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STATUS AND OPERATING EXPERIENCE

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NOVA POWER SYSTEMS:
STATUS AND OPERATING EXPERIENCE*

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Introduction

The Nova Laser is a 100KJ, 100 TW, 10 beam Nd Laser in construction at Lawrence Livermore Laboratory and is being built to be an experimental facility for laser fusion. The world's largest peak power laser, Nova is the latest in a series of increasingly large lasers and is the culmination of over 10 years of development of solid state laser systems.

In preparation for Nova and in order to fill a gap in experimental data, two arms of Nova have been installed in the Novette facility and have been in operation for over a year.

This paper describes the pulse power systems that are used in these two lasers; the status and the operating experiences.

The pulsed power system for the Nova Laser is comprised of several distinct technology areas. The large capacitor banks for driving flashlamps that excite the laser glass is one area, the fast pulsers that drive pockels cell shutters is another area, and the control system for the pulsed power is a third.

This paper discusses the capacitor banks and control systems.

Background

During 1976-1977, when the Shiva Laser was being constructed, the Nova Laser was in the planning stages. Projects the size of Nova take up to ten years to go from study to completion through the funding and construction cycles.

During this period, the lessons learned in building smaller systems were applied to Nova, and new components were developed. [1,2]

The original plan for Nova had 20 beams with 10 in the Shiva building and 10 in the new Nova building. Only 10 beams were finally funded and they were placed in the Nova facility. Additional amplifiers were added to these beams to achieve improved performance.

CAPACITOR BANK ASSEMBLY & INSTALLATION

The assembly of the 60 MJ capacitor bank for the Nova Laser System is being constructed at the Livermore site. The first eight arms of the Nova bank have been finished. The bank for the two arms from Novette and for additional amplifiers will be added in the spring of 1984. A layout of the bank is shown in Figure (1).

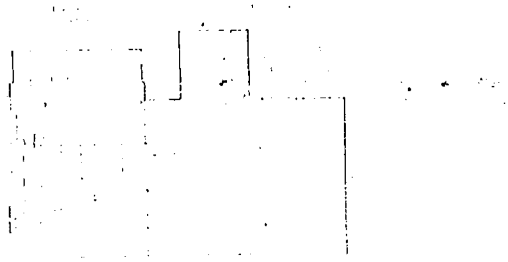

Figure 1. Bank Layout

For assembly, the first step upon moving into the new building was to install the overhead cable trays, LCW Lines (water cooling), and air supply lines required to drive the pneumatic dump relays before installing the capacitor storage racks. These racks are seven shelves high and fifty three feet long. There are a total of 16 rows of shelves in the Nova capacitor bank for the 1827 circuits.

After cable tray and racks were in place, the assembly was accomplished using efficient production line techniques:

A. A six man crew installed the 365,000 ft. of RG217/V high voltage cable.

B. A three man crew cleaned the capacitors, installed them in trays, installed the bus work, put them on roll-around carts and moved them into a room for high voltage tests. Each capacitor was hipotted from terminal to case and terminal to terminal, and after passing this test, moved to the assembly area.

C. Four men on the assembly line installed all the components on the pulse forming network boards. These include the following: charge and dumping resistor, spark gap, ground plane, load select board, H.V. fuse, inductor, and associated interconnections.

D. Two men on the assembly line installed loaded PFN boards on the capacitor modules.

E. One man installed the capacitor module shorting switch and adjusted the PFN board to the capacitor tray.

F. One man performed a quality control inspection.

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After assembly and test, the modules, which weigh up to 1,000 pounds, were transferred from the cart to a capacitor loading platform which operates from a forklift to install the module on the shelf. During the Nova assembly, we assembled and tested 32 modules per day. It took 12 weeks to assemble, test, and place in the bank, the 1500 circuits of the first eight arms of Nova. A typical row is shown in Figure 2.

Figure 2. Row of Nova Bank

Bank Description

Since the last report for this conference, [3] the overall laser was scoped down to 10 beams. The new configuration is summarized in Table 1. The total number of circuits is 1827, and the bank is nominally 60 MJ.

As reported, the bank is built with 3KJ, 5KJ and 12.5KJ capacitors; the 3KJ and 5KJ units are being salvaged from previous lasers, Shiva and Argus. The 12.5KJ units are a new high density type developed for Nova. [4] The 12.5KJ units are physically about the same size as the 3KJ units.

