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TITLE: HIMASS ELECTROMAGNETIC LAUNCHER AT LOS ALAMOS

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INTRODUCTION

Data collected from the experiments were used to further understand the effects of bore size, projectile mass, and materials used in the sidewall insulators on the overall performance of the EML. Plans for future experiments, based on these results, may include solid armature projectiles and better wrapping techniques for higher barrel strengths.

THE RAIL GUN

The gun inductance of $\sim 0.35 \mu\text{H/m}$, coupled with current inputs of 3-4 MA, produced calculated peak plasma pressures of $2.0\text{-}3 \text{ MPa}$. Rail forces were calculated to be $\sim 3 \times 10^7 \text{ N}$, with a dL/ds of $9 \mu\text{H/m}^2$. Using these parameters, we could determine the pre-load level on the Kevlar winding [2]. In both experiments, the barrels survived quite well, and, with some end trimming at the breech to remove burned areas, were reusable.

THE EXPERIMENT

The railgun capacitor bank is coupled to the generator with coaxial cables. The output from the generator is fed into the flat-plate inductor through 48 coaxial cables. Heavy copper transition plates connect the railgun to the inductor.

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HIMASS RAILGUN

C.R. STEEL

36°

10 cm

7.86 cm

2.54 cm

308 cm REVLAP FILAMENTS

SIGNAL

TRANSVERSE CURRENT PROBE(S)

Cu

Cu

C.R. STEEL

MODEL SHOT IN OCT 1985

Fig. 1. Cross section of a wrapped railgun.

Fig. 2. Schematic of railgun experiment.

Velocity measurements were obtained by x-ray flash time-of-flight photos. X-ray film was mounted near the muzzle, parallel to the projectile path. To confirm velocity measurements, we also used wire gate switches.

Rail deflection measurements were obtained at various positions along the top of the barrel starting at the static projectile position. Deflection data were obtained using lead-cored inertia gages anchored to the outer shell of the gun and extended downward until the tip of the gage rested on the rail backup plates (Fig. 3). At peak current, the inductor feed plates were explosively shorted to prevent energy losses.

EXPERIMENTAL RESULTS

Armature voltage measurements obtained using a Pearson 411 current transformer are shown in Fig. 4.

Fig. 3. Inertial lead foil gages.

Fig. 4. Current and voltage measurements.

Plasma armature voltage measurements are important parameters that are necessary in the design of large-bore, large-current launchers. These data directly determine the power dissipation and indirectly define the system efficiencies and wall ablation. The current wave form is also shown as a reference.

The current wave form has three distinct phases. The first phase (0-430 μ s) is a quarter cycle sinusoid wave with a peak current of 160 kA. Both the power and energy input are small, $\sim$ kW/cm³ and 30 J/cm³, respectively.

The second phase (430-630 μ s) shows the rapid current rise as it peaks at 2.6 MA and causes the plasma to become highly ionized. Here the peak power reaches 3.7 MW/cm³ and the energy input to the plasma reaches 280 J/cm³ with a corresponding resistance drop to 0.5 m Ω .

The third phase extends from the peak current to the end of the current flow. The plasma resistance remains nearly constant during this period even though substantial power and energy continue to be dissipated in the plasma. Table I compares the current and voltage measurements for various bore sizes from previous experiments.

The current in the inductor was measured with a Faraday rotation scheme that used a helium neon laser beam fed through an optic fiber cable. This scheme gives a very clear electrically noise-free signal [3] and is particularly applicable to large currents.

TABLE I
PLASMA VOLTAGE FOR VARIOUS BORE SIZES

Test ^a	Bore (mm)	Current (kA)	Current/width (kA/mm)	Voltage Gradient (V/cm)
HIMASS	100	2600	25	132
HYVAX	11	200	20	130 $\pm$ 10
PVE	6 x 25	136	21	132 x 5

^aLos Alamos railgun experiments.

The signal level obtained is directly proportional to the number of turns of fiber optic cable wrapped around a current-carrying conductor. This method of current measurement is not affected by stray magnetic fields outside its loops nor is it distorted by any high voltage.

An array of magnetic pickup probes was used to provide valuable information relative to plasma-current parameters and projectile and plasma velocities [4]. These probes are evenly spaced along the side of the gun barrel (Fig. 1). The integrated signals are shown in Fig. 5. An in situ current calibration is done before firing.

For HIMASS Shot No. 2, Fig. 5 shows the signal output from the first 5 probes. The calibration wave forms show that the probes have a time-dependent response because of current diffusion into the rails. The probes used in this experiment have a measured response of 0.25 V/MA at early times and 0.16 V/MA at late times. The wave forms illustrated have not been corrected for this diffusion-time dependence. For qualitative interpretation, this can be neglected.

From the time of onset of each signal, a trajectory can be derived for the plasma armature. Lack of signals early in time suggest that no breakdown occurred ahead of the projectile. The smooth current rise shows that there was a single arc, with no restrike. No external breakdowns were detected. The rise time of the current (dI/dt) gives a crude measurement of the plasma armature length. A plot showing the trajectory of both the beginning and end of the current wave form suggests a plasma length of $\sim$ 15-20 cm.

Fig. 5. 8 probe current curves.

X-ray time-of-flight photos give a precise velocity measurement. On the x-ray shown in Fig. 6, the difference in actual distance divided by the time difference of the two exposures gives a velocity measurement of 1 km/s. The measured distance on the x-ray film was 1 m and the x-ray pulses were spaced 10 μ s apart. Wire gate switches were also used as a backup velocity measurement. Plasma exiting the gun ahead of the projectile coated the entire gate structure causing a short circuit in the wiring. No information was obtained from the gate switch.

CONCLUSIONS

A comparison of the results of the HIMASS Shot No. 2 data with the results of other devices (see Table 1), suggests a mathematical model, which can be used to predict railgun parameters for various railgun configurations. By allowing for the ablation models developed at Los Alamos [4,5], we determined that the measured velocity was very close to the predicted velocity. X-ray time-of-flight photography is indeed an excellent velocity-measuring method.

The next planned HIMASS shot will incorporate a solid armature projectile. This should allow maximum use of available power because the solid metal armature will have a much lower resistance than it would have if it flowed through a plasma arc.

ACKNOWLEDGMENTS

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