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DESIGN OF THE INDIVIDUAL MARX MODULES FOR THE ATLAS MACHINE 36 MEGAJOULE, 25 MEGAMPERE CAPACITOR BANK

by

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ABSTRACT

This paper presents the preliminary electrical and mechanical design of the Atlas machine's 1.8 megajoule, 600 kV Marx modules. The modules are implemented with plastic cased capacitors similar to those developed for the Defense Nuclear Agency (DNA) ACE II and ACE IV machines. The double ended electrode capacitor style has been dubbed "FASTCAP." Electrodes are provided for mounting rail-gaps on one side and flat plate transmission line damping resistors on the other. This provides for an extremely low circuit inductance. A series array of ten capacitors, each rated at 60 kV, 33.5 uF, and 60 kJ, with their five triggered rail-gaps, form a Marx submodule. Three Marx submodules are nested into a large G-10 fiberglass rack to form a complete Marx module. The module support rack has individual capacitor shelves that ease assembly and replacement. The Marx's design also facilitates construction, testing and verification of a modules performance prior to installation. Modules will be repaired or maintained in a separate test bay without affecting machine operation schedules. Railgap maintenance will become part of a regularly-scheduled preventative maintenance program as spare modules are installed and removed from the machine.

INTRODUCTION

The design parameters for Atlas were chosen to meet a broad range of performances suitable for studies and application to various stockpile stewardship issues. For hydrodynamic loads, with heavy liners in the 10 to 30 gram range, simulations that include liner melt have shown a broad peak in implosion kinetic energy in the 400 to 600 kV regime. With 1 gram liners, an excellent match and performance is attained for radiation loads. For other lighter, X-ray producing loads and opening switch experiments, time-scales and drive requirements are within the machine's capabilities.

A high reliability and shot rate is necessary to produce cost effective physics. After each shot, the target load region must be rebuilt, however rebuild of other machine components is not desirable. A modular system design eases maintenance efforts and affords swap-outs with pre-tested units, with a minimal down time. A modular design also facilitates industrial participation, since subsystems can be easily fabricated at the vendor site. The overall machine design does not require insitu assembly and repair. Since Atlas must fit into an existing building, with 6 foot thick concrete walls, the mechanical layout is rectangular, instead of a more conventional circular or square configuration. A rectangular machine design eases the fabrication and installation of the mylar transmission line insulation. Environment, safety, and health (ES&H) also impact the Atlas engineering design. System costs not only include the expense of handling large amounts of oil and specialty gases and their required ES&H add-ons, but also long term maintenance and required record keeping. These issues lead to our present design goals as shown in Table 1.

TABLE 1: COMPARISON OF CONCEPTUAL DESIGN VS. DESIGN GOAL

	CONCEPTUAL DESIGN	DESIGN GOAL
Insulation	Oil	Air
Capacitors	1200 x 30 kJ	600 x 60 kJ
Series Resistor	Electrolytic	Solid-Body
Shunt Resistor	Electrolytic	Solid-Body
Charging	MG/Inductor	Rectifier
Bank Layout	Race-Track	Rectangular
Modularity	No	Yes

The Marx modules have been designed to maximize their probability of successful (arc-free) use in air. A significant savings of over 200,000 gallons of oil, oil tanks, plumbing, oil processing, and secondary containment may be realized. If testing indicates oil is required, the modular design approach still permits incorporation of oil tanks. It is hoped to use pressurized air for railgap insulating gas, instead of Argon-SF6, to reduce ES&H concerns of gas venting. Our R&D program is examining various design and trigger issues to optimize railgap performance with air. To minimize electrical and mechanical component count and ease assembly, the capacitor design has been altered from a typical metal can and bushing, to a larger single Fastcap capacitor with a bushing at each end. Components mount directly to the capacitors and the plastic case has sufficient tracking length that it does not require any special insulation fixturing. To maintain a nearly critically damped capacitor bank, series and shunt resistor elements are required. This enables the use of high energy density capacitors that efficiently utilize building space. An additional benefit of damping resistors is the limiting of fault currents, fault energy, and fault coulomb transfer. Parasitic and transmission line ringing are nearly eliminated. To avoid reliability issues with electrolytic resistors and in an effort to increase reliability and maintain known values of resistance, solid body resistors have been chosen for Atlas. For the series damping resistors, reticulated vitreous carbon (RVC) foam plate resistors will be utilized. RVC resistors are available as a foam like glassy carbon material available with various pore size, ligament density, and ligament diameter. These characteristics may be altered to achieve the required resistance value. Constructed as large flat plates, the resistors will replace the more typical aluminum plates used in a flat plate transmission line. For the shunt damping resistors, a parallel array of rod style resistors may be used. The probability of railgap prefire can be mitigated by pulse charging the bank in 40 msec with a 1.5 GVA turbo-alternator available at our site. This would require an intermediate inductive energy store and opening switch system. However, we will examine prefire rates versus charge rate to determine the optimum cost benefit ratio. It is possible to charge from the local power grid in 12 seconds. Direct charging from the generator will permit charging in the 1 to 6 second regime. The Atlas building is located next to the generator building, greatly simplifying system inter-connects, if pulse charging is required.