The bank is charged to a nominal 22KV by use of six large power supplies and eight smaller ones. The large power supplies are named "MVA" type since each draws 2 MVA at peak load. They are located in the substation outside the Nova Building. See Figure 3. The smaller units are named "KVA" type since each draws 100 KVA at peak load. The KVA supplies are salvaged from Shiva; the MVA supplies were developed for Nova. [5]

The capacitor banks energy is transferred to its flashlamp loads by 117 switch assemblies. Each switch assembly consists of two size "D" ignitrons in series. Each assembly can accommodate up to 24 circuits. Each assembly is built complete with its own set of diagnostics to measure fire voltage and sense ignitor triggers and ignitron fire. In addition, a current transformer for each circuit is provided. These current transformers in conjunction with the LCD (Lamp Circuit Diagnostic) chassis, record circuit current waveforms for past shot analysis. In addition, the circuit current peaks are compared to thresholds and the data latched for a quick "yes or no" indicator. The details of the switch assemblies and diagnostics have been reported previously. [6]

TABLE I: BANK CONFIGURATION

COMPONENT	Number of Circuits	Energy per Circuit (kJ)	Total Energy per Component (kJ)
RODS	16	50	800 12.5*
9.4 DISC	160	18*	2880 3
9.4 FR	11	21	231 3
15 DISC	120	18	2160 3
15 F.R	40	37.5	1500 12.5
20.8 DISC	240	21*	5040 3
20.8 F.R	50	40	2000 5
31.5 DISC	320	33*	10560 3
	...180	. 37.5	6750 12.5
31.5 F.R	50	40	2000 5
46 DISC	640	37.5	24000 12.5
	1827 Total		33050 12.5
	151 F.R.		4000 5
	1676 Lamp		20871 3
*At 20 kV.		TOTAL	57921 kJ

*Type of Capacitor
i.e., 3kJ, 5kJ or 12.5kJ

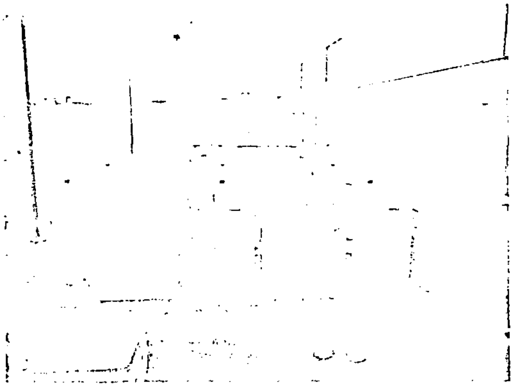

Figure 3. Nova MVA Power Supplies

Bank Activation

The checkout and activation of a large capacitor bank such as Nova is a formidable task. We were successful in activating the Nova bank by rigidly adhering to a few basic procedures for quality control.

The first step was to perform acceptance testing on critical components such as capacitors, ignitrons, inductors, etc. If an item was perceived to have a high failure rate, 100% of that item was inspected. For example, each of 2645 high density capacitors was subjected to 500 pulse discharges at 10% above rated voltage to remove infant mortality failures from the population. [7] If an item was "off the shelf," lot acceptance techniques were used. This was true for items like ignitrons and pulse transformers.

New designs for components used on Nova were only approved after an extensive development and qualification program. The resistors used for dummy loads and dump resistors provide a good example. [2]Resistor manufacturers designed possible candidates and LLNL tested them under simulated operating conditions. At the end of that program, two resistor types were identified as meeting Nova's needs: Disk type and tubular type. The disk type were chosen in competitive bidding.

The second step was to test the capacitor modules themselves before placing the modules on the capacitor racks. Each module received 25 charge and discharge cycles. During this test, the capacitors in each module are discharged through the pulse forming inductor into the dummy load on each module.

We built a test stand capable of testing 16 modules at a time. Typically 32 modules were tested in one day. This test checks all the components on a module as well as all the connections. See Figure 4.

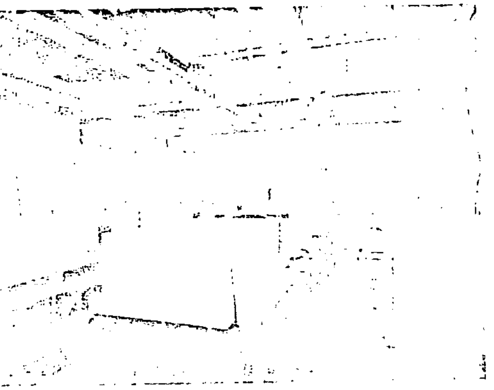

Figure 4. Module Test Stand

After all the modules were installed on the racks and all the cables pulled and connected, the third step was to check the wiring. A point-to-point resistance check was made of all the high voltage cables. Each circuit has two cables, a charge cable from the switch to the module and a load cable from the module to the junction box. In addition, each switch assembly has a cable from the power supply high voltage distribution chassis (fanout) to the switch assembly.

