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Transition Armature Technology Project, Progress Report No. 2

R. S. Hawke

August 1 - September 30, 1991

Lawrence
Livermore
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ARDEC

Transition Armature Technology Project

Progress Report No. 2

Covering the Period August 1 to September 30, 1991

R. S. Hawke

Lawrence Livermore National Laboratory

Executive Summary

This second report covers the period August 1 to September 30, 1991. During this period we modified our approach to Task 1 (Hybrid Armature study) with the addition of a numerical simulation of the steady state plasma brush length with a 1-D, four-phase equation of state code.

A test fixture was designed and fabrication begun on a plasma brush test fixture for hybrid studies. It will be powered by a 140 kJ, 1 MA capacitor bank on loan to the project. Diagnostic data collection with 20 channels of digitizers and data reduction with a microvax were also arranged.

Sliding friction of a solid armature was simulated and found to form a vapor layer at velocities below 2 km/s. The simulations indicated that higher interface pressure results in vapor boundary layer formation at lower velocity. If there is also a minimum interface pressure required to commutate high currents, then an optimum interface pressure will probably result.

Plans for a launcher test bed were begun in preparation for performing dynamic validation tests of the simulated predicted performance of both solid and hybrid armatures. Components of an 8 module, 600 kJ, 5 kV, 1 MA capacitor bank has been moved into the railgun testing lab. The bank will be capable of powering advanced concept, multi-rail launchers. The same diagnostic and data reduction system described above will be shared. Launcher test bed alternatives are under review.

Four (Quadra) and six (Hexa) rail launchers have been modeled and appear to be able to provide a high impedance and lower current launcher. A mock up will be built and used for validation measurements.

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 August 1 to September 30, 1991. The illustrations that were developed to serve as a road map for the 4 project tasks, are included and modified where appropriate. A third and the final FY'91 progress report is in preparation.

Task 1 - Hybrid Armature

Figure 1 is a block diagram of the approach to Task 1. 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 that has been developed during 5 years of research with flyers and slappers [2]. Furthermore it is less costly and faster to operate. 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.

Hybrid Test Fixture

A short railgun-like test fixture has been designed and will be 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 figure 2). The fixture will be initially configured as a 30 mm square bore and has provision for smaller bores, round or square (see figure 3). The diagnostics will initially be closely spaced B-dot probes (2mm diameter by 6mm long, 30 turn coils) used to measure the plasma brush lengths (see figure 2). The fixture will be powered by an LLNL, 140 kJ, 35 kV capacitor bank. Peak current is about 1 MA which will generate a magnetic pressure of about 170 MPa (25ksi) on the plasma brush.

Task 2 - Solid Armature

Figure 4 is a block diagram of the planned approach to task 2. 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 is being used to 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.

The first report [1] had indicated a hope that a vapor layer between Al and Cu or Cu and Cu might occur at a higher velocity than between Fe and Fe. Such is not the case. Table 1 summarizes the predicted velocities at which the liquid and vapor temperatures are reached for a few interface pressures. It was found that the interface pressure is a significant factor and that higher velocities might be reached with lower pressures. There is of course a lower

limit on the interface pressure at which solid contact will be lost. Therefore, there is probably an optimum interface pressure for achieving a maximum velocity solid armature. It should be noted that the effect of joule heating is not yet included in the results shown in table 1 and is expected to be of importance.

Simulations with CALE 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 Technology Project. The 5 kV, 50 mf, 600 kJ bank is capable of operating at currents up to 1 MA. The bank is being moved to a new facility where the 35 kV, 140 kJ bank is located. Both banks will share a screen room containing 20 channels of digitizer and a VAX data reduction system. Three options for a railgun launcher are 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 (see below); however, it requires more development. An assessment of the most appropriate path is in progress.

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 geometries. Multi-rail geometries 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 maintain a given propulsion force. The addition of augmentation can mitigate the need for higher currents.

Figure 5 is a block diagram of the planned evaluation process. First, a 2D code capability to calculate magnetic field and arbitrary current distributions in a self consistent manner has been derived from an existing code. The adapted code is directly interfaceable to NIKE and DYNA stress-strain codes which are widely used and very suitable for barrel design. This combined capability will provide an effective barrel design capability. The inductance gradients will also be calculated with the adapted code. Those geometries that show favorable inductance gradients will be structurally modeled in order to determine the most suitable materials and estimate the operating limits. Prototypes of promising designs will be considered for construction and testing.

As a starting point, a Quadra-rail launcher concept has been chosen for analysis. The concept shown in Figure 6, uses 4 primary rails along with 4 augmentation rails to increase the inductance. The inherent symmetry is obvious as is the natural division of the armature into 4 equal segments. Inductance calculations of the Augmented Quadra-Rail configuration are listed in Table 2 and indicate further study is merited. Furthermore an Augmented Hexa-Rail configuration has been modeled and is included in the table. The inductance calculations will be validated with a mock up. The natural symmetry of the multi-rail configurations will lead to better distributed hoop stresses than is possible with conventional two-rail geometries.