MARX ASSEMBLY

Depicted in Figure 1 is the rear view of the capacitor Marx module assembly. Ten capacitors are stacked in each book-shelf style assembly forming a five level sub-Marx. Three sub-Marx' form a complete Marx module. The sub-Marx's are bracketed by vertical G-10 plates that form the Marx module assembly rack and lifting members. The railgaps mount directly to the capacitors with Multi-lam contact louvers used at the current joint interface. This mitigates the necessity of high torque and critical alignment connections. Carbon rod style charging resistors connect between the charging rails and railgaps. The resistors are captivated with a finger stock socket mounted into the charging rail and a clip on the railgap. The sharp corners of the resistor clip are electrically graded by a 1" diameter copper return bend. To simplify gas interconnects, a pair of vertical 3" schedule-80 pvc pipe are used as air supply and exhaust manifolds.

To remove a Marx module, the railgap triggers, diagnostic fiber optics, main gas feeds, and output transmission line must be disconnected. The trigger cable conduits and machine corona rings have removable upper sections to ease cable disconnection, routing, and provide temporary cable storage. The module and field grading plates can be air-padded away from the transmission line and mylar insulation. The travel limit is determined by the spacing between the module and conduits. The Marx may then be lifted from the grading plates. The Marx module has alignment holes that captivate the field grading plate's alignment pins. The whole assembly can then be air-padded and set into final position, which is also referenced to the overall machine assembly. Internal to the machine, air bladders press against the output transmission line, providing compression between the module and transmission line.

A front view of the Marx assembly is shown in Figure 2. The RVC plate resistors form a large transmission line that provides a low system inductance. Behind each resistor, a full sized G10 backing plate establishes the dimension for the resistor interconnect electrodes and provides resistor support for compressive loads. The backing plates' diagonal extension tabs interconnect to the structure's vertical members and prevents tilting of the Marx structure. The diagonal tab design also maintains a large tracking length between adjacent Marx stages and the resistor elements.

The side view of the Marx module is shown in Figure 3. To prevent arcing between the capacitor headers, the railgaps are fabricated with an integral flash guard. In the position between alternate capacitors, to also protect against arcing, an additional Lexan flash guard is installed. An individual trigger cable is used for each railgap and the braid is referenced to the negative charging rail. The negative charging resistor terminates the trigger cable impedance. The output transmission line is compressed against the Marx bank and RVC resistors with the pressurized air bladder system (not shown). Lifting eyes in each of the four Marx module vertical support members provide attachment points for the lifting fixture.

AIR INSULATED MARX MODULE

The Marx modules are designed to be able to operate in either air or oil. Minor design modification would be required for module operation in oil due to oil-seal issues with trigger cables. The trigger cable routing would have to be re-examined or a different trigger sub-master topology may be required. The techniques to achieve reliable air operation will be fully tested in the Atlas R&D program. The overall system layout facilitates in-air operation. The machine top transmission line plate is ground, with the lower, internal side the high voltage conductor. The building floor and walls are smoothly covered with sheet metal and grounded. This design locates the high voltage in a large faraday shield that assists in containing the EMP and defines the electric field lines. Under each Marx and trigger module, electrostatic field grading plates insure an even field distribution between the output and ground. The trigger cable conduits act as large corona rings that also grade potentials around the Marx. To prevent any edge or corner effects, the plates and pipes are continuous around the machine. The maximum field stress is below 17 kV/cm, with the present system configuration determined by capacitor case size. The field contour plot depicted in Figure 4 shows no regions with high gradients, all lines are smooth and evenly spaced.

