INVESTIGATION OF ELECTROMAGNETIC LAUNCHER BEHAVIOR FOR IMPACT FUSION

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INVESTIGATION OF ELECTROMAGNETIC LAUNCHER BEHAVIOR FOR IMPACT FUSION: ANNUAL REPORT 2

Abstract

The second year of a 4-year program to develop an ultra-high velocity electromagnetic launcher has been completed, with significant progress made in the key technical areas. This lays firmly the cornerstone for major progress in Year 3 of the program. The launcher instrumentation and diagnostics system was developed. More than 20 launcher experiments were conducted using the SUVAC-I augmented launcher system. We tested our novel plasma generation technique using a lithium seeded propellant with encouraging success. We accelerated a 1.4 g projectile to 5.3 km/s in 1.6 m in the series. Un-augmented barrels for SUVAC-II were fabricated. The barrels were tested and commissioned with a total of 8 firings in single-stage configurations. The tests verified the basic soundness of the barrel mechanical and electrical design. Velocity up to 4.4 km/s was achieved with a 1.1 g projectile. Concurrently, we completed the fabrication, assembly and installation of SUVAC-II power supply (1 MJ) and its expanded control system. Experimentation with the multi-stage SUVAC-II launcher is expected to take place in the early part of Year 3. In the mean time, fabrication of the SUVAC-III power supply (an additional 0.4 MJ) has also been initiated.

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1. Executive Summary

At the Westinghouse R&D Center, the second year of a 4-year program to develop an ultra-high velocity electromagnetic launcher has been completed, with significant progress made in the key technical areas. This lays firmly the cornerstone for major progress in Year 3 of the program. The program is sponsored jointly by the U.S. Department of Energy and the Westinghouse Electric Corporation.

The program involves the construction over the period (July 1983 - June 1987) of a multi-stage railgun accelerator which has the potential of accelerating a 1-g projectile to velocity in excess of 20 km/s. This velocity is approximately 3 times greater than what is considered possible by more conventional methods of propulsion including the 2-stage light gas gun. The program's principal objective is to use the accelerator so built to conduct experiments to investigate the technical problems associated with the acceleration of macroparticles to superhigh velocity. This is part of a joint program with the University of Washington to develop the scientific and technological basis to achieve controlled thermonuclear fusion by hypervelocity impact.

Spin-offs from the program include applications of the technology developed to construct facilities for equation-of-state research, hypervelocity impact and penetration studies above 10 Mbar, and relatively low-cost production of plasma temperatures above 50 eV over a volume of several cm³ for laboratory studies. This report summarizes the progress made in the second year of the program. It covers work done in the period 5-1-84 to 4-30-85.

1.1 Program Thrusts and Accomplishments in Year 2

As we entered into Year 2 of the program, several technical issues which may degrade the performance of railgun accelerators in general were uncovered. Theoretical considerations made during Year 1 of our program clearly suggested that plasma ablation, arc restrike, plasma armature instability, plasma turbulence and non-ideal plasma properties could potentially degrade accelerator performance. In the same period, experimental testings of railguns in several institutions throughout this country and overseas (Australia) have produced results which show significant deviations from predicted performances. In particular, experiments at the Los Alamos National Laboratory have emphasized the role of plasma mass and its ablation of the rail and insulator materials in launch dynamics.

In view of our anticipation of these problems, it was considered important that program activities in Year 2 should be focused on identifying and resolving the causes of these problems. At the same time, the funding cycles for the program require that a minimum rate of hardware manufacture should be maintained in order to ensure the timely availability of the appropriate hardware in the later phases of the program. The one subsystem in the entire program which has the lowest risk in development is the distributed power supply consisting of the capacitor modules. The development of the power supply was therefore accelerated while we proceeded at a cautious pace on the development of the high-risk accelerator itself. Consequently, the program emphases adopted in Year 2 of the program are as follow:

1. Conduct a critical number of experiments on the SUVAC-I augmented first stage (Figure 3-1). The progress made during Year 1 culminated in the fabrication of the SUVAC-I launcher system. The system was thus available for experimentation in the early part of the second year. The tests performed on SUVAC-I also provided an opportunity to develop the diagnostics.

