

THE ATLAS PULSED POWER FACILITY FOR HIGH ENERGY DENSITY PHYSICS EXPERIMENTS

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The current Atlas schedule calls for construction of the machine to be complete by August, 2000. Acceptance testing is scheduled to begin in November, 2000, leading to initial operations in January, 2001.

Abstract

The Atlas facility, now under construction at Los Alamos National Laboratory (LANL), will provide a unique capability for performing high-energy-density experiments in support of weapon-physics and basic-research programs. It is intended to be an international user facility, providing opportunities for researchers from national laboratories and academic institutions around the world. Emphasizing hydrodynamic experiments, Atlas will provide the capability for achieving steady shock pressures exceeding 10-Mbar in a volume of several cubic centimeters. In addition, the kinetic energy associated with solid liner implosion velocities exceeding 12 km/s is sufficient to drive dense, hydrodynamic targets into the ionized regime, permitting the study of complex issues associated with strongly-coupled plasmas.

The primary element of Atlas is a 23-MJ capacitor bank, comprised of 96 separate Marx generators housed in 12 separate oil-filled tanks, surrounding a central target chamber. Each tank will house two, independently-removable maintenance units, with each maintenance unit consisting of four Marx modules. Each Marx module has four capacitors that can each be charged to a maximum of 60 kilovolts. When railgap switches are triggered, the Marx modules erect to a maximum of 240 kV. The parallel discharge of these 96 Marx modules will deliver a 30-MA current pulse with a 4-5- μ s risetime to a cylindrical, imploding liner via 24 vertical, tri-plate, oil-insulated transmission lines. An experimental program for testing and certifying all Marx and transmission line components has been completed. A complete maintenance module and its associated transmission line (the First Article) are now under construction and testing.

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I. INTRODUCTION

The Atlas pulsed-power facility,¹ currently under construction at the Los Alamos National Laboratory, is an important component of the Department of Energy's Stockpile Stewardship Program (SSP).² Such high-energy-density facilities are necessary for obtaining experimental data in the extreme physical parameter ranges that occur in nuclear explosions. Lasers and pulsed-(electrical)-power experimental facilities are complementary in providing these capabilities. High-power pulsed laser facilities, such as the National Ignition Facility, currently under development at the Lawrence Livermore National Laboratory, provide the highest temperatures and pressures in small experimental volumes for a few billionths of a second. By comparison, pulsed-power facilities can deliver much higher total energy to larger (e.g., centimeter scale) experimental targets over longer times, although achieving somewhat lower temperatures and pressures. Pulsed power facilities are of most value to the SSP in addressing material properties at high energy density, implosion hydrodynamics, and radiation flow physics. In contrast to the short-pulse (100 ns), high-voltage facilities at Sandia National Laboratory, which are most useful for examining radiation flow physics, the microsecond pulse-power facilities at LANL (Pegasus, Atlas and explosive pulsed-power systems) are most appropriate for examining hydrodynamic issues.

In the typical pulse-power experimental configuration, pulsed electrical currents produced by a capacitor bank or high-explosive magnetic flux-compression generator create strong magnetic fields

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that implode a cylindrical liner via the Lorentz force. A lightweight liner can collide with itself on axis, converting its kinetic energy into soft x-rays. Alternatively, a heavier liner can be used to either compress sample materials to high pressures, or when driven into a central target, produce extremely high shock pressures for hydrodynamic experiments. Pulsed-power-driven liners typically provide highly symmetric implosion drive, with asymmetries of 0.5% or less.

Several pulsed power machines, including Saturn³, PBFA-Z⁴, Shiva Star⁵, Pegasus II⁶, and Procyon⁷, have been used for high energy density physics experiments. For example, Saturn and PBFA-Z are used almost exclusively to implode lightweight liners for radiation experiments, while Shiva Star and Pegasus II are frequently used to drive heavy liners for hydrodynamic experiments. However, neither Pegasus II nor Shiva Star has sufficient energy storage to reach the conditions required for the hydrodynamic experiments envisioned for the future. A comparison of these facilities and the projected Atlas capabilities is shown in Table 1.

