RESULTS FROM SANDIA NATIONAL LABORATORIES / LOCKHEED MARTIN ELECTROMAGNETIC MISSILE LAUNCHER (EMML)[*]

M. S. Aubuchon[†], T. R. Lockner, B. N. Turman
Sandia National Laboratories, P.O. Box 5800, MS-1182, Albuquerque, NM 87185

G. Root, L. Basak, R. Gaigler, B. Skurdal, M. Floyd
Lockheed Martin MS2, 2323 Eastern Boulevard,
Baltimore, MD, 21220

Abstract

Sandia National Laboratories (SNL) and Lockheed Martin MS2 are designing an electromagnetic missile launcher (EMML) for naval applications. The EMML uses an induction coilgun topology with the requirement of launching a 3600 lb. missile up to a velocity of 40 m/s. To demonstrate the feasibility of the electromagnetic propulsion design, a demonstrator launcher was built that consists of approximately 10% of the propulsion coils needed for a tactical design. The demonstrator verified the design by launching a 1430 lb weighted sled to a height of 24 ft in mid-December 2004 (Figure 1). This paper provides the general launcher design, specific pulsed power system component details, system operation, and demonstration results.

Figure 1. Demonstrator launcher; Launcher – bottom left; Weighted sled and missile form – top middle

I. INTRODUCTION

A. Overview

Several hybrid/electric military platforms are being developed for future deployment that will provide an onboard power source capable of driving electromagnetic weapons. Examples of these platforms are the Navy's DDX electric ship & the Army's Future Combat System (FCS) hybrid ground vehicle. There are many different types of electromagnetic weapons including lasers, high power microwaves, particle beams, and mass launchers, all of which have ongoing research to identify their advantages and disadvantages compared to conventional weapons. Several types of mass launcher topologies exist including linear synchronous motors (LSM), linear induction motors (LIM), railguns, and coilguns.

The Electromagnetic Missile Launcher (EMML) is a mass launcher using an induction coilgun topology. The EMML electromagnetically imparts kinetic energy into the missile such that it will exit the launcher and maintain aero stability until the main rocket motors are engaged (Figure 2). The launcher performance parameters are based on launching a Tomahawk type missile with a weight of nearly 3600 lbs.

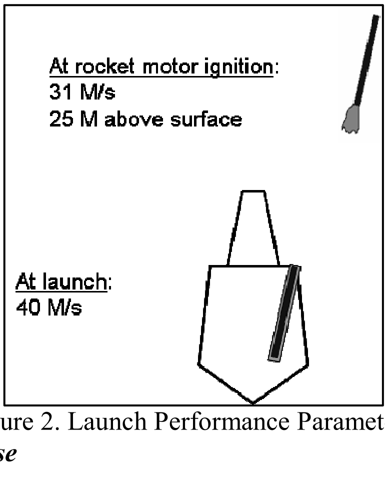

Figure 2. Launch Performance Parameters.

B. Purpose

---

[*] This work was conducted under a Sandia National Laboratories / Lockheed Martin Cooperative Research and Development Agreement (CRADA) No. SC99/01573, Project Task Statement No. 1573.31

[†] E-mail: msaubuc@sandia.gov

Our efforts are aimed at developing novel technology that solves several possible issues facing future naval missions. Current vertical launching systems (VLS) require that missiles be ignited within the launcher on the ship (known as a "hot launch" system). The missile produces hot gasses that must be ducted out of the launch compartment. The gas management system (GMS) has ventilation ducting lined with ablative material in order to protect the internal structure of the ship. After leaving the launcher the exhaust gasses heat the deck surface which remains at an elevated temperature for a period of time after the launch. For future ships with electric propulsion systems and stealth technology this thermal signature is unacceptable. Also as larger missiles are developed with longer booster burn times, such as the kinetic energy interceptors (KEI) class missiles, the GMS may become unacceptably large and heavy.