Summary

During this reporting period we made progress towards numerical simulation of hybrid plasma brushes by using a four phase EOS code. Preliminary results from our boundary layer development simulation have been obtained and indicate higher interface pressures results in vaporization of solid armatures at lower velocities. A railgun test laboratory has been acquired. It includes a 140 kJ, 1 MA capacitor bank, 20 channels of digitizers and a data reduction system. A 600 kJ, 1 MA capacitor bank will be added to the facility. A static armature test fixture has been designed and will be fabricated. Railgun test bed options are under evaluation. Two advanced multi-rail launchers appear to offer high inductance and segmentable armatures and appear to be worthy of further evaluation.

Recommendations

Progress in obtaining two railgun power supplies, data acquisition and reduction systems provides the impetus to design and fabricate a launcher test bed. It's recommended that a design suitable for the needs of this project and ARDEC (and possibly IAT) be considered.

References

- [1] R. S. Hawke, ARDEC Transition Armature Technology Project, Progress Report No. 1.
- [2] I. Lindamuth, *Computational Model of Exploding Metallic Fuses for Multi-meagajoule Switches*, JAP57, 4447-4460 (1985).

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Table 1 Calculated Armature Melting and Vaporization Velocities

		<u>Aluminum</u>	
Interface pressure (MPa)		v_m	v_v (km/s)
60		0.25	1.35
115		0.10	0.87
240		0.20	0.85
		<u>Copper Armature</u>	
		v_m	v_v
65		0.65	1.45
140		0.20	1.05
250		0.10	1.90

v_m is the velocity at which armature melting begins.

v_v is the velocity at which armature vaporization begins.

Table 2 Calculated Augmented Multi-Rail Inductance Parameters

	<u>Quadra-Rail</u>	<u>Hexa-Rail</u>
Series Rail Inductance Gradient:	0.777 ($\mu\text{H}/\text{m}$)	0.878 ($\mu\text{H}/\text{m}$)
Series Augmenter Inductance Gradient:	0.789	0.931
Mutual Inductance Gradient:	0.652	0.637

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Figure 1. Block diagram of approach to Task 1. TKBLIMP, a boundary layer code, will be used to estimate the rate of sabot erosion and material injection into a plasma brush. CALE, a 2D MHD code, will be used to simulate the size, stability and power loss with and without sabot mass injection. CONFUSE, a four phase (solid, liquid, vapor and plasma) equation-of-state (EOS) code will be used to simulate the evolution and stable configuration (i.e. length) of a plasma brush. These simulations will be used to design hybrid armatures for verification tests. The results will be used to establish scaling parameters.

Figure 2. Schematic section of a generic hybrid armature and sabot. A metal link supported by a sabot along with two plasma brushes forms a hybrid armature. Current flows from one rail across the hybrid and returns in the opposing rail. Magnetic pressure in the plasma brush compresses the plasma. Sufficient chamber length, l_g , is needed to keep the plasma confined in the chamber. Projectile acceleration is provided by the Lorentz force acting on the metal link and plasma brush.

Figure 3. Crosssectional view of Hybrid Armature Test Fixture. The fixture is capable of accomodating round and square bores. B-dot probes are located close to the rails in order to determine the hybrid armature behavior. The fixture is designed to operate up to 3kb (~45ksi). It is designed to be a quick turn-around test cell and accomadate variation of brush gap, fuse thickness and material, armature material and later, rail material.

Figure 4. Block diagram of approach to Task 2. The solid armature will be simulated as a macroscopic interface between two ideal surfaces and as a set of microscopic point contacts. TKBLIMP and CALE will be used to study the frictional heating, joule heating, current distribution and material phase changes. The simulations will be used to determine the optimum operating parameters to achieve the maximum velocity attainable with a solid armature. Verification tests will be performed as appropriate.

Figure 5. Block diagram of planned approach to Task 4. Advanced multi-rail barrel concepts will be modeled with TOPAZ EM, a 2D EM code, to first determine the inductance gradients. For those geometries that offer promise, the TOPAZ EM current density and magnetic field distribution results will be used to calculate the surface pressures which will be fed into NIKE and DYNA stress/strain codes to calculate barrel response. These simulations will be used to design full scale and prototype barrels. Were appropriate, prototypes will be built and tested.

Figure 6. Cross section of a full-scale conceptual design of an augmented Quadra-rail launcher. The four rail and multi-rail launchers in general, result in more uniform barrel loads, less distortion, higher operating pressures and the option for natural corresponding four piece separating armatures and sabots. Augmentation is used to supplement the normally low inductance gradient of multi-rail configurations. Both solid and hybrid armatures are compatible with this class of barrel design.

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