Table 1. Comparison of Existing Facilities with Atlas

Facility Name	Facility Site	Energy (MJ)	Current (MA)	Pulse (μ s)
Saturn	SNL	5.4	7 - 10	.05 - 0.1
PBFA-Z	SNL	14	15 - 20	0.1 - 0.5
Procyon	LANL	Exp.	15 - 20	1 - 2
Shiva Star	PL	9.4	12 - 20	8 - 15
Pegasus II	LANL	4.3	6 - 12	8 - 12
Atlas	LANL	23	27 - 32	4 - 5

II. ATLAS REQUIREMENTS

The primary application for Atlas is to drive hydrodynamic experiments. Based on the results of detailed high-energy density flow calculations,^{8,9} the Atlas facility should be capable of producing the minimum set of liner implosion/material property criteria summarized in Table 2.

An important consideration in meeting these criteria is that the inner surface of the imploding liner (aluminum) should remain solid prior to impacting the central target, a 1-cm-diam cylinder, i.e., large enough for relevant material samples and with sufficient room for axial diagnostics. Since such imploding liners are inherently unstable to the magnetically-driven Rayleigh-Taylor instability, this requirement establishes a minimum liner thickness, and therefore mass (~50g). With these assumptions

and the criteria of Table II, it is possible to deduce nominal Atlas device performance parameters. Such considerations, backed by one- and two-dimensional liner implosion calculations, lead to the specific Atlas current, current symmetry and pulse risetime specifications summarized in Table 3. With these parameters, Atlas will provide an order of magnitude increase in dynamic pressure over Pegasus II.

Table 2. Minimum Desirable Material Condition

Parameter/Condition	Criterion
Material Velocity	>12 km/s
Shock Pressure	>10 Mbar
Strain, Strain Rate	>200%, > 10 ⁴ /s
Dense Plasma	Strongly-coupled, partially degenerate

In addition to these basic machine parameters, Atlas must also be reliable, must provide experimenters with clear diagnostic access, must have a reasonable shot rate, and must have a reasonable lifetime. Based on prior experience with operating the Pegasus II facility, as well as the large pulsed-power facilities at Sandia, Atlas has been designed to be capable of reliably operating at a shot rate of approximately two shots per week (100 shots per year) with a lifetime of 10-20 years. Radial and axial diagnostic access around the target chamber will exceed half the available solid angle.

Table 3. Atlas Technical Baseline

Peak current (MA)	27 - 32
Pulse risetime (μ s)	4 - 5
Lifetime (# of full-voltage shots)	>1,000
Max. rep. rate (shots/week)	2
Machine reliability (% target failures)	<5
Target viewing angle	> 3 π
Current symmetry at liner (%)	> 99

With solid-liner implosion velocities in excess of 12 km/s, steady shock pressures as high as 18 Mbar may be achievable, depending on the detailed liner and target designs. In addition, the kinetic energy associated with such implosions, in the range of 2-5 MJ, is sufficient to drive large, dense, hydrodynamic targets into the ionized, strongly-coupled-plasma regime.

III. MACHINE CONFIGURATION

The basic configuration of Atlas was frozen in September, 1998. A large capacitor bank delivers electrical energy to the central target region via multiple transmission lines. A conceptual layout of the machine is shown in Figure 1.

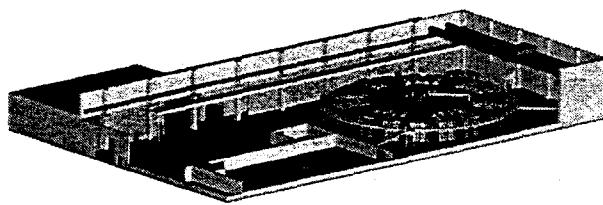


Figure 1. The Atlas Facility will be located in Building TSL-125 in TA-53 at the Los Alamos National Laboratory. The device itself is a circular machine approximately 80-ft in diameter. Capacitor banks at the periphery of the machine deliver their electrical energy to a central target region via oil-insulated, vertical tri-plate, transmission lines.

The Atlas facility can be divided into four major sections: (1) high-power electrical section, (2) supporting mechanical equipment, (3) the target chamber region, and (4) the controls, diagnostics, and data acquisition systems.

High-power electrical section. The high power electrical section includes the capacitor banks, load protection switches, the vertical tri-plate transmission lines, and the transition hardware that connects the transmission lines to the power flow channel. This section also includes a capacitor bank charging system and a railgap triggering system.

Mechanical support systems. These systems include the vacuum system for the target chamber; the Argon/SF₆ gas system for pressurizing the railgaps and venting the spent gas to atmosphere; the insulating-oil transfer and storage system; and machine and personnel support structures.