The EMML solves these issues by replacing the GMS with EM propulsion and reduces the residual deck heating by keeping propulsion coil I^2 R losses hidden inside the ship. It is readily scalable to larger missiles and provides other advantages such as reducing or eliminating the propellant required for the initial boost stage.

C. Coilgun Technology

The (induction) coilgun is a type of electromagnetic mass launcher that uses the Lorentz force to accelerate a projectile. A coilgun consists of a stack of outer coils forming the "barrel" (stator) that generates a magnetic field which pushes a second, coaxial, single coil axially along a guide-way. The moving coil is referred to as the armature. A typical induction coilgun has a shorted armature in which current is induced by the changing magnetic flux from the outer coils. The induced armature current interacts with the magnetic field from the outer coils and produces a J x B force propelling the armature along the guide-way.

Each coil is driven by its own capacitor bank. Energy is stored up in capacitors and then discharged through the coil at the appropriate time. More details on the operation of a coilgun can be found in the listed reference [1].

II. EMML DEMONSTRATION

To demonstrate and validate the EMML propulsion design, a portion of the full scale design was fabricated, assembled, integrated, tested, and demonstrated. The launcher demonstrator consisted of several components: the electromagnetic propulsion system (coils, power storage, switching charging power supply), the launch control system (coil discharge sequencing), the launcher structure, the canister, and the weighted sled (payload, adaptor, armature, missile form). Approximately 10% of the total propulsion coils required to meet the EMML launch performance parameters previously discussed were fabricated. Although only a portion of the full scale EMML design was fabricated, the demonstrator was capable of meeting the energy and physical cross-sectional size requirements.

A. Design

The demonstrator launcher had several driving requirements. An 800+ lb representative missile mass, fitting within a specified geometry, needed to be launched out of the canister using EM propulsion. The weighted sled had a mass of about 1430 lbs (excluding the 25 lb missile form) representing a missile, the armature, and an adaptor to hold the missile and armature together. The weighted sled had a lower mass than the EMML design goal in order to demonstrate the launch of an intermediate missile class as a path to the heavier missiles. A typical simulated acceleration profile of the demonstrator launcher is shown in Figure 3. It does not correspond to the demonstration launch but is representative of the acceleration and velocity profiles.

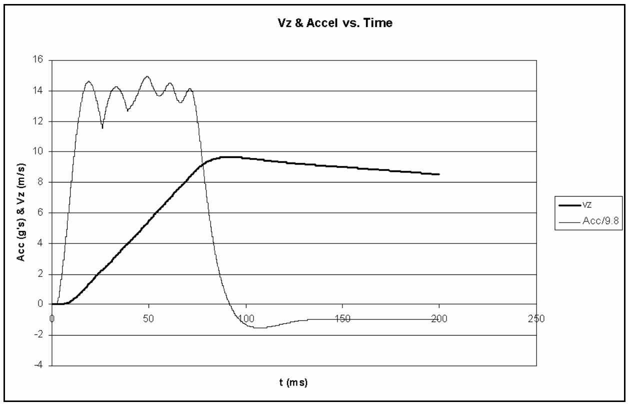

Figure 3. Typical plot of simulated performance

The geometry was specified such that it would accommodate current missiles in the United States Navy (USN) inventory, which forced some launcher parameters to be less than optimal. VLS systems have a square footprint to accommodate the missile envelope and to decrease the launcher footprint for maximum packing density. Thus the EMML demonstrator had a square footprint to accommodate the missile envelope, adaptation hardware, and to decrease the launcher footprint. In addition to increasing the difficulty of fabrication, the square geometry increased the radial loading on the coils. The square canister structure also introduced a vertical support structure in the corners which reduced the coupling efficiency between the outer coils and the armature.

Figure 4 is a diagram of the demonstrator launcher geometry viewed from the top down. There are several layers described below. From the outside working inward (Figure 5): 1) Structural composite form, 2) outer coil, 3) structural composite form, 4) gap between outer coils and canister, 5) canister with structural corner supports, 6) armature coil, 7) armature metal form with bolt pattern for attaching other experimental items, 8) center hole.

