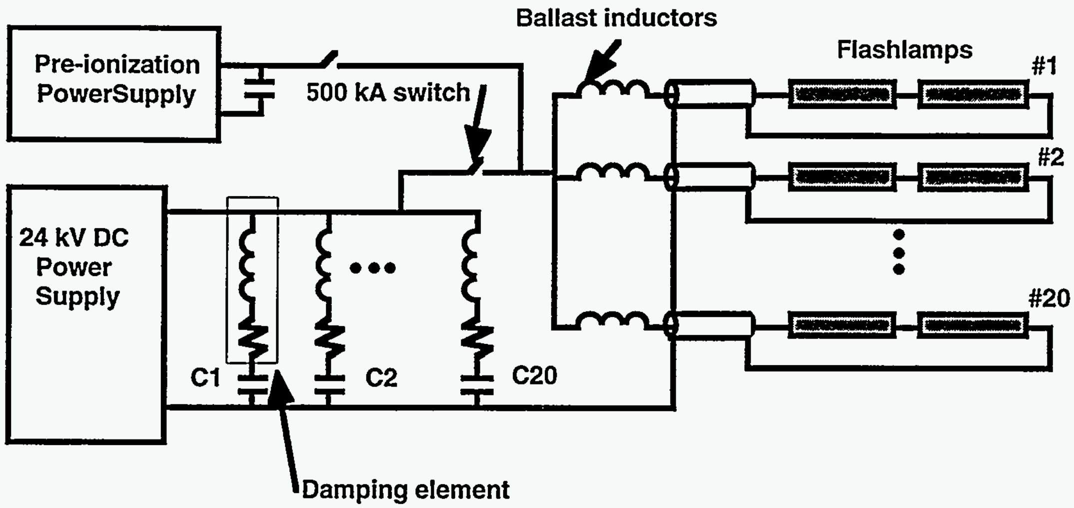

Figure 1. Block diagram of an individual module of the NIF power conditioning system.

System specifications/description	
Total energy storage	367 MJ
Number of modules	216
Module specifications/description	
Energy Storage	1.7 MJ
Operating voltage	23.5 kV
Output pulse duration	360 µs
Peak switch current	500 kA
Load	40 flashlamps
Lifetime	20,000 shots

Table 1. System and module specifications for NIF power conditioning system.

The architecture of the power conditioning system for NIF was chosen to reduce cost over past laser systems such as NOVA and Beamlet by partitioning energy into larger quantities. Unlike NOVA and Beamlet where individual PFNs drive pairs of flashlamps, in the NIF power conditioning system, all of the energy storage capacitors are in parallel, separated only by resistive inductors called damping elements. The risk of catastrophic faults is considerably higher because the energy storage elements are partitioned in much larger quantities of energy. This places a greater burden on component designs to insure robust operation and reliability.

In addition, the larger partitioning of energy increases the amount of energy that must be controlled by a single switch assembly. The switch requirements for these 1.7 MJ modules exceeds present capabilities in high power switching. As shown in table 1, the switch must be able to conduct 500 kA for 360 µs. The NIF power conditioning development program is addressing the switch issue, as well as other issues that are important for the design and implementation of the NIF power conditioning system.

2. DEVELOPMENT PROGRAM

The NIF power conditioning development effort is focused in three primary areas, switch development, component development and system development. Responsibility for these development activities is shared between Sandia National Laboratory (SNL) and Lawrence

DISCLAIMER

Livermore National Laboratory (LLNL). The following sections will describe development efforts in these areas.

Switch Development

The switching requirements for the NIF power conditioning modules are very demanding. A switch that can conduct a 500 kA, 360 μsec pulse reliably for 20,000 shots at a reasonable cost does not presently exist. Initially a wide spectrum of switch technologies will be tested and evaluated. After initial testing, we will focus on a smaller subset of the switches which demonstrate the most promising results. Presently we are in the intial test and evaluation phase where we are investigating the candidate technologies that are shown table 2.

The testing and evaluation of NIF switches requires a large test facility that can reliably operate at a maximum of 24 kV and 500 kA for $>10^6$ shots. In addition, this test facility needs to be flexible enough to test switches at 12 kV and 500 kA and at 24 kV and 250 kA. A switch test stand with this capability was built at Sandia National Laboratory in Albuquerque. The test stand, shown in figure 2, is conservatively designed with capacitors that are operating at half their design operating voltage. A modular design was adopted to achieve the flexibility needed to test switches at the different combinations of voltage and current. A typical test current waveform at full output is shown in figure 3.