2. Fabricate additional barrel sections for the 2nd and 3rd stage of SUVAC-II. These additional barrel sections are based upon the un-augmented design as shown in Figure 4-1.
3. Conduct a critical number of experiments on the SUVAC-II un-augmented barrels in a single-stage configuration.
4. Test and develop our novel plasma armature generation technique.
5. Fabricate the distributed power supply for the entire SUVAC-II system (additional 600 kJ). This power supply will be required in the beginning of Year 3 of the program.
6. Initiate development of the SUVAC-III power supply (additional 400 kJ). This is required in the second half of Year 3.

The above tasks were successfully accomplished in the reported period. Specifically,

1. We made more than 20 firings in the SUVAC-I augmented barrel.
2. With the augmented first stage, we successfully accelerated a 1.4 g projectile to 5.3 km/s. Most significantly, we obtained close agreement between predicted and experimental performance, due mainly to the fact that we developed and used a less ablative plasma armature, and that our theory took into prior consideration the mass of the plasma armature as a significant part of the launch payload.
3. The three additional 6-ft barrel sections required for the 2nd and 3rd stage of SUVAC-II launcher were fabricated.
4. The un-augmented SUVAC-II barrel was thoroughly tested and commissioned in two series of tests in a single-stage configuration with a total of more than 8 firings. A wide range of current, voltage and energy input was used, resulting in establishing a significant database on the gun and the plasma armature behavior. With a 1.14 g projectile, a maximum velocity of 4.5 km/s was reached using 200 kJ of energy as input.

5. A data transmission system with high EMI immunity (120 db attenuation at 120 kHz) and high common mode voltage rejection was installed.
6. Accelerator diagnostics system was installed and tested. The system includes magnetic probes, optical probes, breakwire screens, flash x-ray stations, Rogowski coils, optically isolated voltage probes on the muzzle, breech and the power supply, was installed and tested. Together with the data transmission and acquisition system, the diagnostics have produced virtually EMI-free signals. This will provide the needed foundation in instrumentation for the more demanding experimentations planned for Year 3.
7. Fabrication, assembly and installation of the entire SUVAC-II power supply (1 MJ) was completed. Expansion of the control system, hardware and software, was completed. The SUVAC-II power supply and its firing system is ready for testing and commissioning.
8. Component fabrication, and assembly of the SUVAC-III power supply (an additional 400 kJ) has been completed. It remains to install the additional units and integrate them with the control system.

1.2 Prospects and Tasks Plan for Year 3

The success of Year 2 has clearly demonstrated the soundness of our overall program strategy and technical directions. Our program strategy emphasizes flexibility in program structure and hardware design of subsystems which are identified as high-risk elements. This has allowed our program to benefit from findings of our own and other railgun programs in this country and overseas. This is especially important in view of the current high level of activity in this area catalysed by the presidential Strategic Defense Initiative program. The experimental results have clearly vindicated our general approach towards the development of an hypervelocity railgun, an approach which contains the following key elements:

1. Flux augmentation which enables the use of relatively low current through the firing rails to provide the required acceleration
2. Controlled plasma armature generation
3. The use of refractory rail materials (molybdenum)
4. Advanced barrel containment concepts which include both mechanical and magnetic stiffening in an appropriate geometry

These key elements will continue to be the strong determinants in our program plan for Year 3. The single major task in Year 3 is the successful development of the controlled operation of a multi-stage railgun in a distributed-energy-store configuration. Our efforts will be focused on the development of SUVAC-III, with the objective of attaining a velocity of 20 km/s with a 1-g projectile by August 1986. The following program milestones are set for Year 3:

1. Develop the controlled operation of a 2-stage distributed-energy-store railgun. (May 85 - July 85).
2. Assemble and install the full 3-stage 24-ft SUVAC-II launcher. (July 85 - Aug 85).
3. Test and commission SUVAC-II (Aug 85).
4. Velocity attempt with SUVAC-II: 12 km/s (Sept 85).
5. Assemble and install SUVAC-III power supply to provide a total of 1.4 MJ of distributed energy (Oct 85).
6. Test and commission SUVAC-III power supply (Nov 85).
7. Improve barrel design for SUVAC-III (Sept 85).
8. Fabricate SUVAC-III barrels (Oct 85 - Jan 86).
9. Assemble and install SUVAC-III barrels (Jan 86 - Mar 86).
10. Test and commission SUVAC-III launcher system (Mar - May 86).