Target area. The target area includes the power flow channel (PFC), the liner assembly, and the target chamber. The PFC brings current from the pulsed-power transmission lines to the load assembly. The target chamber can be either a vacuum or atmospheric pressure vessel. Because of the variety of anticipated experiments, a high degree of flexible diagnostic access is necessary for end-on and radial views of the

target. The PFC and liner assembly are viewed as expendable since they will be destroyed every shot.

Controls, diagnostics, and data acquisition. The control system will govern the normal charging and discharging of the capacitor bank. It will also provide a controlled de-energizing of the capacitor bank when needed. Additionally, the control system will provide timing signals to the data acquisition systems, and will control the mechanical support subsystems such as the Argon/SF₆, oil, and vacuum systems. The machine diagnostics and data acquisition system will record important machine parameters such as charging and discharging current, charging and discharging voltages, and switch trigger times.

IV. CAPACITOR BANK DESIGN

The primary machine element, a 23-MJ capacitor bank, is comprised of 96 separate Marx generators housed in 12 separate oil-filled tanks surrounding the target chamber. Each tank will house two, independently-removable maintenance units (MUs), with each unit consisting of four Marx modules. Each Marx module has four capacitors that can be charged to a maximum of 60-kV. When two railgap closing switches¹⁰ are triggered, the four capacitors are connected in series and a Marx module erects to a maximum of 240-kV. Stainless steel damping resistors,¹¹ mounted on the rear of each module, limit potential fault currents and reduce voltage reversal on the capacitors. In fact, the 240-kV maximum was selected as the result of a trade study involving inductance sensitivity, parts count and availability, and voltage reversal sensitivity. Maxwell Technologies, Inc. is the commercial supplier for all the capacitors, railgap switches, and the charging and triggering systems.

A schematic design of a maintenance unit, indicating the four Marx modules and the routing of high-voltage, coaxial cables to a header, is shown in Figure 2. Each maintenance unit will be independently removable from the system and will contain its own control and data acquisition module and railgap trigger system. High-voltage, coaxial cables also transmit current from the cable header to a load protection switch (LPS). This switch, normally closed until just prior to machine firing, acts to shunt the electrical energy to ground in the event of a Marx prefire, thus preventing damage to the liner. The LPS is shown in Figure 3. The other side of the LPS is connected to an oil-insulated, vertical, tri-plate transmission line. A total of 24 of these lines converge at a central transition ring that surrounds the target chamber. An integrated schematic is shown in Figure 4.

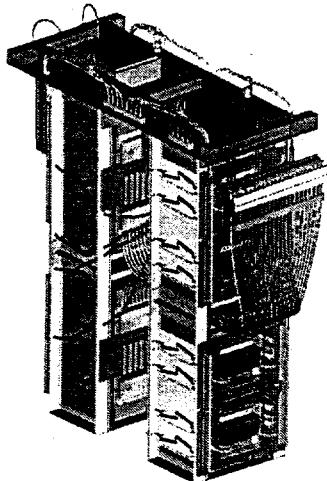


Figure 2. Atlas maintenance unit, showing the four Marx modules and the attachment to the cable header.

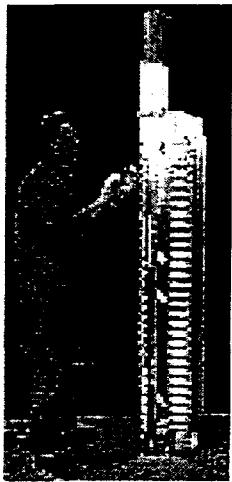


Figure 3. The load protection switch.

V. COMPONENT TEST RESULTS

Capacitors. The capacitors used in Atlas are Maxwell Technologies, Inc. Model #39232, 34 μ F, 60 kV, L< 25 nH capacitors. The voltage reversal is tolerance is specified at nominally 15%. These capacitors were extensively evaluated to certify their performance capabilities under Atlas operating conditions prior to placement of the large capacitor order. The capacitors are now arriving and spot checks are being performed to verify the specified capacitor lifetime. One capacitor failure has been observed (after more than 800 full voltage charge cycles) out of the 6 capacitors that have been tested thus far.

