NRL Materials Testing Facility

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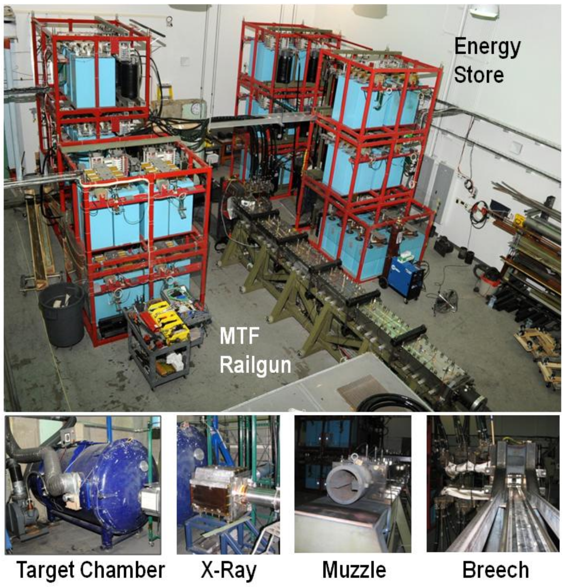
Abstract- The Naval Research Laboratory performs basic research on high power railgun electric launchers. The program uses a 1.5-MJ, 2.5 km/s launch velocity railgun located in NRL's Materials Testing Facility. The railgun consists of an 11-MJ capacitive energy store configured as 22, 0.5-MJ modules. Each bank module has an independently triggered thyristor switch, series inductor, and crowbar diode and is joined to the railgun breech with coaxial cables. Individual bank timing and charge levels can be set to produce up to 1.5 MA peak current and 4-5 ms long current pulses. The 6-m long railgun used a nominally 5 cm bore diameter with steel or copper rails and epoxy laminate insulators. The muzzle contains a Tungsten-Copper arc horn to minimize damage from residual drive current upon launch. Aluminum armatures with acrylic bore riders are used for the launch package. Launch data is recorded digitally and analyzed using in-house computer codes. The system design and operation will be discussed.

I. INTRODUCTION

The Naval Research Laboratory has operated a railgun laboratory for the last 5 years [1]. The Materials Testing Facility (MTF) houses a 6 m long, 1.5 MJ launch energy railgun coupled to an 11 MJ capacitive energy store. The railgun is designed to allow flexibility in core design and access for diagnostics. The status of the facility and some of the in situ and ex situ diagnostics will be discussed.

II. MTF LABORATORY

Fig. 1 shows a picture of the MTF facility including the capacitive energy store and the 6-m railgun. The figure includes pictures of the target chamber, dual-axis flash x-ray imager, muzzle arc containment, and the breech. The focus of the NRL program and the MTF laboratory is the basic physics of high power railgun operation. The system is sized to reach relevant power and current levels while allowing operation in a laboratory environment. The railgun recently fired its 1000th shot in this effort.



Target Chamber X-Ray Muzzle Breech

Figure 1. NRL MTF Laboratory and the MTF Railgun.

Fig. 2 shows a close up of the MTF railgun. The railgun is divided into six 1-m long 304 stainless steel segments and clamped together with vertical thread rods and auxiliary steel supports. The entire structure is mounted on an epoxy laminate base. Current is fed through a breech arrangement with several "toe" clamps holding the rails in place. The rails are terminated in tungsten copper electrodes which arc to steel electrodes in the muzzle. The muzzle blast is contained by a cylindrical steel structure. Magnetic field probes are located along the length of the gun to measure the location of the armature as it is accelerated down the barrel. Voltage probes are located at the breech and muzzle to monitor the voltage across the rails at these locations.

