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NOVA PULSE POWER SYSTEM DESCRIPTION AND STATUS
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Summary

The Nova laser system is designed to produce critical data in the nation's inertial confinement fusion effort. It is the world's largest peak power laser and presents various unique pulse power problems. In this paper, pulse power systems for this laser are described, the evolutionary points from prior systems are pointed out, and the current status of the hardware is given.

Introduction

Inertial confinement fusion is being vigorously pursued at LLNL. The Nova laser system is the latest in a series of increasingly large lasers that have been built to characterize fusion targets and to approach a demonstration of break even. The Nova laser will deliver 300 kJ of 1.06 micron light on target when it is completed. At this time DOE is considering frequency conversion of Nova to 2 and 3 μm. The amplifiers for this system use Nd-doped phosphate glass as the amplifying medium. The pump energy to excite this medium is supplied by flashlamps which in turn are driven by energy stored in capacitors. Each lamp pair is driven by a circuit storing from 18 to 50 kJ of energy. The total stored energy for the Nova system is about 100 MJ.

Because of the size of the Nova bank, many areas were studied to reduce cost yet retain needed levels of performance. The one with the most leverage was capacitors. For this component, vendors were solicited and to develop high energy-density capacitors to a specification derived from a statistical study of the desired reliability of the Nova bank.

A second subassembly where significant cost savings were realized was the power supplies. By going to substation-size supplies and placing them outside the laboratory building, savings were realized in economics of scale in the supply and in building space.

The number of components were reduced wherever possible as well. The flashlamp drive system, for example, consists of many circuits grouped around common switches to conserve switch count. Figure (1) illustrates how up to 24 circuits make use of one switch, yet retain individual fuses for isolation.

There are many other areas where evolutionary improvements have been made to enhance performance or reduce cost. New high power resistors have been developed, for example, that have ten times the energy absorbing capacity of the earlier versions.

In addition, LLNL has been working with the University of Texas to develop rotary energy storage devices such as the Compensated Pulsed Alternator and the Active Rotary Flux Compressor. The goal of this effort is to provide lower cost energy storage for pulse power. The application these devices will no doubt be in a larger system than Nova, perhaps regenerated.

All the flashlamp drive system, however, is not the only pulse power element in the laser, albeit the largest physically.

A major effort in pulse power is directed toward driving the several optical shutters found in each chain. There are three basic types of shutters used. For small apertures (< 5 cm) Pockels Cells are employed. These are single crystals of KD*P which when placed in an electric field rotate the plane of polarization of incoming polarized light. By placing this crystal between polarizers and switching the electric field, a fast optical switch is created. Switching times in the 1 ns regime are realized using this technique and applications are in the oscillator switch out and in the front end of each laser chain. For optical apertures from 5 to 35 cm, Faraday Rotators are used. These devices use a similar, polarization-rotating technique but employ a magnetic rather than electric field effect. Because of this the Faraday rotator cannot be rapidly switched but instead is used as an optical diode, transmitting forward light down the chain but diverting reflected light into beam dumps. Each Faraday rotator requires a great deal of stored energy for large sizes, eg, 200 kJ for 20.8 cm aperture. Because of the cost of stored energy and the cost of rotator optics, alternative shutters have been studied. The Plasma shutter is such an alternative.

The plasma shutter explodes a wire and puffs it across a pinhole to block reflected light from propagating down the chain. This pulser requires 650 kA of current and <400 ns rise time to obtain the needed closure time.

These devices are discussed further below.

Switching

The Nova energy storage system uses ignitrons for the switch element. In order to insure reliable operation of these tubes, a number of steps have been taken. The most troublesome aspect of ignitrons is their propensity for prefire. New tubes are now bought to a specification that sets a maximum prefire rate under incoming test conditions. In addition, the cathode of each tube is water cooled to 16-18 degrees C, and the anode is heated to 500 degrees C. Anode heating was accomplished in the past by heat lamps. On Nova, direct contact heaters powered by isolation transformers are used. This has reduced the power consumption from 500 watts per tube to 25. In addition, to prevent prefire, two tubes are placed in series in each switch and a voltage divider is used to equalize tube voltage. Periodic high potting to