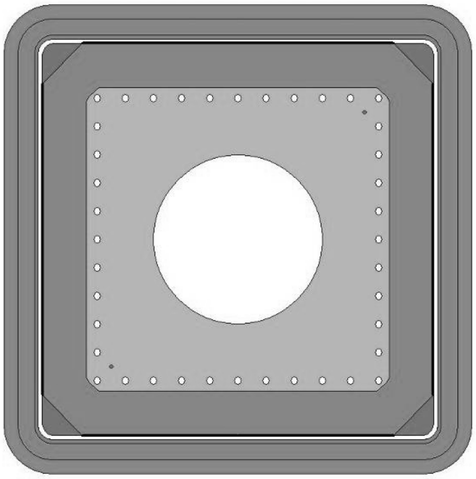

Figure 4. Top down view of EMML geometry

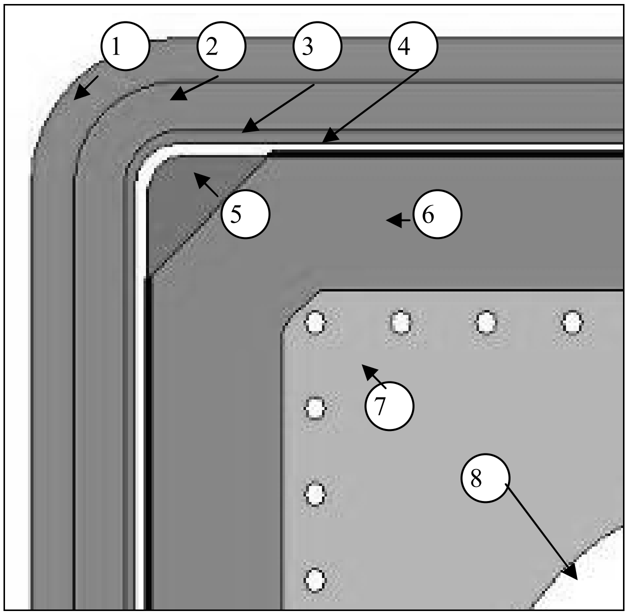

Figure 5. Close-up of geometry

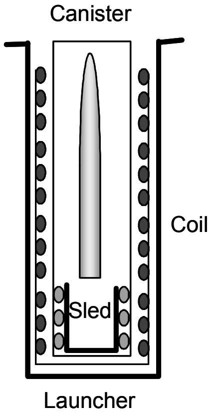

Figure 6. Notional drawing of EMML geometry

Figure 6 shows a notional cross section of the EMML geometry implemented in the demonstrator launcher. The sled contains the armature and missile adaptor and the acceleration coils are positioned outside of the canister. Note that the magnetic fields generated by the outer acceleration coils need to penetrate the canisters metal skin before interacting with the armature.

B. Fabrication

Fabrication and assembly was performed by Sandia and Lockheed Martin. Sandia provided the propulsion coils, armature, capacitor banks, power supply, launching test area, and electrical diagnostics. Lockheed Martin provided the launcher support structure, canister, weighted sled (payload, adaptor, and missile form), indoor testing catching mechanism, and launch control electronics for pulse timing. The following discussion will focus on the pulsed power and coilgun propulsion system.

The propulsion coils and armature were designed, structurally analyzed, and fabricated at Sandia. The coils were wound with a winding fixture (Figure 7) and then transferred to a composite coil form. They were then potted in low viscosity epoxy (Figure 8). Finally, terminals were attached to the form and the entire coil was aligned in the launcher structure (Figure 9).

Figure 7. Winding coil on spool

Figure 8. Applying adhesive to bond lid on outer coil

Simulations indicated that a solid aluminum armature was acceptable for the demonstration launcher versus a wound copper armature. The solid armature, compared to the wound armature, was more robust, cost less, and was easier to build. It also mitigated the potential destruction caused by the weighted adaptor landing on top of the armature in the sand pit (Figure 10). For a tactical design a wound copper armature is required due to the acceleration time. Several lower energy tests were conducted with the wound armature to verify its performance but it was not subjected to an outdoor launch.