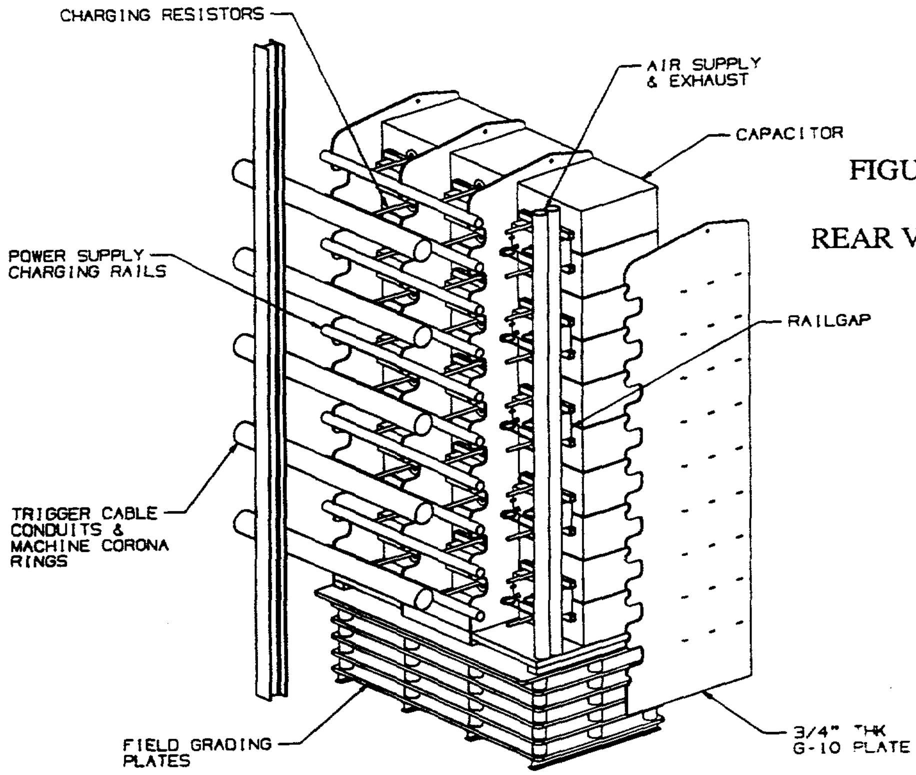
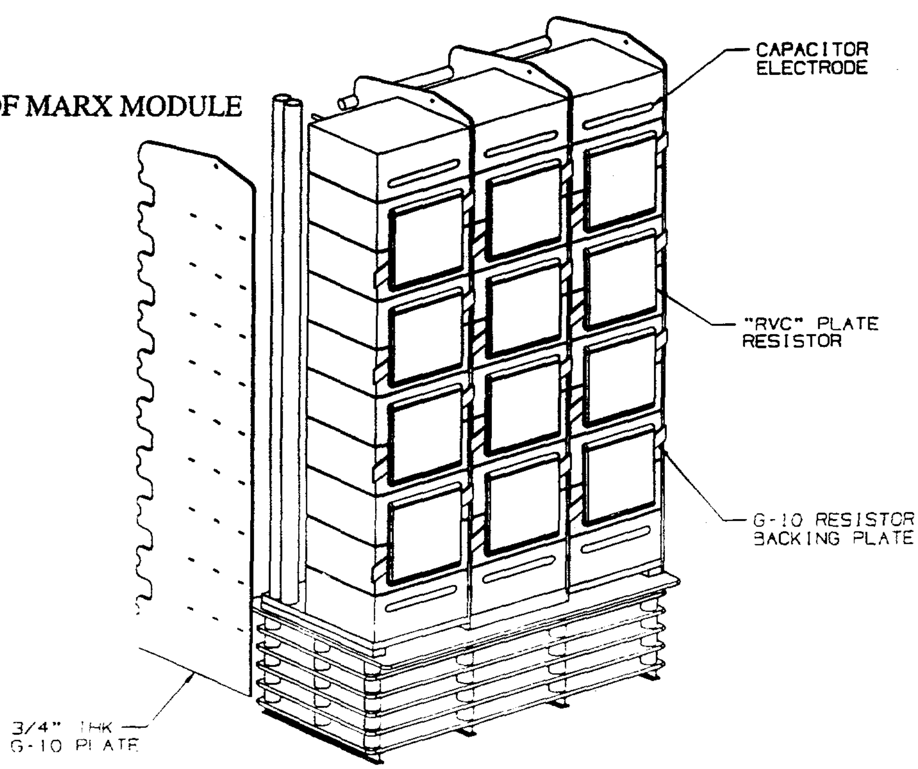