Figure 1: Nova Power Conditioning Circuit
**Nova Pulse Power System Description And Status**

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25 kV ac is also performed to check the condition of
each tube. In order to detect and localize any
prefire that might occur, a voltage monitor is placed
in each switch rack. This monitor is fiber optic
coupled to the control system, so if a prefire occurs
the event is immediately recognized and action is
taken. Ignitor failure is another failure mode of
ignitrons. On Nova, both ignitrons on each tube are
fired on each shot, and current transformers monitor
each trigger. This trigger information is fiber
optic coupled to the control system as well, so that
failures can be localized and repaired quickly. A
monitor is fiber optic coupled to the control system
as well, so that ignitrons from three vendors for qualification to the
control system physically as much as
determined by applying Weibull statistics to our test
data. LLNL will purchase about 25 MJ of these
capacitors for Nova I at a cost of $0.052/joule.
The staging of the capacitor bank for Nova I is
detailed Table II.
At this writing orders for capacitors for Nova I
have been placed.

High Power Resistors
Since Shiva, a considerable effort was made to
improve the resistors used for the PFN. In
particular extensive testing was performed on
resistors for use as dummy loads and dumps. The
dummy load is an alternate load for the energy
storage modules. The dumps are used in the crowbar
system to safe the capacitors in the modules.
Samples of these resistors are shown in Figure 3.

Figure 3: High Power Resistors

The requirements for the dummy load are an
impedance of approximately 8 ohms, an energy
capability of 50 kJ, and a voltage rating of 22 kV.
We have found three different resistors that meet
these requirements. The first two types are ceramic
capacitors - one made by Allen Bradley of England
and the other made by Carborundum's Japanese affiliate;
the Japanese also have cooling fins. The third type
is a tubular ceramic made by Carborundum. All three
de these types are capable of absorbing 200 kJ in a
single pulse. The resistors have also been tested at
50 kJ per pulse at five minutes repetition rate.
The ceramic disc types have achieved hundreds of
shots before failure. The tubular type has over 1000
shots before failure; this type of resistor should
cost significantly less.
The requirements for the dump resistor are an
impedance of 1000 to 2000 ohms, an energy capability
of 200 kJ single pulse, and a voltage rating of
22 kV. We have tested two types of resistors for this application; a ceramic disc made by Allen Bradley of England and a tubular ceramic made by Carborundum. Both types are capable of absorbing 200 kJ in a single pulse. Both resistors have been tested at 50 kJ per pulse at a five minute repetition rate. Both types have also achieved over 1000 shots before failure.

Power Supplies

To charge the Nova bank within 30 seconds, as required for adequate bank lifetime, 12 to 14 MVA of dc power must be applied to the bank. Large substation sized power supplies have been designed to supply this much power at an efficient cost. Smaller, Shiva-type, 100 KVA supplies will be used to charge the modules for the rod amplifiers and rotators, but most of the bank will be charged by six large supplies located in the substation area outside the Nova lab building.

These supplies are designed as three phase voltage doublers. Each supply is capable of charging 12 MJ of capacitors to 22 kV in thirty seconds. They are powered via a fused disconnect from the 13.8 kV ac power mains. They draw approximately 2.0 MVA peak power. A picture of the prototype Nova power supply is shown in Figure 4.

Figure 5: Planar Triode Pulser Chassis

In the case of front-end cells, the risetime had to be maintained at 1-3 ns with < 200 ps jitter. For this application, planar triode pulsers were used. The planar triode is a 3000 MHz device which can be operated in a switched mode. In this mode for 5-25 ns pulses the switchable cathode current can be greatly extended and a single tube is capable of putting out 30 amperes with several kilovolts of anode swing. A picture of a planar triode driver chassis for a 5 cm Pockels cell is shown in Figure 5.

