ATLAS CHAMBER, POWER FLOW CHANNEL, AND DIAGNOSTIC INTERFACE DESIGN

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ABSTRACT

The Atlas pulsed-power machine, presently being designed at Los Alamos, will deliver a pulse of ~ 45 MA, in 4-5 μsec, with energies of up to 6 MJ (from a bank of 36 MJ maximum) to a load assembly, located in vacuum. Design considerations for the vacuum vessel, power flow channel from the vessel inward, are presented. In contrast to Sandia's PBFA II-Z, where 20 MA currents and 2-2.5 MJ of energy are delivered to (~15 mg) loads in ~ 100 nsec, the Atlas structures will have to be designed for longer timescales and higher energies to drive heavy liners (~70 g). Design issues for the chamber include materials stresses, formation of (and protection from) debris and molten jets, impulse loading, and survivability and ease of replacement of internal structures. For the power flow channel designs, issues are minimizing inductance, preventing movement of conductors during and after firing, damage mitigation, reducing the cost of materials and installation, and electrical insulation. A key issue for damage mitigation is the radius within which total destruction of material objects occurs. Choices of vessel size, insulator materials, cost and ease of manufacturing, and mechanical stability issues are presently in the conceptual design phase. Typical access requirements for diagnostics (including radial and axial X-ray backlighting, flux loops, spectroscopy, interferometry, bolometry, etc.) are provided for in the design.

INTRODUCTION

The Atlas machine design at Los Alamos[1] has evolved considerably in the last two years. It is now envisioned[2] as a 240 kV, 36 MJ, oil-filled vertical tri-plate transmission line machine, capable of driving hydrodynamic target loads at up to 45 MA currents with a 4-5 μsec rise time, with a shot rate of up to twice per week. The Atlas design effort has just completed Department of Energy key design review requirements, and is proceeding towards actual construction. The machine mission is to study the physics of high energy density regimes, focussing primarily on the high pressures achievable (~20Mbar) with imploding liner geometries. This paper outlines design considerations for the target chamber, power flow channel, and diagnostic interface issues.

VACUUM VESSEL REQUIREMENTS

The Atlas vacuum vessel serves three key functions: 1) It provides a vacuum for shots needing vacuum insulation or minimal gas at the load assembly; 2) It serves as the primary blast and debris containment device; and 3) It allows for varied diagnostic access and functions as a mechanical support for many diagnostics.

The vacuum vessel is expected to contain most blast and debris effects from the 6-12 MJ of energy and shrapnel, which will be dissipated within it. At the same time it will also

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provide mechanical support and access for various diagnostics, and vacuum for insulation as needed. The design base pressure is 10^{-6} Torr, achievable in 2-4 hours of pumping. The net time for pump-down should be less than 8 hours, so in-vessel work in the morning can be done, while still taking a shot in the afternoon of the same day. The vessel should mitigate damage from flying debris, and reduce the acoustic shock (overpressure) to the building from the implosion. It is expected that vacuum might be lost on each shot, and at the time of a shot, all pumps will be isolated from the vessel to prevent damage. The vessel must be quickly demountable in sections small enough to be lifted by the 15-ton overhead crane in the Atlas building. The vessel must accommodate both radial and axial diagnostics. The vessel must have appropriate mechanical supports (electrically isolated as necessary) to carry the static and dynamic loads of the target region to the building floor. This may include supporting additional dead weights inside the vacuum vessel which are required to inertially hold the PFC together. Finally, the vessel must be reusable, and the time to prepare it for the next shot should only be a few days (multiple vessels will be on hand).