TASKS

TIME OF COMPLETION

	1984				1985	
	Jun	Aug	Oct	Dec	Feb	Apr
Developed diagnostics	*					
Developed data transmission system	*					
Expanded data analysis system	*					
Tested lithium seeded propellant plasma armature		*				
Tested and commissioned SUVAC-I augmented first stage		*				
Attained 5.3 km/s with SUVAC-I			*			
Fabricated SUVAC-II barrels			*			
Developed bus connections for SUVAC-II barrels				*		
Tested & commissioned SUVAC-II barrels				*		
Developed gun and plasma armature performance database					*	
Fabricated SUVAC-II power supply			*			
Assembled and installed SUVAC-II power supply			*			
Expanded the control system to accommodate SUVAC-II						*
Fabricated SUVAC-III power supply					*	
Assembled SUVAC-III power supply						*

Figure 1-1. Major program milestones accomplished in Year 2.

2. Introduction

The overall SUVAC program is designed to have the maximum flexibility so that hardware development can incorporate the latest experimental and theoretical findings. This flexibility is achieved both through a well-planned program structure and in the design of the system components.

In order to appreciate the main thrusts of the SUVAC program in Year 2, it is important to examine the state of railgun R&D in 1984. Firstly, theoretical considerations made during Year 1 of our program suggested that plasma ablation, arc restrike, plasma armature instability, plasma turbulence and non-ideal plasma properties could potentially degrade accelerator performance. At the same time, experiments conducted in Los Alamos National Laboratory, in Lawrence Livermore National Laboratory, and in Boeing Scientific Laboratory had begun to reveal some of the fundamental problems which might limit the velocity achievable by particular railgun systems. A critical problem is the ablation of barrel materials by the extremely hot plasma armature used in railguns. Experimental railgun performances have typically deviated from theoretical predictions by as much as 50 %.

On the one hand, in view of our anticipation of these problems, it was considered important that program activities in Year 2 should be focused on identifying and resolving the causes of these problems. In an attempt to reduce the plasma ablation problem, one of the main tasks early in the SUVAC program was to develop a technique for the controlled generation of plasma armatures with desirable properties. This task is pursued in collaboration with a plasma armature development program sponsored by the Army Research Office.

On the other hand, the funding cycles for the program required that a minimum rate of hardware manufacture should be maintained in order to ensure the timely availability of the appropriate hardware in the later phases of the program. This is necessary so that a constant rate of experimental progress can be maintained. The one subsystem in the entire program which has the lowest risk in development is the distributed power supply consisting of the capacitor modules. The development of the power supply was therefore accelerated while we proceeded at a cautious pace on the development of the high-risk accelerator itself.

Consequently, the program emphases adopted in Year 2 of the program are as follow:

1. Conduct a minimum but critical number of experiments on the SUVAC-I augmented first stage (Figure 3-1). The purpose is to further elucidate the nature of these problems and to develop solutions to them in the early phase of the program.
2. Fabricate additional barrel sections for the 2nd and 3rd stage of SUVAC-II. These additional barrel sections are based upon the un-augmented design as shown in Figure 4-1.
3. Conduct a minimum but critical number of experiments on the SUVAC-II un-augmented barrels in a single-stage configuration. The objective is again the same as (1).
4. Test and develop our novel plasma armature generation technique
5. Fabricate the distributed power supply for the entire SUVAC-II system (additional 600 kJ). This power supply will be required in the beginning of Year 3 of the program.
6. Initiate development of the SUVAC-III power supply (additional 400 kJ).

In this report, we shall briefly summarise the results of these main

activities. The details of these activities will be described in the topical reports to be issued later.