After the cabling was verified as being correct, the fourth step was to "hipot" all the cables. Each cable was checked three ways: shield to ground, center conductor to ground and center conductor to shield. Each check consists of a one minute high voltage test to 25KV dc. The cables were checked out switch by switch, since in a switch assembly up to 30 cables are clustered together. During these checks, the capacitor in the modules is shorted. Typically the cables for eight switches are resistance checked and hipotted by three men in an eight hour shift.

The fifth step was to check out the power supplies, fanouts, switches and circuit modules as a system. This was done one power supply at a time. Usually four of perhaps twenty switches connected to a power supply were charged. The circuit modules were then charged and the energy transferred to the dump resistors. After the dump mechanisms and resistors were verified as being operational, the circuit modules were then charged and discharged into their respective dummy loads. Typically, these steps were repeated a few times at increasing charge voltages until the modules were charged and discharged at nominal energy. All circuits connected to a power supply were similarly checked out.

The bank is not fully operational until the circuit modules are dischaged into flashlamps in amplifiers. As the amplifiers become available on the space frame, this becomes a daily task. Usually a few amplifiers become operational each week. The entire process is scheduled to be complete by May 1984. As of today, all of the amplifier circuits have been charged to nominal voltage and fired into dummy loads.

Pulse Power Controls

The pulsed power system is controlled and monitored by a computer system as illustrated in Figure 5. The Nova control system contains three VAX 11/780 central control computers. The pulsed power system generally only runs on one of these computers, although any of the remaining computers could be used.

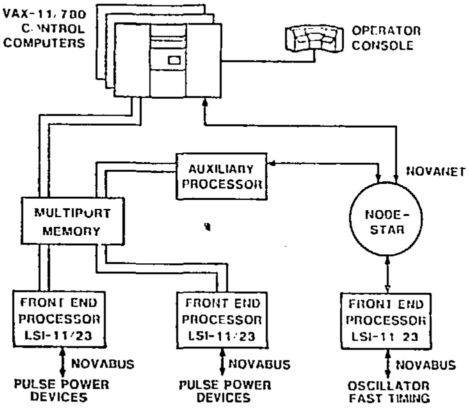

Figure 5. Pulse Power Control System

The operator console contains a Ramtek CRT display with a touch panel and a DEC VT125 computer terminal. The operator controls the system by selecting various high-level functions available through a series of CRT display menus. Several terminal menus are also available to provide low-level control and maintenance functions.

The VAX responds to operator requests by generating a series of commands to the hardware devices. These commands are sent to the LSI 11/23 front-end processors through a shared memory or over a fiber-optic communication network. The FEPs interpret the commands and perform the appropriate functions to the hardware. In reverse, the FEP's constantly poll the hardware for status changes and send new information back to VAX through the multiport or over the fiber-optic network. Information may be presented to the operator on one of the display menus.

The two FEP's connected to the shared memory are used to control the various pulsed power devices such as power supplies and capacitor bank interfaces. The third FEP is used to control the laser master oscillator fast-timing hardware. An additional LSI-11/23 processor is also included to provide auxiliary control of the system.

Controls Layering

A controls model was developed as an aid to system definition and software design. This model divides the control system into six layers of controls functionality, illustrated in Figure 6. The highest four layers are primarily software based; the lowest two layers are primarily hardware based. Each layer uses its own services to build upon the services provided by the layer below in order to provide higher-level services to the layer above. The highest layer provides services to the operator; the lowest layer interfaces directly to the pulsed power elements. Communication is performed only between two adjacent layers and only through a strict, well defined interface. Adherence to this model has enforced structured design and modular development.

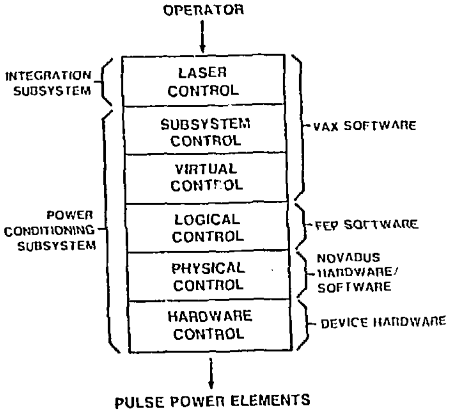

Figure 6. Software Layers

The highest layer is the laser control layer and is used to integrate the pulsed power, alignment, laser diagnostics and target diagnostics subsystems into a unified system by which an operator can control the entire laser rather than just an individual subsystem. Although this layer extends beyond the pulsed power system, it must use many of the services that the pulsed power system provides. In addition, this layer provides global shot scheduling with coarse second to minute type timing resolution.

