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Transition Armature Study Progress Report No. 3

R. S. Hawke

October 1 - November 30, 1991

Lawrence
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ARDEC
Transition Armature Study
Progress Report No. 3 ††
May 13, 1992
Covering the Period October 1 to November 30, 1991
R. S. Hawke
Lawrence Livermore National Laboratory
Executive Summary

This third report covers the period October 1 to November 30, 1991. During this period we: 1) fabricated a test fixture for studying hybrid armature brush behavior, 2) reactivated a 140kJ, 1MA capacitor bank, 3) reactivated 25 channels digital data acquisition and reduction system and 4) concluded the use of a DNA funded railgun would serve as the most expedient means to acquire a railgun test bed.

Fabrication of a plasma brush test fixture for studying the formation, evolution and stability of plasma brushes was completed. The fixture will serve to study plasma brush parameters, such as brush length and voltage drop, as a function of initial solid foil mass, gap size and current concentration.

A 40kV, 168 μ f, 140kJ capacitor bank capable of providing more than 1MA of current was reactivated. (The LLNL bank had been developed for opening switch research which was successfully completed.) The bank will be used to power the test fixture with 10 μ s, flat top current pulses.

A 25 channel LeCroy digital data acquisition system interfaced to an LSI-11 and a Mini VAX computer was reactivated and brought on line to record the B-dot signals, voltages and current data from the test fixture.

An evaluation of the most expedient means of obtaining a small bore railgun test bed for armature studies led to the conclusion that a portion of the DNA funded, LANL fabricated, LTS (Lethality Test System) railgun which was loaned to SNL, would be the best choice. A request to borrow the equipment for 3 years was initiated.

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Detailed Report

Introduction

The first Progress report [1] included a detailed introduction of the Armature Study Project. Briefly the goal of the project is to develop an understanding of the physics and engineering limits and design requirements which will lead to 1) high performance solid and hybrid armatures, 2) their use in worn barrels and 3) the design and demonstration of advanced barrel concepts.

The project is divided into 4 tasks: Task 1) design and scaling of high performance hybrid armature/projectile for the 1-4 km/s range, Task 2) determine maximum velocity achievable with solid armature/rail interface, Task 3) develop armatures capable of high performance throughout life of barrel and Task 4) evaluate advanced launcher concepts.

The reader is referred to the 1st report for a broader description of the project goals and detailed test plan. This report provides an update of the progress achieved from October 1 to November 30, 1991. The modified illustrations that were developed to serve as a road map for the 4 project tasks, are included in the 2nd report [2].

Task 1 - Hybrid Armature

The goal of Task 1 is to design a high performance hybrid armature and develop scaling relations for bore size, projectile mass and launch velocity.

Numerical Simulation of Hybrid Plasma Brush Characteristics

Originally we planned to use a 2D MHD code (CALE) to model the behavior of the plasma brush. An interim step, using a four phase equation-of-state (EOS) code (CONFUSE) will be used to predict the characteristics of a quasi steady state, stationary brush. This code will provide a more precise estimate of the brush because it has a well refined EOS capability. The CONFUSE code will be used to guide the tests described below. CALE will later be employed to predict the behavior of brushes in dynamic tests with a launcher. Neither code was employed during this reporting period.

Hybrid Test Fixture

A short railgun-like test fixture has been fabricated. It will be used to verify the numerical simulations of hybrid brush length dependence on linear current density (magnetic pressure) and other factors such as initial plasma mass (fuse thickness) and brush chamber gap thickness (see Fig. 1). The fixture is configured as a 30mm square bore and has provision for smaller bores, round or square. The

diagnostics are closely spaced B-dot probes (2mm diameter by 6mm long, 30 turn coils) used to measure the plasma brush lengths. The fixture will be powered by a 140kJ, 40kV capacitor bank. Peak current is about 1MA which will generate an average magnetic pressure of about 170MPa (25ksi) on the hybrid armature and up to 700MPa (100ksi) on the plasma brush. Fig. 2 is a photograph of the test fixture components prior to assembly while Fig. 3 shows the assembled test fixture. Testing will commence with FY'92 funds.

Task 2 - Solid Armature

The goal of task 2 is to determine 1) the physics limits to solid armature function and 2) the optimum engineering parameters that can achieve the maximum velocity. A solid armature is inherently more electrically efficient than a hybrid which has a relatively large voltage drop across the brushes. It is also more difficult to maintain solid electrical contact between the armature and the rails, especially at velocities above 1 km/s.

