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THE ATLAS PROJECT (U)

Author(s):

RHONALD KEINIGS, XPA
HUAN LEE, XPA
JAMES TRAINOR, PDO

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Current/Performance Scaling Studies for the Atlas Project (U)

Rhon Keinigs and Huan Lee (XPA) and James Trainor (PDO)

Los Alamos National Laboratory

Atlas is a high energy pulse power facility being built at Los Alamos to enhance our ability to address issues relevant to the Department of Energy's stockpile stewardship program.¹ Projected to be operational by 1999, Atlas is designed to deliver between forty to fifty megaamperes of current to an imploding cylindrical load, nominally a 70 gram aluminum liner. At this high of a current density, composite liners admit the possibility of performing shock compression experiments that achieve on the order of 30 Mbar. In addition to shock experiments directed toward investigating issues relating to equations-of-state, Atlas will be employed to study hydrodynamic instabilities, perform experiments in the strongly coupled plasma regime, and investigate material properties under extreme conditions. The high current that can be achieved with Atlas differentiates this facility from other pulsed power machines. Because of the current levels and the energy densities generated, much consideration has been given to the type of transmission line required to deliver current to the load. The merits and disadvantages of several designs have been studied and debated over the past year. As part of this study we have investigated the effect of changes in machine inductance on liner performance. Typically, whenever one tries to reduce inductance in order to increase current, the engineering design for a machine becomes more stringent. To address the issue of making changes in transmission line (TL) inductance we have used a one-dimensional MHD model to calculate the peak velocities for an aluminum liner, and the maximum pressures that can be generated when the liner impacts an aluminum target. The thicknesses and radii of the liners have been optimized for

a range of transmission line inductances that corresponds to the two principal proposed TL concepts. For these simulations we define "performance" to relate to the pressures generated in the target, although for some experiments this may not be the best indicator. The results indicate that an increase in inductance of $x\%$ results in a decrease in target pressure of approximately $x/2\%$. The two primary designs for the Atlas transmission line differ in inductance by 35%, implying a difference in performance of 17%, with the lower inductance design generating the higher pressure in the target.

The model we used to perform the simulations is RAVEN, a one-dimensional MHD code. In addition to including material properties such as strength and Sesame EOS, RAVEN incorporates a lumped circuit element model to simulate the effects of capacitor bank discharging and transmission line inductances and resistances. The Atlas circuit is shown in Fig. 1.

Fig. 1. Atlas circuit modeled in the RAVEN code

The bank capacitance, $C = 1250 \mu\text{f}$, and the bank inductance, $L_b = 2 \text{ nH}$. In this circuit branch there is a shunt resistance, $R_s = 34 \text{ m}\Omega$, and a damping resistor, R , which is required to keep the voltage reversal from damaging the banks. The damping resistance must be

reevaluated for each inductance case studied. The transmission line inductance is denoted by L_t , and the time-independent part of the liner inductance is defined by

$$L_0(nH) = 2h \ln\left(\frac{r_w}{r_o}\right) \quad (1)$$

In this equation, h defines the liner height in cm, r_w defines the return current conductor radius, and $r_o = r(0)$, where $r(t)$ defines the outer liner radius. For the simulations the liner height is fixed at 4 cm, and r_w is adjusted to give $L_0 = 1$ nH. The initial liner radius, r_o , is varied. The time dependent component of the liner inductance is given by

$$L(t) = 2h \ln\left(\frac{r_o}{r(t)}\right) \quad (2)$$

$L(t)$ is dynamically calculated by the MHD module in RAVEN and updated within the circuit model. However, only 5 MJ of the available 36 MJ of bank energy actually is converted into kinetic energy of the liner, and because of this poor conversion efficiency, $L(t)$ can be ignored in determining the correct damping resistance to use in the simulations. Also, because very little current passes through the shunt resistor, R_s can also be ignored. Neglecting these terms, the voltage on the capacitor can be approximated by that of a simple RLC circuit, and the damping resistance obtained from the constraint on the maximum reversal voltage permitted. The voltage on the capacitor is

$$V(t) = V_0 e^{-\nu t} [\cos \omega t + \frac{\nu}{\omega} \sin \omega t] \quad (3)$$