DESIGN IMPLEMENTATION

Atlas will be the largest multiple-shot, pulsed-power machine in existence. It has been the experience on SHIVA-STAR[3,4] (< 9.4 MJ) and Pegasus[5] (< 4.3 MJ), (two similar, but lower energy pulsed-power machines), that from quasi-cylindrical implosions, most of the damage is axial. Sandia's PBFA II-Z machine[6] has a much faster timescale (~100 nanoseconds) than Atlas, although currents are about 1/2 of Atlas', and impulse is 100× smaller than on Atlas. PBFA II-Z uses a 3-m diameter target chamber, Pegasus uses 1-m diameter cylinder, and Shiva-Star used a 0.5-m diameter chamber. All three of these machines have used vacuum insulated power flow channels, typically with multiple convolutions to protect vacuum insulator from UV-induced breakdown from radiation producing loads. The innermost pieces of the power flow channel (PFC) and all of the target is obliterated on each of these machines. On Atlas, we are planning on up to a 1-meter diameter "zone of destruction". By judicious use of crushable "blast mats" hanging on the inner walls of the vessel, we have chosen a nominal 2-m diameter vacuum vessel as the smallest size that will comfortably survive the explosions, and allow room for replacement of necessary mylar or solid electrical insulation in the power flow channel. Vacuum windows on the vertical axis are likely to be destroyed on every shot. At a radius of 1-m, if we had 3-5 MJ dissipated in radiation (it won't be.... probably only 1-3 MJ at best), then the energy per unit surface area at the wall would be 30-50 J/cm^2 on a timescale of ~1 μsec. Typical laser radiation damage thresholds are in the range of 1-10 J/cm^2 in a few nanoseconds, and ion beams cause damage with the similar energy fluxes on 1 μsec timescales. So we may expect to ablate surfaces, and destroy optics. The key questions are what fraction of the energy will be available in shrapnel kinetic energy (what size, velocity, and spatial distribution); and what fraction of the energy will be radiated. Although the initial Atlas design had considered a more conservative 10-foot diameter vessel, we have chosen a 6-foot diameter to make fabrication easier, and also have more options to use multiple vessels.

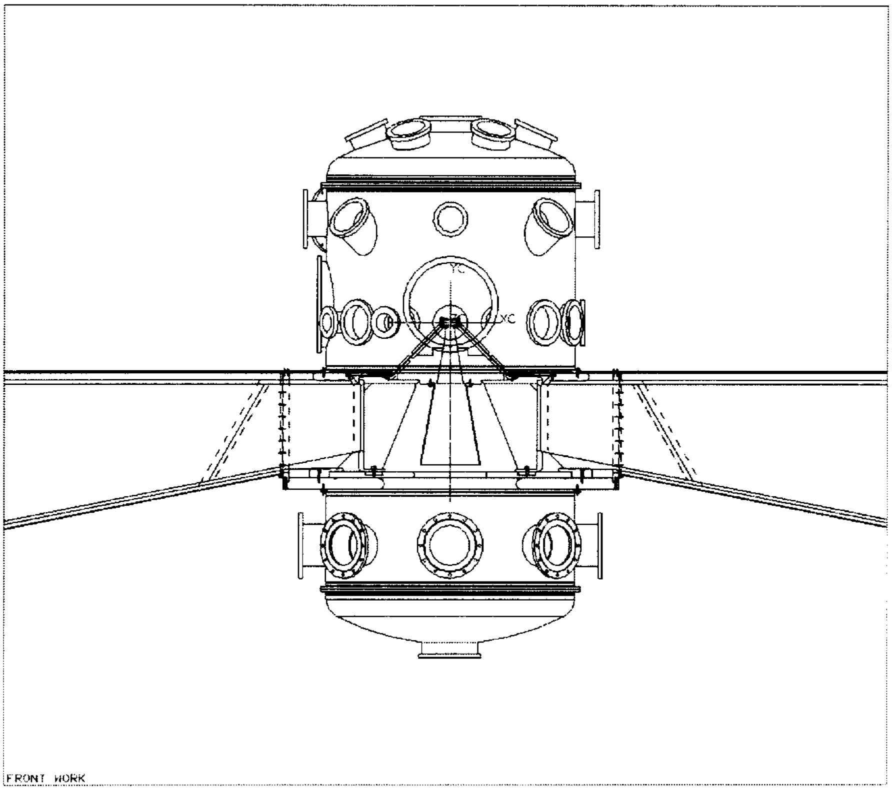

Figure 1: Cut-away section of the Atlas machine, including (from edge to center): vertical tri-plate, upper and lower vessel sections, PFC, and raised target.