The subsystem control layer presents high level control of the overall laser pulsed power subsystem to the laser control layer. Based on the pulsed power, timing, and facility control provided from the layer below, this layer internally makes decisions that globally effect the entire subsystem. This includes such operations as aborting shot sequences when facility related failures are detected or selecting various laser component configurations.

The virtual control layer is used to provide control of high level pulsed power components. Control of these components are internally translated into lower layer requests. An operator at this level may select various laser components or sets of laser components for a particular operation. At present, four basic types of operations have been defined: a test sequence, a PILC sequence, a dry-run sequence, and a shot sequence. A test sequence is used to verify that the system is functioning properly by performing several diagnostic functions and hardware checks. A PILC sequence (pulsed ionization lamp check) may then be used to determine flash-lamp failures. The dry-run sequence performs a shot sequence but without high voltage. The shot sequence is used to actually verify charge, and fire the system.

Upon selecting a set of components, one of the four types of sequences can be initiated. The virtual control layer internally determines which lower level devices are necessary, the functions that must be performed, and the times at which they must occur. As the sequence progresses, the selected hardware is automatically configured and verified. Verification failures generally result in the sequence being held while severe failures at critical times result in an abort.

The virtual control layer also provides control of high level system timing and monitoring of the facility related subsystem including the safety interlocks and the nitrogen supply system.

The logical control layer provides direct control of the numerous pulsed power devices that constitute the various laser components. This includes control of power supplies, ignitrons, and lamp check diagnostic packages (LCD). An operator at this level is capable of individually monitoring and commanding each pulsed power device. The bulk of this control is carried out within the front-end processors. As logical level requests are generated within the VAX, they are transferred over the network or through the shared memory to the FEPs. These requests are then in turn translated into lower level requests provided by services from the next lower layer. New status is returned to the VAX in a similar manner and is also available through the logical level interface.

The physical control layer performs control based on individual hardware interfaces incorporated within each pulsed power devices. The heart of this control structure is an interconnection network known as the Novabus. The Novabus connects the FEP's with the pulse power devices by extending the FEPs internal bus over a serialized fiber optic bus throughout the laser facility. Bus messages from the computer are relayed down each fiber-optic chain to the appropriate device. To improve reliability, each device is serviced by two redundant computer buses. In this potentially harsh electrical environment, voltage isolation and noise immunity were key issues in the design of all the Novabus components.

Within each device there is control electronics which comprises the hardware control layer and is inherent in the design of the various devices themselves and responsible for driving the actual pulse power elements. Included in this layer is the ignitron electronics for firing and monitoring the ignitron switches and the LCD electronics for detecting and sampling flashlamp circuit currents.

Novette Operating Experiences

Since the Novette bank and controls systems use Nova hardware, the operating experience on Novette is a useful measure of expected operation on Nova.

The first six months operating experience with Novette was reported in Ref 8. As of now, we have an additional 10 months of experience with the system.

This data is given in Table 2. It shows that while pulse power problems affected only 2% of the first 600 shots, they affected 5% of the next 332. Several points are in order:

First, the shots during the last 10 months exercised the entire bank much more often than the first six months, since early experiements were involved with the front end of the laser, so that more circuits were involved per shot. Second, the largest failure rate occurred with the fuses. These occurred in circuits where the fuses were underrated and are being upgraded. Third, the flashlamp failures occurred among the 19" flashlamps for the 46 cm amplifiers. This problem has been studied, a solution found, and new flashlamps are being introduced into the system. Fourth, the inductor failures resulted from magnetic pressure flexing the inductor tabs. Several fixes are envisioned. None has yet been implemented.

When the solutions to these failure areas have been implemented, the failure rate should drop to a lower level. The present level is acceptable, operationally, but better performance is obtainable with the steps mentioned above.

TABLE 2

Novette Pulse Power Operational Experiences

	Activation 8/82-2/83		Operation 2/83-11/83	
Shot Attempts	595		332	
Shot Successes	439	74%	280	84%
Pulse Power Problem	10	2%	18	5%

Component Failures

Component	Population	Activation Failures	Operation Failures
Flashlamps	884	13	22*
Capacitors	1296	5	0
Fuses	318	6	34**
Ignitrons	50	2	0
Diodes	44	1	4
Resistors	1554	4	4
Inductors	238	0	12***
Power Supplies	16	1	6

* Mechanical failure of the electrode quartz

** Rebuilt 5kA fuses

*** Mechanical failure of the plastic case.

Summary and Conclusion

The Nova Power Systems have been installed and activated through the first eight arms without the additional amplifiers. Assembly and activation, although large tasks, presented no unusual problems and took place efficiently. The controls system was available from the point of first need and was very useful in activating the bank.

Operational experience on Novette shows acceptable performance. Steps are being taken to improve the performance for Nova.

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