Candidate Switch Technologies
Ignitrons
Spark gaps
Pseudosparks
Vacuum switches
SCR/GTOs
RSDs
Low pressure switches

Table 2. List of candidate switch technologies to be tested at Sandia switch test facility.

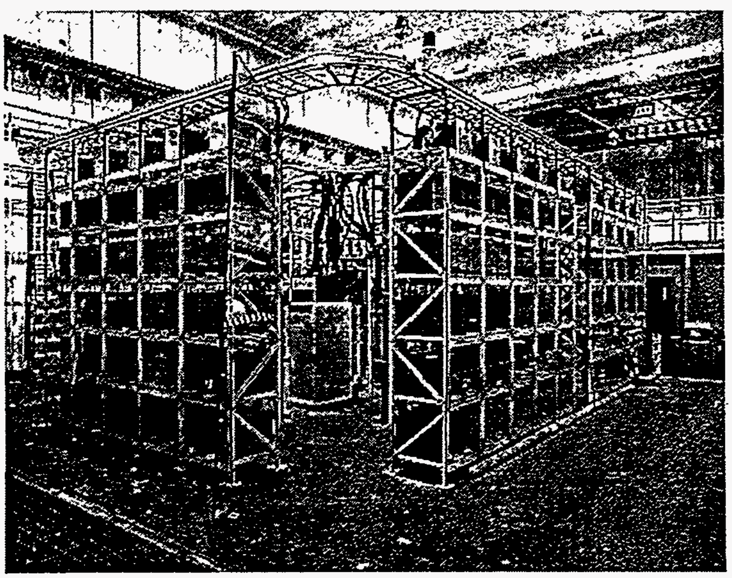

Figure 2. Photograph of NIF Switch Test Facility at Sandia National Laboratory (Albuquerque)

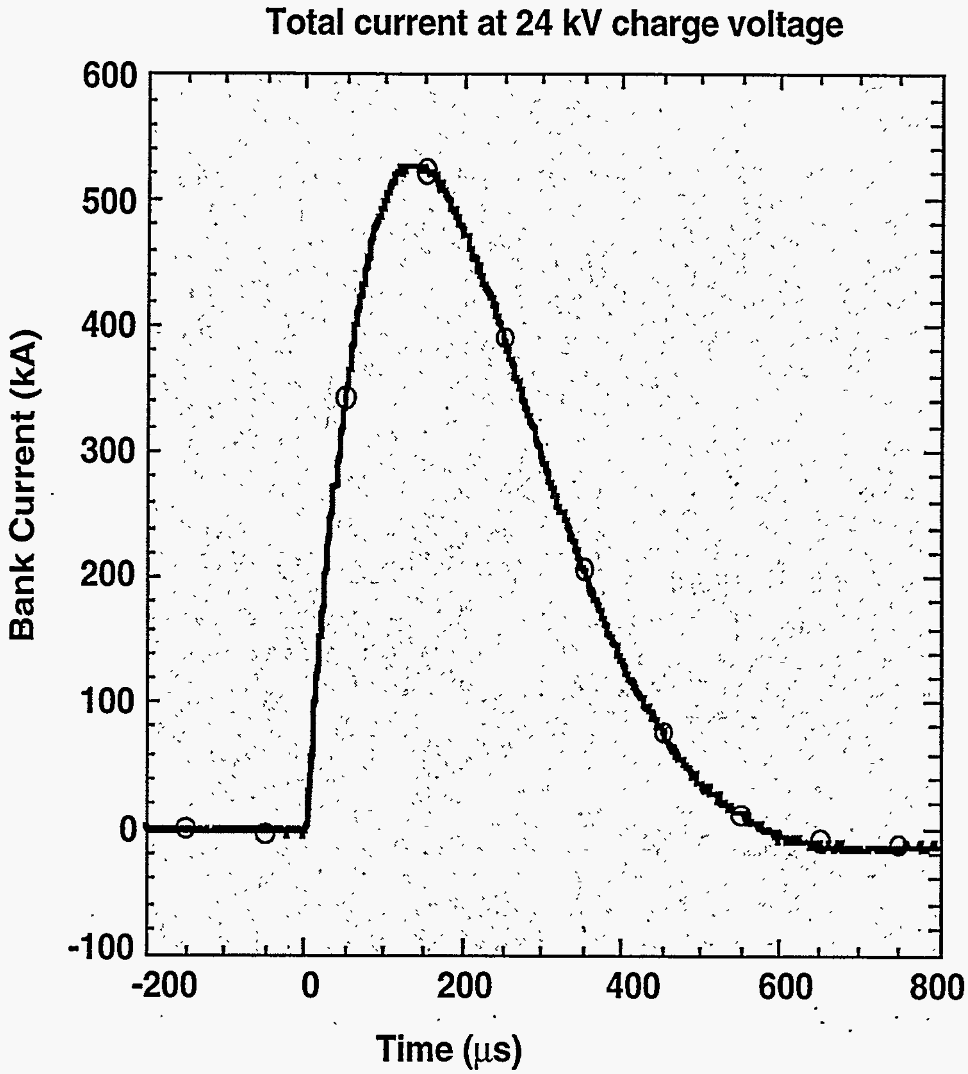

Figure 3. Full current waveform with peak current of 525 kA from SNL switch test facility.