Optical Shutter Pulsers

In order to pulse the Pockels cells in the nanosecond regime, a number of techniques have been used. Pockels cells in the laser chains must each be switched simultaneously. To accomplish this, on Shiva a spark gap was used to switch a parallel group of charged cables into 20 cells. This system worked well but required more maintenance than was desirable for Nova, so the N-way fanout was redesigned to be switched with a hydrogen thyatron. Risetime was degraded from 3-5 ns to 15 ns but for chain Pockels cells the increase in reliability is more important.
The control computer, a DEC VAX-11/780, interfaces with the operator via a system of touch panels and color graphic displays. The operator controls the system by touching a CRT displaying a "menu" of control options. The VAX computer responds to the operator's touch by generating a series of commands which in turn routes the command to the desired hardware. The FEP constantly polls the hardware devices for status information which is stored in the memory shared with the control computer. Thus, the control computer has visibility of the overall system at all times.

Pulsed power devices are connected to the FEP's in a redundant fashion as shown in Figure 6.

![Figure 6: Redundant Connection of Pulsed Power Devices](image)

**Table 1: Stress Levels and Nominal Life Spans of Capacitors.**

<table>
<thead>
<tr>
<th>Component</th>
<th># Circuits per Component</th>
<th>Energy per Circuit</th>
<th>Energy per Component</th>
<th>Energy Total</th>
<th>Energy Lamps Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rod</td>
<td>16</td>
<td>1</td>
<td>16</td>
<td>50</td>
<td>42*</td>
</tr>
<tr>
<td>9.4 Disc</td>
<td>20</td>
<td>0</td>
<td>160</td>
<td>144</td>
<td>18</td>
</tr>
<tr>
<td>9.4 F.R.</td>
<td>12</td>
<td>1</td>
<td>12</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>15 F.R.</td>
<td>10</td>
<td>1</td>
<td>10</td>
<td>10</td>
<td>12.5</td>
</tr>
<tr>
<td>15 Disc</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>20 B.F.R.</td>
<td>10</td>
<td>5</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>20 B Disc</td>
<td>30</td>
<td>8</td>
<td>200</td>
<td>25</td>
<td>12.5</td>
</tr>
<tr>
<td>31.5 F.R.</td>
<td>10</td>
<td>5</td>
<td>200</td>
<td>40</td>
<td>200</td>
</tr>
<tr>
<td>31.5 Disc</td>
<td>40</td>
<td>10</td>
<td>400</td>
<td>37.5</td>
<td>37.5</td>
</tr>
<tr>
<td>46 Disc</td>
<td>10</td>
<td>16</td>
<td>480</td>
<td>600</td>
<td>37.5</td>
</tr>
</tbody>
</table>

*Nonreversal (3 kJ)

**Table 2: Capacitor Bank Staging.**

<table>
<thead>
<tr>
<th>Component</th>
<th># Total Circuits</th>
<th>Energy Total</th>
<th>Energy Lamps Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rod</td>
<td>16</td>
<td>672.3 kJ</td>
<td>96-19</td>
</tr>
<tr>
<td>9.4 Disc</td>
<td>20</td>
<td>2880.3 kJ</td>
<td>320-44</td>
</tr>
<tr>
<td>9.4 F.R.</td>
<td>12</td>
<td>256-8 kJ</td>
<td>96-19</td>
</tr>
<tr>
<td>15 F.R.</td>
<td>10</td>
<td>1000-12.5 kJ</td>
<td>240-44</td>
</tr>
<tr>
<td>15 Disc</td>
<td>12</td>
<td>240-5 kJ</td>
<td>240-44</td>
</tr>
<tr>
<td>20 B.F.R.</td>
<td>10</td>
<td>480-44 kJ</td>
<td>480-44</td>
</tr>
<tr>
<td>20 B Disc</td>
<td>30</td>
<td>240-5 kJ</td>
<td>240-44</td>
</tr>
<tr>
<td>31.5 F.R.</td>
<td>10</td>
<td>480-44 kJ</td>
<td>480-44</td>
</tr>
<tr>
<td>31.5 Disc</td>
<td>40</td>
<td>1800-12.5 kJ</td>
<td>240-44</td>
</tr>
<tr>
<td>46 Disc</td>
<td>10</td>
<td>240-5 kJ</td>
<td>240-44</td>
</tr>
</tbody>
</table>

Total Circuits = 1560 # 12.5 kJ Capacitors = 2000 or 25000 kJ

*Operated at 22 kV

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2. B. Carder, E. Goodwin, D. Eimerl and J. Trenholm, "Optimized High-Power Compulsor Design".
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