The target is raised above the plane of the transmission lines, to allow for better radial access, at the expense of a somewhat higher inductance (~0.5 nH extra). It is important to minimize the displacement of the transmission lines and power flow channel, at least for the 5-15 microseconds of interest. This is accomplished by by placing large weights on the disk and conical transmission lines inside the vessel , The vessel is divided into upper and lower half sections, with a middle section containing the vertical tri-plate to flat bi-plate transition hardware. The top half of the transmission line will be at "ground", and the bottom half will be at high-voltage and insulated from the grounded chamber. An O-ring assembly with hold-down clamps will seal the vessel flanges to the disk transmission line structures. Figure 2 shows a 3-D CAD view of the top-half of the vacuum vessel. There are two 24" diameter ports for manhole or large beam laser backlighter access. The main radial access ports have a 25-cm diameter clear aperture at 46 cm above the transmission line deck, and will be used for radial x-ray radiography[7]. Multi-pulse axial radiography is also envisioned, although "seeing" through the glide-plane structures will be a challenge. The 25-cm (clear) ports are also provided for future compatibility with so-called "Ten-inch" manipulators (TIM) used on inertial confinement fusion (ICF) experiments (such as NOVA and OMEGA-Upgrade), which may enable the use of certain ICF diagnostics. Restrictions on radial axis will not come from the vacuum vessel, but will most likely be imposed by the outer coaxial conductor surrounding the load. The upper side ports either provide a direct view of the load, or are used for pumping and *do not* directly view the load.

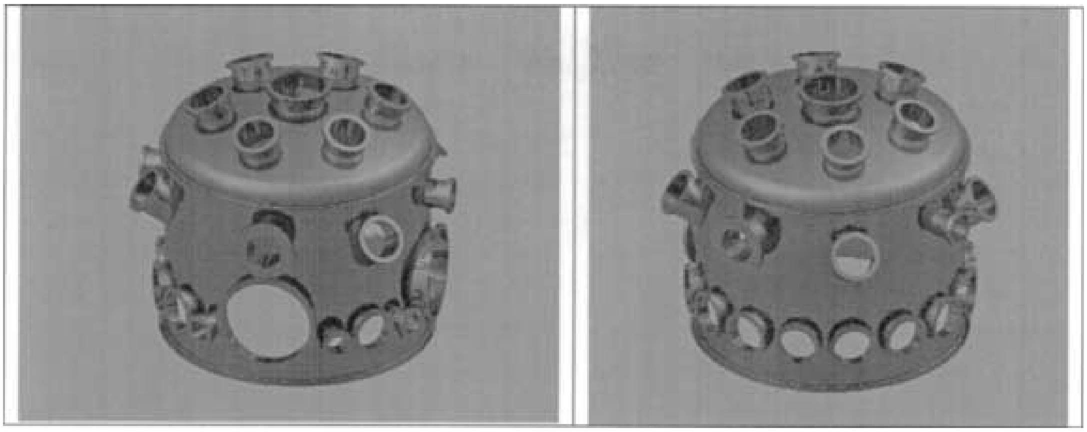

Figure 2: 3-D rendition of upper vacuum vessel for Atlas, showing variety of ports on both sides.

The main spool pieces (the cylindrical parts) of the vessel will be 1.9-cm thick stainless steel, and the domes will be spun from slightly thinner 1.25-cm stainless steel. Nominal weights of the vessel parts are estimated to be: upper dome 820 kg, upper spool 2450 kg, lower spool 1450 kg, lower dome 682 kg.

POWER FLOW CHANNEL

The Atlas power flow channel (PFC) transmits power from the transmission line system, which terminates at the vacuum chamber outer wall (r ~ 100 cm.), to the load (r ~ 6 cm). It is therefore located inside the vacuum/debris chamber. This is the most difficult component to design because of the extreme conditions this system is subjected to and because of the lack of experience operating under these conditions. For example, for a bi-plate transmission line system we estimate that at r ~ 28 cm the elastic limit of the conductors is exceeded, at r ~ 12 cm the inside surface of the conductor melts near the end of the pulse, and near the load at r ~ 6 cm the metal conductors are compressed by more than 10% by the magnetic forces. As an illustration of the impulsive forces imparted to the conductors, consider a 5-cm-thick steel-disk conductor located at r =10 cm. If unrestrained, this disk would reach a terminal velocity of 80 m/sec and would have the potential for significant damage to other parts of the system. Tests on the Los Alamos Ranchero explosive generator system are planned to gain experience under Atlas relevant conditions before Atlas comes on line. Key design requirements for the PFC are:

1. Low inductance – The power flow channel has to be kept to no more than 3 nH to meet the requirement on overall system inductance (<10 nH), which determines the maximum current delivered to the load. This requirement is difficult to meet because radial convergence of the current to the load makes this an inherently high-inductance component.
2. Survival during the shot – The PFC must maintain its mechanical and electrical integrity during the shot while being subjected to extreme separation forces (due to the very high currents) and high voltage (due to high rate of current rise). Electrical insulation of the PFC while at the same time meeting the 3 nH inductance requirement is a challenging design problem.
3. Damage mitigation – Damage to components upstream of the PFC due to the large forces on the PFC will have to be mitigated by breakaway connections at judiciously located positions. Also loading the system with weights to minimize the kinetic energy imparted to the structure by the large impulse during the shot will be required.