Component Development

The design of components that make up the NIF power conditioning system must balance the conflicting needs for long term operation and reliability against low cost. This requires a very thorough understanding of the component requirements in normal operation as well as during all possible fault modes[1]. This thorough understanding enables the minimization of safety margin and cost in the power conditioning component designs. A thorough testing and development program is necessary to make these careful tradeoffs between cost and performance.

We have contracted with American Controls Engineering (ACE) in San Diego, CA to design and test the power conditioning system components under both normal and fault conditions. A test facility was built at ACE that is electrically very similar to a NIF module, although it is physically different. A photo of the test bank is shown in figure 4.

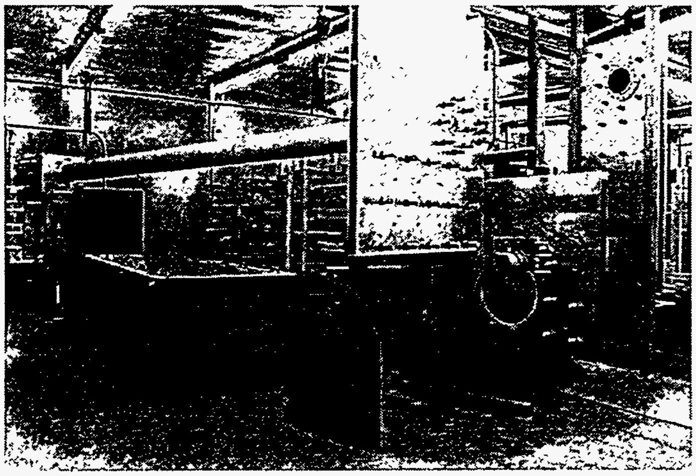

Figure 4. Capacitor module at ACE used for component testing and design validation.

ACE is conducting a wide variety of characterization and evaluation tests on many different components in the system including damping elements, transmission lines, schrapnel containment structures, rack structures, buss structures and flashlamps. Data from these tests is used to optimize the design of the various components as well as the system.

The NIF power conditioning system will require over 4000, 290 μF metalized dielectric capacitors. We are presently working with multiple capacitor manufacturers to develop low cost, reliable capacitors for NIF. Capacitors are procured from the various vendors, thoroughly tested and returned to the manufacturer for evaluation. The capacitors are tested to the NIF specification, including both normal operating parameters as well as fault conditions.

The capacitor test facility at LLNL is presently being expanded to 24 stations. The capacitors under test will be charged to 23.5 kV in a maximum of 60 seconds and discharged in 360 μsec using NL-8900 ignitrons. The discharge is nominally 25 kA with a maximum 10% current reversal. Each capacitor is tested to end of life or to the specified lifetime of >20,000 shots, which ever comes first.

System Development

Another very important component of the NIF power conditioning development effort is the validation of the system design. This requires the contruction and operation of a complete prototype NIF capacitor module that is electrically and physically similar if not identical to the proposed NIF system.

Sandia National Laboratory is building a prototype of a single module of the NIF power conditioning system. This prototype will eventually include all components of the power conditioning system operating into a flashlamp load. The first phases of the prototype construction has just recently been completed and is shown in figure 5. Testing has begun on a capacitor module of 20, 290 μF capacitors with ACE designed damping elements in series with each capacitor. The 1.7 MJ capacitor module is discharged with a self-breaking spark gap into a dummy load. The output current waveform shown in figure 6.

The next phases will inlude the addition of pre-ionizing hardware, embedded controls, a transmission line system with ballast inductors and a flashlamp load.