Railgap switches. Each of the 192 switches in the Atlas system will operate at a maximum 120-kV holdoff voltage, a 330-kA conduction current, and a 3-coul charge transfer. MTI Model #40302 was selected because of its demonstrated low jitter, low inductance, and high coulomb-transfer capabilities in other pulsed power systems.⁶ Several units were tested at current levels exceeding 800-kA and at a charge-transfer exceeding 5-coulombs. The switch performed well with the exception of deformation of the trigger rail under prefire conditions. Our tests indicate that after approximately 400- to 500-coul of accumulated charge transfer, the switch will prefire at 120-kV. For an individual switch to have a prefire probability of less than 10^{-4} , periodic maintenance will be required approximately every 300 coulombs.

Load Protection Switch. A prototype LPS has been assembled. Mechanical lifetime tests (over 2000 opening cycles) are complete and the measured opening time (250 ms) is acceptable. High-pot voltage (400 kV) stand-off tests have also been successfully completed.

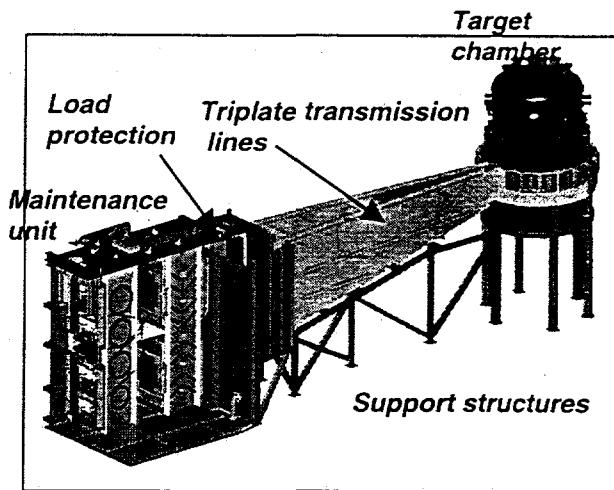


Figure 4. An integrated view of the MU, transmission lines, and target chamber.

Transmission Lines. Voltage hold-off tests have been conducted on a 1-m² section of the tri-plate transmission lines. Arcing was not observed until the applied voltage reached 425 kV, well in excess of the 220 kV that is nominally expected.

Current Joints. Several designs of the joint between the transition ring and the power flow channel have been conducted on Pegasus at linear current densities in the range of 110-120 kA/cm. As a result of these tests, the baseline approach is an indium gasket under low force.

The initial design of the joint between the T-lines and the transition ring was based on Multilam LAO G/0.25/55 AG, at 4-5 kA/louver. Although several different materials were tried, unacceptable damage was observed at the ends of the joint after only 50 high current pulses. An alternative joint design has been fabricated and will soon undergo testing.

VI. PRESENT STATUS OF THE CONSTRUCTION PROJECT

Two important integrated component validation tests are currently in progress. A complete four-Marx-module maintenance unit has been assembled and is undergoing high-voltage testing into a resistive load. A typical discharge current waveform from this MU is shown in Figure 5. At a charging voltage of 50 kV, the peak discharge current is about 1.3 MA. In addition, an integrated test of the LPS with a half-length section of the tri-plate transmission line is now underway. Assuming both these tests are successful, an integrated test of an MU with LPS and T-line (the First Article) will be conducted later in the summer. Successful completion of these First Article tests will provide confidence that the Atlas facility will reliably operate at its full machine specifications.

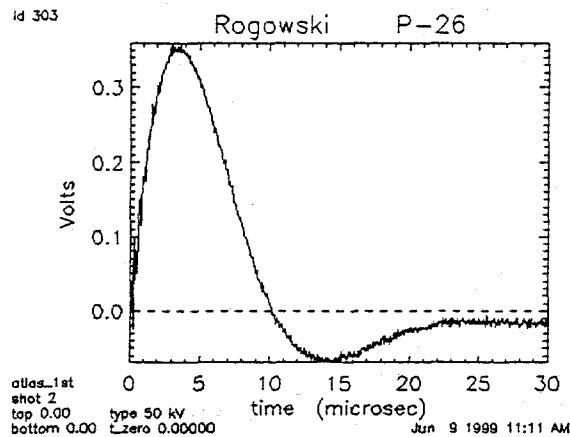


Figure 5. Discharge current waveform from the First Article MU. The peak of the waveform corresponds to a total current of 1.3 MA. The charging voltage was 50 kV.

Our current project schedule calls for construction of the full machine to begin in December, 1999. Acceptance testing is scheduled to begin in November, 2000 leading to an initial operating capability in January 2001.

VII. ACKNOWLEDGMENTS

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