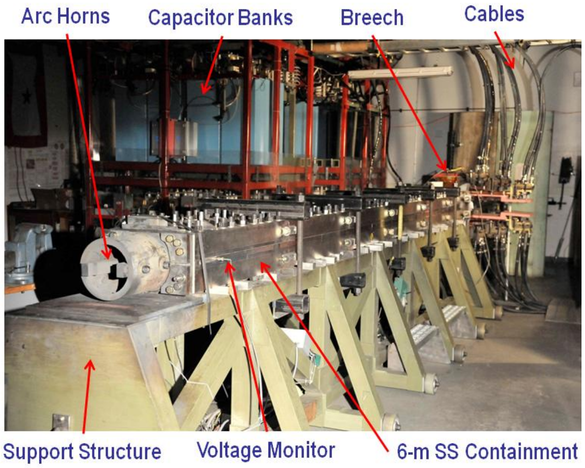


Figure 2. MTF Railgun

Fig. 3 shows a cross section of the railgun. The rails are mounted vertically. Thin liners of different materials are used next to a one inch thick copper backing rail. The rail spacing is determined by a set of "T" insulators located on the top and bottom of the core. The figure shows a nominally 1.8 inch x 1.75 inch flat rail core. Epoxy laminate material (G10) is used for the "T" insulator and for the insulators surrounding the rails. The stainless steel containments clamp the core in place. A set of wedges located inside of the containment are adjusted to provide pre-load to the rails. Different core designs can be substituted for the square bore design shown in the figure by altering the insulators. The solid containment design limits the inductance gradient for the system to ~0.4 micro-Henry/meter due to return currents driven in the containment.

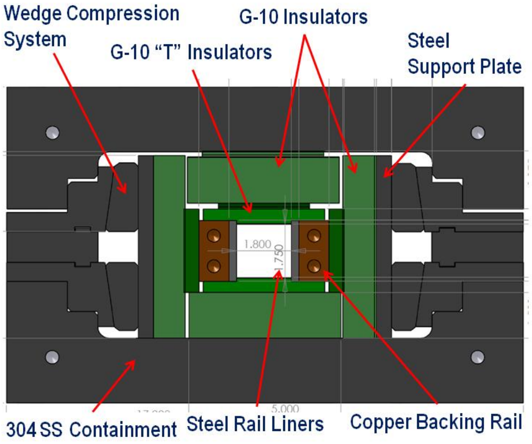


Figure 3. Cross section of MTF railgun.

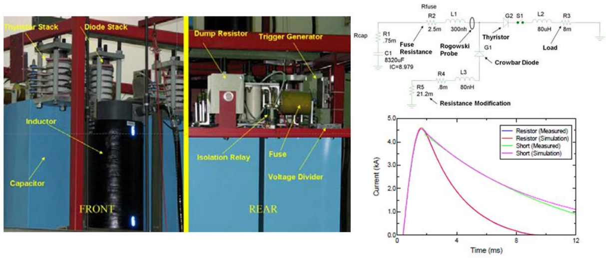


Figure 4. MTF Capacitor Bank Design and circuit model.

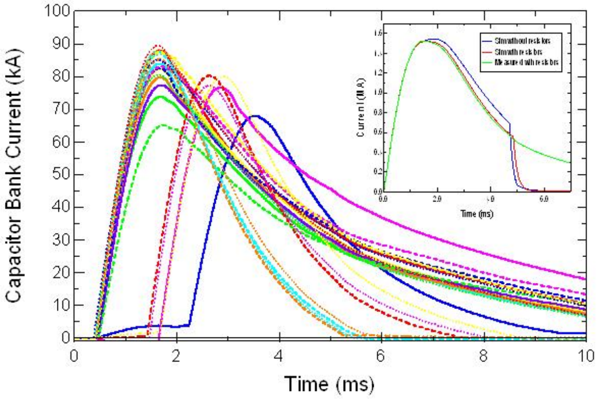


Figure 5. Waveforms produced by individual capacitor banks.