3. SUVAC-I Experiment and Test Results

3.1 SUVAC-I Launcher System

The geometry of the first stage of the multi-stage SUVAC launcher (SUVAC-I), is shown in Figure 3-1. Its design was fully described in Thio et al [1]. It employs series augmentation, by which the primary magnetic field produced by the inner firing rails is augmented by a secondary magnetic field produced by the outer rails called the augmentation winding. In SUVAC-I, the augmentation winding is connected in series with the main firing rails. By using augmentation, the same propulsive force can be generated with a smaller current than in the case without augmentation. The principal advantage of the technique in the present context is that it reduces the arc ablation rate and thus reduces the effect of arc ablation on the launch dynamics. In a wider context, augmentation increases the efficiency of the accelerator, especially when the armature velocity is low. The calculated value for the barrel inductance gradient asymptoted to $0.73 \mu\text{H/m}$ whereas the measured value to $0.71 \mu\text{H/m}$.

Figure 3-2 shows the fully installed SUVAC-I system comprising the 400-kJ capacitor bank and the 1.83-m (6-ft) launcher, together with the ballistics and catch tanks. Figure 3-3 shows a close-up of the barrel viewed from the muzzle end of the gun. The upper steel clamps were removed to expose the insulator.

In the insulator (both G-11 and Lexan have been used), inlets were made to hold magnetic pick-up loops. These probes, sometime called B-dot probes, were used to measure the magnetic field produced by the current in the plasma armature. These probes were aligned with the planes of the loops being perpendicular to the bore axis. Two of these probes can be seen in the picture.

Across the rails at the muzzle, voltage measuring leads were also attached and can also be seen in the picture. Special care was taken to minimize EMI pick-up by the leads which are shielded. A T&M voltage divider designed for pulsed applications is used to step down the voltage. The measured voltage is converted into a light pulse with intensity proportional to the measured voltage and is transmitted via a fiber optic cable into the instrument room and is received by an optical receiver which converts the light pulse into an electrical signal in proportion to its intensity. Similar voltage probes and optical links were used to monitor the breech and capacitor voltages. Currents from each of the four 100-kJ capacitor module were separately monitored and the total current fed into the breech of the accelerator were monitored by Rogowski coils.

The instrument room is an EMI shielded room with a rating of 120-db attenuation at 100 kHz. All transient signals were recorded by a 10-channel transient digitizers system shown in Figure 3-4. The system is comprised of 4 units of Biomation Model 2805 transient digitizers and 1 unit of Nicolet 2096 digital oscilloscopes. Each of the Biomation 2805 provides 2 channels of recording which is capable of digitizing at a maximum rate of 5 megasamples/s and recording length of 2048 samples per channel. The Nicolet 2096 provides 2 channels of recording with a digitizing rate of 2 megasamples/s and a recording length of 2048 samples per channel. When necessary, the system is augmented with further units of similar Nicolet scopes. The recorded data is read from the recorders' memory by a microcomputer (MACSYM) and is further transferred to a mainframe computer (PRIME 750) for further processing and analysis. This system will be completely replaced by a more advanced system based upon the IEEE-593 CAMAC system which will have more than 60 channels of high-speed recordings in Year 3 of the program.

3.2 Experimental Results

More than 20 shots were fired on the SUVAC-I launcher with currents ranging from 100 kA to 275 kA, and input energy from 30 kJ to 200 kJ. No structural damage was observed, verifying the basic soundness of the mechanical design.

The most complete set of data were obtained for Shot DX1-100384-1 which was made on October 3, 1984. The projectile was made of polycarbonate (Lexan), with a mass of 1.429 g and dimensions of 9.45 mm x 9.47 mm x 15.2 mm. The bore measured 9.43 mm x 9.45 mm. The force required to load the projectile was approximately 89 N. The plasma generation package consisted of a mixture of 102.9 mg of nitrocellulose and 171.4 mg of lithium nitrate wrapped into a cylindrical form in a aluminum foil weighing 36.4 mg. Figure 3-5 shows the position vs time profile of the projectile deduced from the B-dot probes signals. The predicted performance using the (W)-DoE multi-stage railgun simulation code PARADES was also shown on the same figure. Time differentiation of these curves produces correspondingly the experimental velocity and the predicted velocity vs time profiles which are shown in Figure 3-6. The estimated velocity obtained in this shot was 5.3 km/s.

