Title: THE ATLAS PULSED POWER SYSTEM: A DRIVER FOR MULTI-MEGAGAUSS FIELDS

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THE ATLAS PULSED POWER SYSTEM; A DRIVER FOR PRODUCING MULTI-MEGAGAUSS FIELDS*

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Abstract
Atlas is a pulsed power machine designed for hydrodynamic experiments for the Los Alamos High Energy Density Physics Experimental program. It is presently under construction and should be operational in late 2000. Atlas will store 23 MJ at an erected voltage of 240 kV. This will produce a current of 30 MA into a static load and as much as 32 MA into a dynamic load. The current pulse will have a rise time of ~5 μs and will produce a magnetic field driving the impactor liner of several hundred Tesla at the target radius of one to two centimeters. The collision can produce shock pressures of ~15 megabars. Design of the pulsed power system will be presented along with data obtained from the Atlas prototype Marx module.

Introduction
The pulsed power system for Atlas is designed to provide a current pulse which will be used to implode "heavy" metallic liners in a Z-pinch configuration. The self-magnetic field on the surface of a liner carrying 30 MA at an initial radius of 4 cm is 1.5 MG rising to 6 MG at a radius of 1 cm. The JxB forces on a 40 g liner will cause it to implode in about 7 μs reaching a velocity of about 16 mm/μs with a kinetic energy of 5 MJ. The optimum liner in simulations done to date is Aluminum, 4 cm tall, 4 cm in radius, with a mass of about 40 g. These parameters are chosen to give the fastest velocity while keeping the inner surface of the liner solid.

Circuit description
To provide the current pulse to the load, a direct-drive capacitor bank is used, i.e., there is no pulse shaping switches between the capacitors and the load. There are no 'auxiliary' circuits such as crowbar switches. To control the current oscillations after the liner has imploded, resistive damping is used. Hydrodynamic experiments on Pegasus done at currents from 6 MA to 12 MA have shown good stability of the liner inner surface for implosion times of 8-9 μs. The combination of available energy, capacitor energy storage technology, and implosion time scale, imply an optimum voltage of 240 kV. We achieve this voltage by Marxing 4 ea., 60 kV, 60 kJ capacitors. The Atlas pulsed power system is composed of 96 of these Marx units connected in parallel. The Marx units are in oil tanks and are connected to an oil filled vertical tri-plate transmission line (VTL), via cables. The VTL connects to a disk line in the center of the machine. This solid dielectric-insulated disk line contains the conical power flow channel and the load. Below is a schematic representation of a Marx module.

Pictorial representation of a Marx module with no trigger circuit or isolation resistors. This building block of Atlas stores 240 kJ at 240 kV erected. The maximum current/module is 330 kA (normal); 750 kA (fault). The fault current is a full voltage discharge into the 'short' of the load protection switch (LPS) located at the input to the transmission line.
The circuit diagram of a Marx module is shown below in Fig.2.

![Marx module schematic](image)

**Fig.2 Marx module schematic**

(Rsht1-Rsht4=20MΩ; C1-C4=34μF; Lcap1-Lcap4=60nH; all other R's = 400Ω; Rser=1.5mΩ; Rshunt=5Ω; total cable L=100nH; header L~ 10nH; total equivalent system (w/o Marx's) L=12.3nH)

The RC filter and diode at the input to the Marx is to protect the power supply and limit current in case of a short during charge. The Atlas system inductance budget is given in the table below.

<table>
<thead>
<tr>
<th>Component</th>
<th>Inductance (nH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marx modules</td>
<td>2.6 nH</td>
</tr>
<tr>
<td>Cables</td>
<td>.94nH</td>
</tr>
<tr>
<td>Header / LPS</td>
<td>.53nH</td>
</tr>
<tr>
<td>VTL / transition</td>
<td>6.1 nH</td>
</tr>
<tr>
<td>Disk line</td>
<td>.76nH</td>
</tr>
<tr>
<td>Power flow channel</td>
<td>3.9nH</td>
</tr>
<tr>
<td>Load</td>
<td>1 nH</td>
</tr>
<tr>
<td>Total</td>
<td>15.8 nH</td>
</tr>
</tbody>
</table>

The value of the series resistance is chosen to limit the ΔV on the capacitors, the charge transferred through the railgaps. and to allow maximum current into a dynamic load where the load provides additional damping. This means that the machine cannot be fired at full voltage into a static load.