III. CAPACITOR BANK DESIGN

Fig. 1 shows the capacitor banks stacked close to the breech of the railgun. There are twenty-two 500 kJ solid state switched capacitor banks connected to the railgun [2]. Fig. 4 shows the details of a single bank. The capacitor banks are charged in parallel from several independent power supplies. A thyristor stack is triggered to connect the banks to a series 80 micro-Henry inductor and the railgun. A circuit model for a module of the bank configuration is shown in the figure. After peak current a diode stack shorts out the bank isolating the railgun from the banks and trapping the energy in the inductor. A resistor located in the diode leg provides a series resistance for the individual bank module allowing the decay time of the current from a particular bank to be modified [3]. The effect of the resistor can be seen on the graph in Fig 4. The different banks can be independently triggered allowing one to modify the current waveform delivered to the railgun. Fig. 5 shows a typical set of current profiles from the different banks. The use of the resistors and the different bank timings allow one to program the wave form. The goal is to generate a relatively flat topped current waveform but decrease the muzzle current to minimize muzzle arc damage.

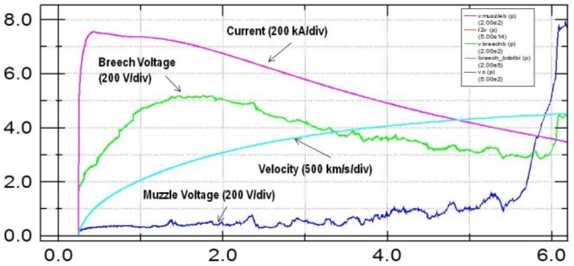


Figure 6. Waveforms produced by a 1.5 MA launch of a 500 g launch package.

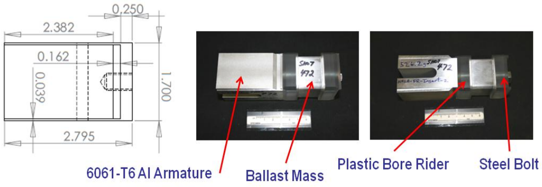


Figure 7. Launch package design.

IV. LAUNCH PARAMETERS

Fig. 6 shows a typical set of launch parameters for a simple armature shown in Fig. 7. The current waveform generated by delaying some number of the bank modules produces a ~1.5 MA peak and ~750 kA current at the muzzle. The breech voltage reaches ~ 1 kV for the 500 g launch package (LP) used in this test. The velocity profile is shown reaching 1 km/s within the first meter of launch and 2.3 km/s at muzzle exit (6-m). The velocity trace is generated using the array of magnetic field probes and fitting the data to a smooth curve. The muzzle voltage measured at the 5.75 m location is ~100 V for the first 4.5 m of the launch until it starts to ramp up, reaching over 200 V by muzzle exit. The launch package (LP) used in this experiment is shown in Fig. 7. This simple "C" style armature was designed to survive the launch acceleration. The armature legs were thick enough to withstand the action ($\equiv\int I^2dt$) generated by the current waveform shown in Fig. 6.

Fig. 7 shows a picture of the dual-axis flash x-ray imager located 5 meters downstream of the muzzle. The imager uses a trigger coil just upstream of the chamber [3]. Two orthogonally mounted x-ray heads provide an image of the LP before it strikes a steel target plate in the target chamber. The figure shows several x-ray images. In some cases the legs start to melt or crack off resulting in the images of the legs separated from the body. The leg failure occurs at the muzzle or during transit to the x-ray imager location.

The voltages and x-ray images provide the majority of performance data for the individual launches. Additional information on the performance can be obtained from ex situ analysis of the rails.

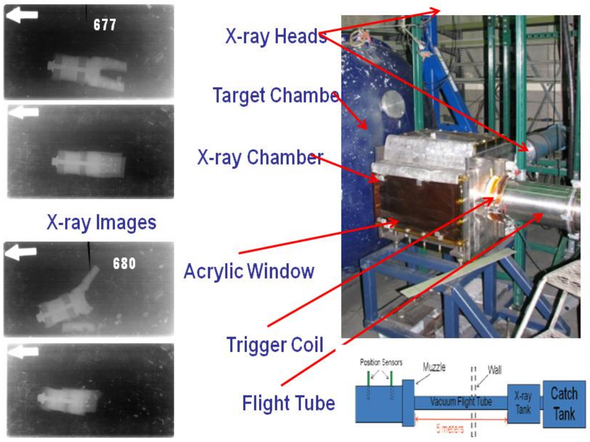


Figure 8. Dual axis flash x-ray imager and sample images from high power launch.