4. Rapid replacement between shots --- A significant fraction of the PFC will not survive after firing. This again is a result of the large magnetic forces imposed on the channel. To meet our shot repetition goal the hardware has to be designed for rapid replacement between shots.
5. Low cost – The cost of damaged hardware can dominate the cost of a shot has to be kept within the Atlas operating budget.
6. Diagnostic access --- The PFC can not interfere with diagnostic lines of sight to the load.
7. Current density at joints --- The attachment of the PFC to the transmission lines has to be made at a large enough radius so that current at the attachment does not damage the transmission line.

There are two designs under consideration. The first is a conservative design illustrated in Figure.1. In this design, power is transmitted to the vacuum chamber wall by the radially converging, vertically oriented, oil insulated, tri-plate lines, where a transition to the PFC is made. In this transition section, the multiple (39) oil insulated tri-plate lines are mated to a horizontal bi-plate insulated with solid dielectric for minimum inductance. Near the transition multiple sheets of Mylar are overlapped with a solid molded sheet of 0.5-cm-thick polyethylene used to insulate the final conical section of the transmission line leading to the load. The overlap length is about 50-cm long to eliminate surface tracking. The function of the final conical section of the transmission line is to transmit power to the load and to raise the load above the plane of the primary transmission line system for diagnostic access. Heavy steel weights (~5,000 kg) located on both the top and bottom conductors of the flat and conical transmission line sections provide inertia to limit transmission line motion during and after the shot. A key issue is termination the solid dielectric insulation at the load. Currently we plan to bring the insulated up through the radial gap between the liner and the outer return conductor of the load. This technique has been used successfully in Russia.[8,9] Another possibility is to terminate the insulation near the load allowing a vacuum channel between the liner and the outer return conductor. This approach has been used successfully in explosive driven experiments at the 20 MA level using the Los Alamos Procyon II generator.[10]

The second, more advanced PFC design, being studied uses a series of interleaved vertical fins to carry the current to near the load. This approach has three main advantages: (1) The inductance can be reduced by the use of multiple conductors;(2) The magnetic forces are dramatically reduced because the current is shared among multiple conductors (the forces on a single conductor scale roughly as the $1/n^2$, where n is the number of conductors); and (3) The forces are balanced so there is no net momentum imparted to the structure. The last two advantages eliminate the need for ballast weights and diminish the building static and dynamic floor-loading problem. The major disadvantages of this concept are the increased complexity and cost of such an assembly.

ATLAS DIAGNOSTICS

The diagnostics used on Atlas will depend on the experiments being conducted. The three major categories of experiments envisioned are: hydrodynamics, radiation flow, and basic physics. The list below is not meant to be all-inclusive, but gives a flavor of diagnostics under consideration.

- Axial and radial x-ray radiography, either by electron-beam driven flash x-ray sources or laser backlighting
- Magnetic field , Rogowski, and capacitive voltage probes
- Optical VISAR for measuring the velocity of a moving metal wall
- Spectroscopy and bolometry
- Gated and streak camera visible imaging
- Soft X-ray imaging (self emission)
- Infrared pyrometry for thermal impulse in materials
- Interferometry, shadowgraphy, and holography
- Time resolved neutron diagnostics
- Pressure measurement (Diamond Raman)
- Shock impulse arrival (Fiber-optic pins)
- Magnetic and electric field sensing (Faraday rotation, Kerr effect, etc.)

Most diagnostics will be supported from on the target chamber walls (such as radiography heads and other reentrant devices), or rest directly on the upper power flow channel surface (such as mirrors). We will attempt to shield or hide from direct blast (behind throw-away mirrors, if appropriate) any high-value diagnostic equipment. The Atlas target hall sits on top of a basement room which is intended as a location for a variety of laser diagnostics, including possibly a 1 kJ-class high- power short- pulse laser backlighter. Two large (61-cm diameter) access holes will connect the basement to the machine hall.

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