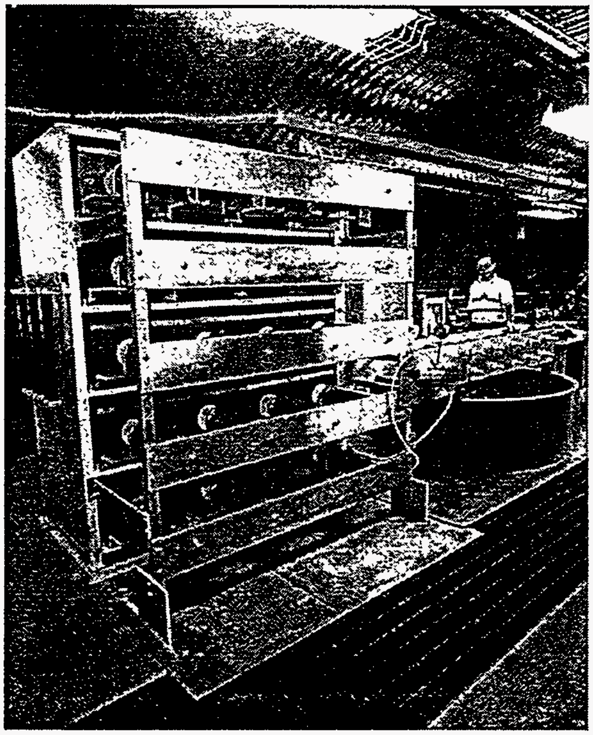

Figure 5. First phase of NIF prototype at SNL

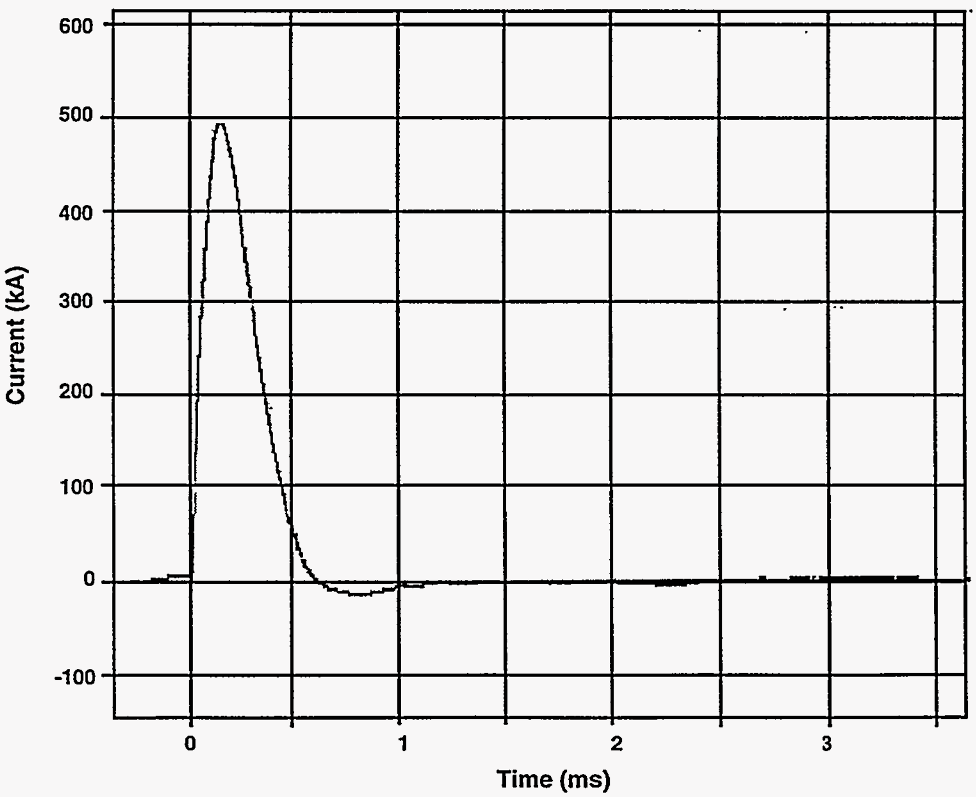

Figure 6. Output current waveform of initial phase of NIF protoype module at SNL.

3. Summary

The NIF power conditioning system is a very large system of capacitive energy storage elements. Although simple in concept, the system design requires careful attention to the details of component and system design in order to meet the very aggressive cost goals. A very comprehensive development effort in power conditioning is essential to the success of NIF. We have assembled an array of test facilities that will validate almost every aspect of the NIF power conditioning system design before construction.

4. Acknolwedgements

The power conditioning development effort is a joint effort between LLNL and SNL. The author wishes to thank the support staff at both laboratories for their contributions to this development program.

5. References

D. Larson, R. Anderson, J. Boyes, "Fault Tolerance of the NIF Power Conditioning System", *Proceedings of the First Annual Conference on Solid State Lasers for Application to Inertial Confinement Fusion,* M. André, H. T. Powell, Vol 2633, pp 587-595, SPIE, Bellingham, WA 1995.