Figure 3-7 shows the pair of molybdenum rails which were used in most of the SUVAC-I experiments. Figure 3-8 shows the first 6 inches of the rails from the point of plasma initiation. The plasma generation package was typically positioned at about 7.5 inches from the breech end of the rails. The indentations in the rails (at about the 6-inch mark) were machined to facilitate vertical loading of the projectile into the region between the rails. Figure 3-9 shows the middle portion of the same rails while Figure 3-10 shows the muzzle end portion of the rails. The rails have been re-used in more than 20 shots without requiring any re-machining.

WESTINGHOUSE-DOE 30 km/s ULTRA-HIGH VELOCITY LAUNCHER—FIRST STAGE BOOSTER

Figure 3-1. SUVAC-I Barrel Geometry and Design.

Figure 3-2. The SUVAC-I Launcher and Power Supply (400 kJ) System.

Figure 3-3. Showing a close-up of the SUVAC-I barrel from the muzzle: The upper steel clamps were removed to expose the insulator and the inlets which hold the B-dot probes. Two of the B-dot probes and the muzzle voltage probe are also shown..

Figure 3-4. SUVAC-I Tests: The high-speed digital data acquisition system.

Figure 3-5. Predicted and observed position profile obtained with SUVAC-I augmented first stage: Shot DX1-100384-1.

Figure 3-6. Predicted and observed velocity profile obtained with SUVAC augmented first stage.

Figure 3-7. Molybdenum rails used in SUVAC-I experiments: The rails have been tested in more than 20 shots with currents in the range from 100 kA to 270 kA. The total rail width is 15.88 mm; the part exposed to the plasma is nominally 9.5 mm wide (the bore width)..

Figure 3-8. SUVAC-I Test Series: Showing the first 6 inches of the molybdenum alloy rails from the plasma initiation point. The plasma generation package was positioned typically at 7.5" from the breech end of the rails..

Figure 3-9. SUVAC-I Test Series: Showing the middle portions of the rails used in the SUVAC-I augmented first stage experiments.

Figure 3-10. SUVAC-I Test Series: Showing the muzzle end of the rails used in the SUVAC-I augmented first stage experiments.

4. SUVAC-II: Barrel Development Test and Commission

A major effort in Year 2 has been the fabrication, testing and commissioning of the un-augmented barrel for the second and third stage of the SUVAC-II launcher. The experiments also served to provide a valuable database on the behavior of the lithium propellant plasma armature over a broad range of operating parameters.

4.1 The SUVAC-II Un-augmented Barrel and the Test Assembly

The design and crosssectional geometry of the barrel extensions for the second and third stage of the SUVAC-II accelerator are shown in Figure 4-1. Its mechanical and electrical design has been described by Thio et al [1]. It has the simple, un-augmented rail geometry. Its inductance gradient was calculated to be $0.32 \mu\text{H/m}$ (high frequency limit) whereas the measured inductance gradient was $0.33 \mu\text{H/m}$. Figure 4-2 shows the barrel having been assembled and installed in a single-stage configuration connected to the terminals of the capacitor bank of the first stage. A series of tests were performed on this barrel to check out its performance.

The ballistics instrumentation for the SUVAC-II series of experiments were shown in Figure 4-3. In this test series, we have added a set of break-wire screens and a pair of optical probes which detect the optical radiation from the plasma armature for in-bore and ex-bore time-of-flight measurements, and two flash X-ray stations at the muzzle. A total of 6 B-dot probes were used to monitor the magnetic field produced by the plasma armature current. In addition, the

muzzle voltage, the breech voltage, the capacitor bank voltage, the breech current, and the currents from each of the capacitor modules were monitored. The breakwire screen and its support (Figure 4-9) were designed to withstand the aerodynamic shock produced by the supersonic projectile. As the experiments were performed at atmospheric pressure, the estimated shock pressure reached 35 MPa to 40 MPa for projectile velocity in the vicinity of 5 km/s. As it turns out the tenacity of the break wires were such that the projectiles were broken by the wires. Thus they were used only in the first series (CX2) and were not used in the later, PCX1 series.