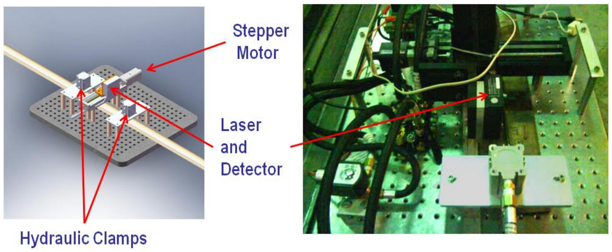


Figure 9. Diagram and picture of a portable laser profilometer.

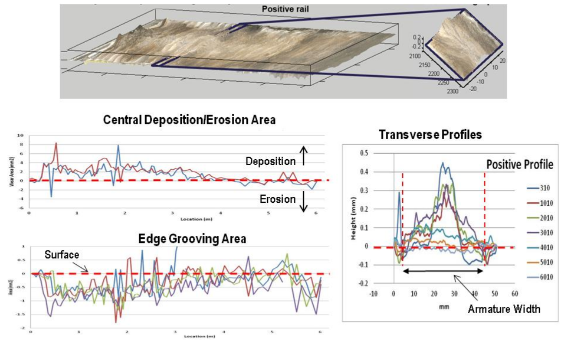


Figure 10. Surface profiles generated by the laser profilometer.

V. SURFACE PROFILE ANALYSIS

A lot of information on the effect of high power launch on the rails can be obtained from surface profilometry. Fig. 9 shows a drawing and picture of a small, portable, laser profilometer used to measure surface contours. The system consists of a laser/detector combination mounted on a moveable stage and swept laterally across the rail with a stepper motor. The rail is clamped to a flat surface with pneumatic clamps. The laser head can measure the distance to the surface with ~15 micron resolution using a 30 micron diameter spot size. The stepper motor moves the laser across the rail with a 20 micron resolution. The entire profilometer stage is slid along the rail to generate profiles of the entire rail. A computer system controls the laser and records the data. Software is then used to generate transverse profiles the rail surface. Fig. 10 shows an example of profiles from the rail surface. The rail is 2 inches wide and 6-m long. The figure is distorted to view the full surface map. Individual profiles from different locations as shown on the right are then lined up in a 3D plot. The optical image is then superimposed on the profile map to allow correlation between surface features and the profile. Profile maps like that in Fig. 10 provides a powerful tool for observing effects of high power launch.

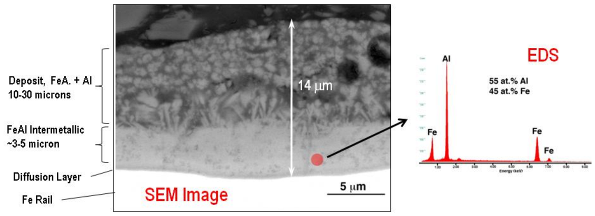


Figure 11. SEM image from the rail shown in Fig. 10. EDS spectrum generated from a location near the bottom of the groove.

VI. METALLOGRAPHIC ANALYSIS

Additional information can be obtained from ex situ analysis of the rail material. Rails are cut into small segments, polished, and analyzed using metallographic techniques [5]. Fig. 11 shows an example of the analysis. The image shown is from a spot located 93 cm from the breech and 4 mm from the edge of the rail. This is near the center of the edge groove generated on the rail. The scanning electron microscope (SEM) image shows a ~30 micron by 25 micron area at this location. The image is at the bottom of the groove and represents the surface morphology from the final shot on the rails. The Energy Dispersive x-ray Spectroscopy (EDS) graph on the right shows the detailed composition of the materials within the spot. This tool coupled with the SEM provides detailed localized analysis of the surface materials.

VII. SUMMARY AND CONCLUSIONS

The present status of the NRL MTF railgun has been presented. The system is in continuous use for investigations on the physics behind high power railgun operation [6]. Multiple rail geometries and armature designs are tested at high power for both launch performance and rail damage.

ACKNOWLEDGEMENTS

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