where the frequency is given by

$$\omega = \left(\frac{1}{LC} - \left(\frac{R}{2L} \right)^2 \right)^{-1/2}, \quad (4)$$

and the damping constant is

$$\nu = \frac{R}{2L}. \quad (5)$$

Defining the fraction of voltage reversal by $f = V(t_{rev})/V_0$, $\Psi = \pi/\ln(f^{-1})$, and doing some

algebra, one finds that the required damping resistance is

$$R = \frac{2}{(1 + \Psi^2)^{1/2}} \left(\frac{L}{C} \right)^{1/2} \quad (6)$$

For the Atlas banks the voltage reversal is limited to 15% of the maximum applied bank voltage of 240 kV. Therefore, setting $f = 0.15$ and $C = 1250$ μ f, the damping resistance t can be expressed as

$$R(m\Omega) = 9.25 \times 10^{-4} L^{1/2}(nH) \quad (7)$$

The total inductances and corresponding damping resistances used in the simulations are given in Table 1. At the time this work was being performed the two transmission lines being considered for Atlas had calculated inductances of 7.6 nH and 10.3 nH. For completeness we spanned a range of values for L that included these inductances.

Table 1

$L_t(nH)$	7.6	8.6	9.6	10.3	12.3
$R(m\Omega)$	2.55	2.7	2.87	2.9	3.2

The same circuit analysis used to determine R can also be used to approximate the peak current. With C measured in μ f and L measured nH one finds

$$I_p(MA) = 1.12 V_0(kV) \left(\frac{C}{L_t} \right)^{1/2} \frac{(1 + \Psi^2)^{1/2}}{\Psi} \exp\left(\frac{\tan^{-1}(\Psi)}{\Psi}\right) \sin \Psi \quad (8)$$

Note that the peak current scales as $L^{-1/2}$, seeming to indicate that higher inductance may translate into degraded liner performance. However, as pointed out by Lee², this decrease in current is partially offset by the increase in the time required to reach peak current, $\tau_p \propto L^{1/2}$. In other words, the liner is accelerated over a longer time period.

For the calculations our goal was to maximize the velocity of the inner liner surface, while requiring that 4 mm of the liner remain solid at impact. The liner mass and initial starting radius was varied for each inductance to achieve the goal. The outer target radius was fixed at 0.5 cm for all of the simulations. The current waveforms for four of the inductances modeled are shown in Fig.

Fig. 2 Current Waveforms.

2, indicating that the peak current is proportional to $L^{-1/2}$ and the time to reach $I_p \propto L^{1/2}$, as found in the simple circuit analysis. The bounce in the current waveform is due to turnaround of the outer liner surface.

The shock pressures generated in a 2 mm thick aluminum target, and the liner are shown in Fig. 3 for three inductances. These pressures remain constant for approximately $0.2\mu s$.

There appears to be a simple power scaling of pressure with inductance in the Atlas parameter regime. If one defines the lowest of the inductances as a reference inductance, L_{ref} , and P_{ref} to be the corresponding shock pressure generated in the liner and target, then one finds the pressure generated for a different inductance, L , to be approximately given by

$$P(L) = (1 - x/2)P_{ref} \quad (9)$$

where,

Fig. 3. Pressures in target and liner as a function of radial cell number.

$$x = \frac{L - L_{ref}}{L_{ref}} \quad (10)$$

Defining $\Delta P = P(L) - P_{ref}$ and $\Delta L = L - L_{ref}$ the pressure scaling can be reexpressed as

$$\frac{\Delta P}{P} = -\frac{1}{2} \frac{\Delta L}{L} \quad (11)$$

The normalized pressures obtained using the above scaling are shown in Fig.4.

Fig. 4. Normalized pressure.

References:

1. R. J. Trainor, et. al., "Overview of the Atlas Project", Presented at the 11th IEEE International Pulsed Power Conf., Baltimore, MD, July 1997.
2. H. Lee, "Optimal Design of Composite Liners for Generating Multi-Megabar Pressures by Magnetic Implosion", Proc. NEDPC, LA-13200-C, 1995.