![Atlas schematic](image)

**Fig.3 Atlas schematic**
In Fig. 3 above, the series resistor is shown as a variable resistor. This is because the resistor is made of folded stainless steel and has a ΔT of ~80°C. This resistor also represents the varying resistance of the railgap switches. A static R of 1.8mΩ gives an equivalent result to the actual time varying R.

Test have been done on all of the Atlas Marx components. A prototype Marx has been constructed and tested for over 500 full voltage shots at an equivalent system current of 27 MA. A module of the Atlas distributed control system was used to control and acquire data from the Marx. No failures have occurred in the Marx, including 10 fault condition shots at ~600 kA/Marx.

The major Marx components are:
1. Capacitors; Maxwell 34μF, 60kV, I(fault)=750kA, ΔV=69kV/capacitor for rated lifetime, fiberglass case with electrodes on either end
2. Trigger system; Maxwell charged cable system, measured jitter <5ns on Marx
3. Switches; Maxwell railgaps, L=20nHswitch, Q=5C/shot, I(fault)=750kA, demonstrated maintenance interval=160 shots, insulating gas, 85%Ar+15% SF6
4. Connecting cables; RG-220
5. Series resistor; folded 304 SS in Kapton laminate, R(cold)=150mΩ/module
6. Shunt resistor; CuSO4 solution in Tygon tubing, R=5Ω/module
7. Isolation resistors; 170kV, 165kJ, 400Ω

Shown below is a side view of one of the 12 oil tanks housing 8 Marx modules, the VTL, disk line, and target chamber. The Marx modules are arranged into groups of 4 forming what we call a maintenance unit (MU). A MU will be removed for switch maintenance and inspection on a rotating basis every 96 shots. Each MU has its own transmission line and load protection switch (LPS). The LPS shorts the MU output until just before firing.

Fig. 4 MU in tank with VTL and target chamber.
Test results

- Data and simulation
- 180kV & 240kV
- Includes switch resistance (Martin's scaling) and R(T) for series resistor

The graph above shows current from the prototype at 240 kV (285 kA) and 180 kV (213 kA). At each voltage, a simulation is fitted to the data using the varying resistance for the railgap switches and the SS series resistor. The model accurately predicts the current at different voltages. It is this model that is used to predict the current on the full Atlas system. The model predicts that at a voltage of 190 kV, 30 MA can be delivered to a load with ΔV on each capacitor=69 kV. If the energy used to implode the load is not returned to the capacitors, by a liner bounce for example, the load will provide additional damping. A flashover of the load region when the Poynting vector reverses will effectively prevent this energy return. This flashover is observed on Pegasus. Under this assumption, the voltage can be raised to 220 kV with 32 MA delivered to the load and keep ΔV within specification. Raising the voltage higher to have a ΔV of 72-75 kV/cap. will have a minimal effect on capacitor lifetime. This is an option since Weibull analysis of capacitor life test have shown that under a worst case assumption, 6 capacitor failures could be expected in 1000 system shots at full voltage.

Conclusion

Preliminary test of Atlas components have shown that a system reliability of 95% should be achievable using the load protection switch to protect the load from trigger prefires. This reliability is based on full voltage operation at 240 kV erected voltage. Shots taken at lower voltage will improve this reliability number. Atlas is presently in the final design and construction phase. Parts have been ordered for construction of a "first article" consisting of a complete MU with its VTL and a dummy load. The building that Atlas will occupy is being prepared for occupancy of the machine. Construction is planned to be complete by late 2000 or early 2001. A series of hydrodynamic and EOS experiments have been planned for Atlas in support of its role in stockpile stewardship. Other experiments such as magnetized target fusion experiments are being considered by interested parties.

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