FIGURE 1:

REAR VIEW OF MARX MODULE

FIGURE 2: FRONT VIEW OF MARX MODULE



INDUCTANCE BUDGET

The Atlas air design does not sacrifice component spacing and the resultant added inductance to maintain voltage integrity. Electric fields during charging are along the capacitors (plastic case) length or through the Lexan flash guards. Capacitor foil pack design permits closely space capacitors. A list of the Marx inductance's are provided in Table 2. Worst case values are utilized to provide a conservative estimate of bank performance.

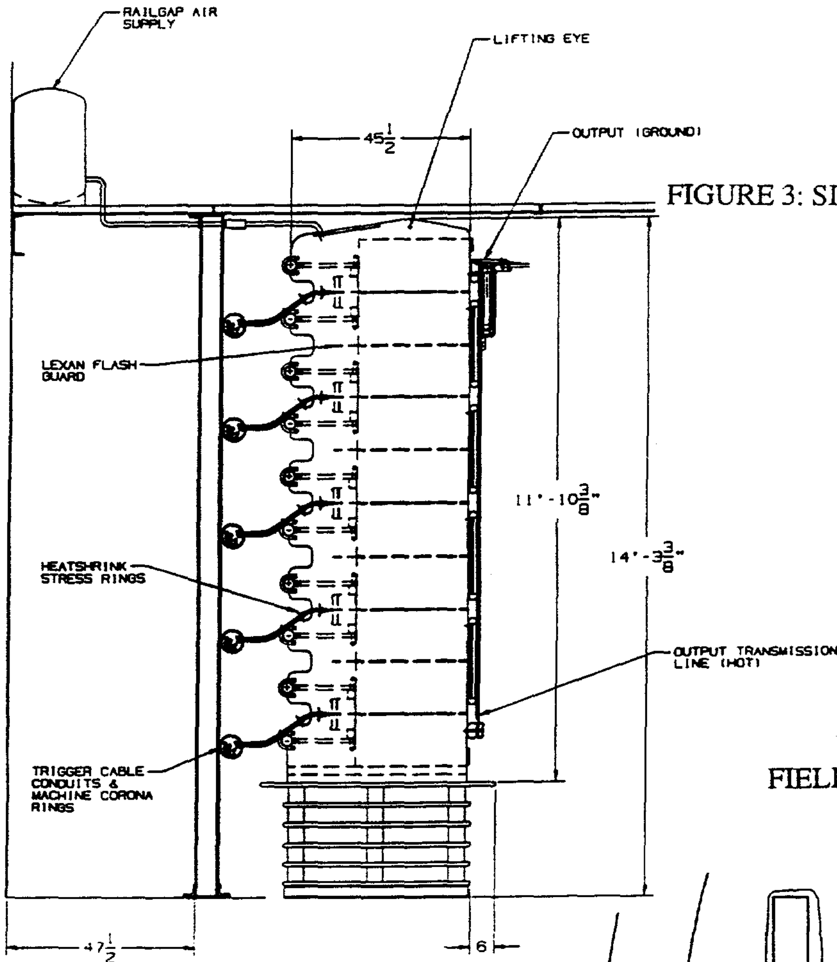


FIGURE 3: SIDE VIEW OF MARX MODULE

FIGURE 4:

FIELD PLOT OF GRADING PLATES

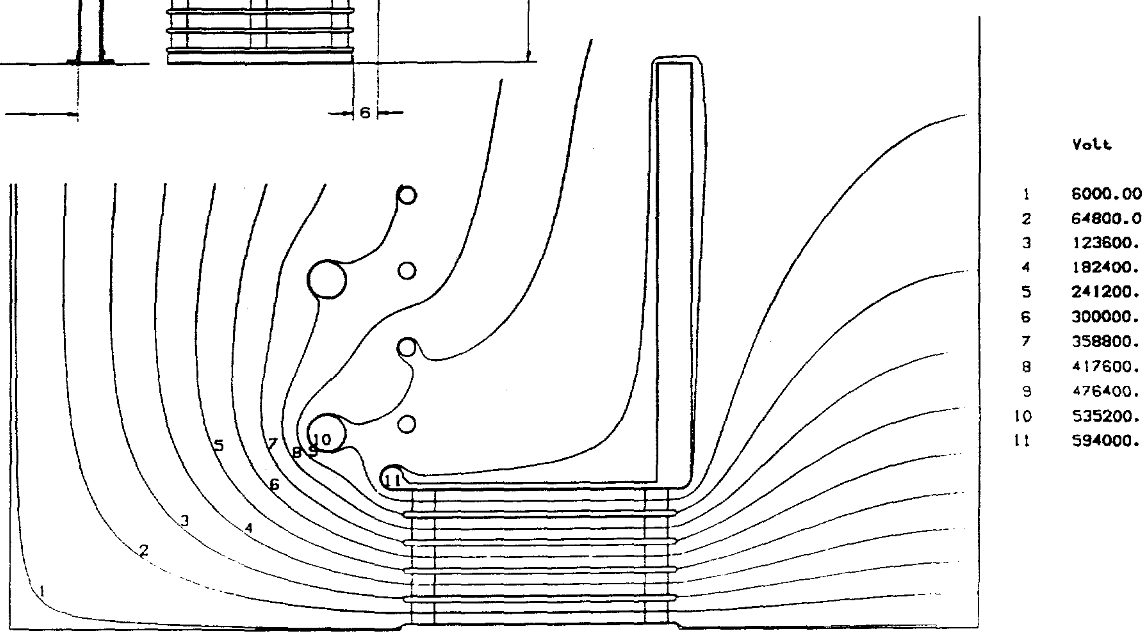


TABLE 2: MARX BANK INDUCTANCE'S

ELEMENT	NUMBER REQUIRED	UNIT INDUCTANCE	TOTAL INDUCTANCE
Capacitor	10	15 nH	150 nH
Railgap	5	25 nH	125 nH
Flux Between Capacitors	5	15 nH	75 nH
RVC Plate Resistors	4	24 nH	96 nH
Capacitor End Space	5	13 nH	65 nH
Resistor Mount	10	3 nH	30 nH

This results in about 541 nH for each of the 60 Marx modules and a total machine bank inductance of ~9 nH.

MECHANICAL DESIGN ISSUES

The structural housing for the capacitors will be made from woven glass-epoxy laminate, G-10. The G-10 comes as plates as large as 4' x 12,' which are then cut to shape on a water-jet machine. As an aid to assembly, tab-and-slot methods will be employed at the joints. For joints that will see a high shear load, the tabs will be Torlon dowels epoxied into holes in the G-10 sheets.

Four vertical sheets of 3/4" thick G-10 are the main tensile members. Cross-members of 5/8" thickness fastened across the back via pegs provide rigidity in the case of side loading. Additional rigidity is provided by a larger flat sheet extending across the top of the rack. Tabs of 1/4 " G-10 are inserted through the vertical members and fastened with epoxy. These tabs provide a support surface for the capacitors. Thicker sheets of G-10 attached to the vertical members via torlon dowels are used for the bottom layer of the rack. Although G-10 has insulating properties that make it desirable for use in our application, structural properties influence the design of the method of lifting the 26,000 pound capacitor rack. Preliminary G-10 testing at Los Alamos indicates that a single lifting eye has a average fracture load of 25,800 lbs. The eyes fail in a mode that is commonly attributed to primary tension, the fracture plane is perpendicular to the load axis, running horizontally across the face of the eye. With four eyes for rack lifting, the present design has a safety factor of ~4. The strength of the material will be reduced by fiber damage caused by cyclic tensile loading. We are currently examining other lifting-eye configurations to yield a higher safety factor.

CONCLUSION

The Atlas bank design is an evolutionary design based on the Maxwell Laboratories ACE machine designs. Improvements in reliability will be obtained by resistively damping the capacitor elements and disc transmission line. By appropriately choosing system geometry and potential grading methods, air operation should be realizable and reliable. Bank charging rates will be evaluated in the Atlas R&D effort to determine the appropriate method for reliable machine operations.

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