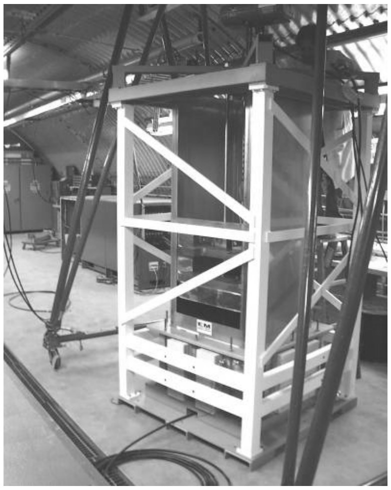

Figure 9. EMML Launcher structure, canister, propulsion coils, armature and weighted adaptor

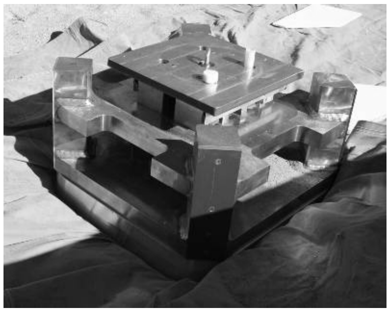

Figure 10. Armature and weighted adaptor in sand pit after launch

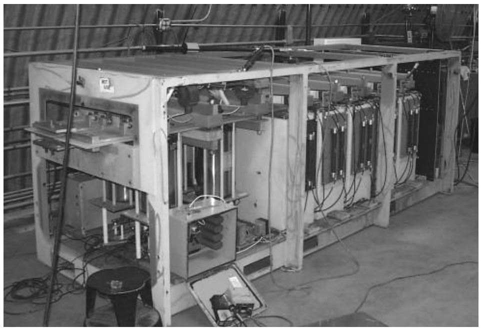

Figure 11: Single capacitor bank

C. Power Storage - Capacitor Banks

Each stage of the demonstrated coilgun was driven by an independent capacitor bank. To minimize cost, banks from a previous experiment were used (Figure 11). Each bank had a capacitance of 8mF, was rated for 10kV, and could source greater than 10kA. The banks used an ignitron mercury switch as the main closing switch. These banks were substantially larger than required in terms of energy for the EMML testing and demonstration. The demonstrator launcher used less than 10% of the possible stored energy in the banks, but the high capacitance was required because of the low velocities and relatively long pulse lengths.

D. Results

Table 1 lists parameters from the December 14th 2004 EMML demonstration that took place at Sandia.

Parameter	**Value**
Mass launched:	1430 lbs.
Launch angle:	10°
Peak vertical height of launch:	24 ft
Peak velocity:	12 m/s
Peak acceleration:	17 G's
Acceleration distance:	45 cm
Horizontal distance of launch:	14 ft
Final mechanical energy:	47.9 kJ
Total stored electrical energy for launch:	275 kJ
Efficiency of launch (total mechanical energy / total stored electrical energy):	17.4%
Capacitance per stage:	8 mF
Stored energy per stage:	55 kJ
Charge voltage (all banks):	3.7 kV
Peak stage current:	910 A

Table 1. Parameters from demonstration launch

III. CONCLUSION

The Electromagnetic Missile Launcher (EMML), developed by Sandia National Laboratories & Lockheed Martin MS2 had a successful demonstration milestone. The demonstration showed the feasibility of using EM propulsion for launching a representative missile mass. To the author's knowledge this was the largest mass ever launched with induction coilgun technology. Additionally, this demonstration validated the design and manufacturing techniques for an EM launch application of this scale. Further development and testing of the design is planned.

IV. REFERENCES

[1] Ronald J. Kaye, "Operational Requirements and Issues for Coilgun Electromagnetic Launchers", IEEE Transactions on Magnetics, v.41, no.1, pp. 194-199, January 2005