Numerical Simulation of Solid-Rail Interface

Motion of the solid armature results in frictional heating of the armature and to a lesser extent of the rails. This frictional heating results in surface melting and possibly vaporization. TKBLIMP can simulate this interface and estimate the maximum attainable velocity prior to melting and vaporization as a function of materials and interface pressure. TKBLIMP combines the effects of elastic material response, surface contact friction, and surface energy balance to estimate the melting and vaporization transitions as functions of velocity, interface pressure and armature/barrel materials.

Simulations with CALE and TKBLIMP have been inactive during this reporting period.

Launcher Test Bed

A power supply and railgun launcher are needed for verification and development tests of both hybrid and solid armatures. An LLNL capacitor bank has been loaned to the ARDEC Transition Armature Study. The 5kV, 50mf, 600kJ bank is capable of operating at currents up to 1MA. The bank has been moved to a new facility where the 40kV, 140kJ bank is located. Both banks will share a screen room containing 25 channels of digitizer and a VAX data reduction system. Three options for a railgun launcher were under consideration, 1) standard "vee" block containment, 2) hydraulic loaded, laminated containment and 3) fiber composite containment. The standard "vee" block is the most straight forward and best developed. The hydraulic laminate structure offers the potential for faster refurbishment but requires development. The fiber composite approach would provide a test bed and a step towards developing an advanced launcher; however,

it requires more development. An assessment of the most appropriate path concluded the LTS railgun would be the best choice.

Task 3 - Worn Barrel Armatures

The goal of this task is to develop both solid and hybrid armatures which will provide high performance over the lifetime of a barrel which experiences wear and erosion. This task is an extension of work described in Tasks 1 and 2 and has not yet begun.

Task 4 - Advanced Launcher Concepts

The goal of this task is to generate and evaluate non-conventional railguns. Initially the focus is on multi-rail geometry's. Multi-rail geometry's can accommodate multi-segment sabots which are easier to separate from the payload after launch and might also result in more uniform projectile base loading. Furthermore, multi-rail barrels will experience a more uniform stress distribution resulting in a stronger barrel. Generally multi-rail launchers have lower inductance gradients, hence higher currents are required to provide a given propulsion force. The addition of augmentation can mitigate the need for higher currents.

A 2D code capability to calculate magnetic field and arbitrary current distributions in a self consistent manner has been derived from an existing code TOPAZ. The adapted code TOPAZ-EM is directly interfaceable to NIKE and DYNA stress-strain codes and the original TOPAZ heat transfer code which are widely used and very suitable for barrel design. This combined capability provides an effective barrel design capability.

As a starting point, Quadra-Rail and Hexa-Rail Launcher concepts have been chosen for analysis. The Quadra-Rail concept uses 4 primary rails along with 4 augmentation rails to increase the inductance. Inductance calculations of the Augmented Quadra-Rail and Augmented Hexa-Rail configurations were summarized in the second report. Mockups of the two geometry's were assembled.

Summary

During this reporting period we fabricated a hybrid test fixture and acquired a railgun test laboratory. It includes a 140kJ, 1MA capacitor bank, 25 channels of digitizers and a data reduction system. A 600kJ, 1MA capacitor bank will be part of the facility. Railgun test bed options have been evaluated. Mockups of two advanced multi-rail launchers have been fabricated to provide further evaluation.

References

- [1] R. S. Hawke, ARDEC Transition Armature Technology Project, Progress Report No. 1. [Dec. 12, 1991]
- [2] R. S. Hawke, ARDEC Transition Armature Technology Project, Progress Report No. 2. [Feb. 21, 1992]

Fig.1 Hybrid Armature Brush Test Fixture. Fig. 1 is a side section view. Initially the current flows through the rail, foil and metal link. After the current vaporizes the metal foil, a plasma brush is formed. The brush expands until the hydrodynamic pressure is in equilibrium with the magnetic pressure generated by the Lorentz forces from the rail and hybrid current generated magnetic field interacting with the brush current. The present configuration is a 30mm square bore. B-dot probes are located adjacent to the 4 sides of the 2 rails at 1cm intervals. The 1mm gap brush chamber is 45mm long and 30mm wide.

Fig. 2 Hybrid Armature Test Fixture Components (Magnetic Armature eXperiment). This is a photograph of the fabricated components ready for assembly. It includes the containment fixture, core consisting of rails and insulators, and B-dot probes.

Fig. 3 Assembled Test Fixture. The assemble test fixture is configured as a 30mm square bore railgun. It can also accommodate round bores and smaller bores. The fixture has been designed to operate up to 3kb (300MPa) of net armature pressure.

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