Figure 4-4 shows the bus-bar connections at the breech which feed the current from the terminals of the capacitor banks into the accelerator. Figure 4-5 shows the details of the breech. The belts used to seal the bore can also be seen in the picture.

4.2 Experimental Results

Two series of tests were conducted. In the first series (CX2), a low transmission inductance of $2.1 \mu\text{H}$ was used. With this inductance, a sharp pulse with a peak current of 395 kA was produced in the accelerator with 207 kJ of input energy (by charging the capacitor bank (8.2 mF) to 7 kV). In the second series, the PCX1 series, a broader current pulse at a lower amplitude was applied to the accelerator by using a higher transmission inductance of $5.1 \mu\text{H}$. With the capacitor bank charged to 7 kV, a peak current of 250 kA could be produced in the accelerator. In the PCX1 series, the voltages were varied from 3 kV to 7 kV over a total of 6 shots.

We shall present here the gun performance data as reduced from the measured data for Shot CX2-120584-1.

In Shot CX2-120584-1, the projectile was again made of polycarbonate, measuring 9.45 mm x 9.6 mm x 13.26 mm, and weighing 1.145 g.

The force required to overcome friction in loading the projectile is approximately 100 N. The plasma generation package consisted of a mixture of 162 mg of nitrocellulose, 170 mg of lithium nitrate contained in an aluminum foil cylinder of 41 mg.

The magnetic signatures of the plasma armatures as sensed by the B-dot probes were shown in Figure 4-6. The center of these magnetic pick-up loops was located at a distance of 19.94 mm above the axis of the bore. They have an inner radius of 1.587 mm and an outer radius of 3.4 mm, containing 15 turns of #32 gauge wire. From these b-dot probes data, the position versus time history of the projectile was deduced and is shown in Figure 4-7. Also shown is the predicted position-time profile. Time differentiation of these curves yields the measured and predicted velocity profiles which are shown in Figure 4-8. In this experiment, the projectile reached a velocity of 4.5 km/s.

The condition of the molybdenum rails used in the CX2 series can be examined from the Figures 4-12, 4-13, and 4-14. The degree of erosion of these rails was minor in relation to the relatively high current concentration experienced by these rails. The rails were subjected to a current concentration of 415 kA per cm of bore height. The insulator, however, showed a high degree of ablation and charring. The insulator used was G-11 which was a glass-in-epoxy composite.

Detailed analysis of the data from the PCX1 series is still in progress and will be reported later. In this series, a HYCAM high-speed framing camera was used to observe the muzzle arc. A picture from Shot PCX1-030485-1 of the muzzle plasma is shown in Figure 4-10. A witness plate from another shot PCX1-031285-1 is shown in Figure 4-11.

Throughout the entire test series, CX2 and PCX1, the barrel shows no mechanical or structural damage, verifying the basic soundness of the mechanical design of the barrel.

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Figure 4-1. SUVAC-II un-augmented 2nd stage barrel.

Figure 4-2. Testing and commissioning of the SUVAC-II un-augmented barrel in a single-stage configuration..

Figure 4-3. Testing and commissioning of SUVAC-II un-augmented barrel in a single-stage configuration: Showing the ballistics diagnostics at the muzzle, which includes fiber optics plasma light detectors, muzzle voltage probe, breakwire screen, flash X-ray, witness plate, and the catch tank..

Figure 4-4. Testing and commissioning of SUVAC-II un-augmented barrel in a single-stage configuration: Showing the bus-bar connections at the breech to the terminals of the capacitor bank..

Figure 4-5. Testing and commissioning of SUVAC-II un-augmented barrel in a single-stage configuration: Showing a close-up of the breech..

Figure 4-6. Voltage signals from the magnetic pick-up loops. The instantaneous voltage value is a measure of the time rate of change of the horizontal component of the magnetic field produced at the loop by the moving armature current. Note the appearance of a secondary signal following the primary signal indicating the occurrence of a secondary arc which may have been formed by restrike or break-up of the primary one. The secondary arc seems to nearly catch up with the primary arc at the probe BDOTPOS6.

Curve 749916-A

Figure 4-7. Observed and simulated position profile in Shot CX2-120584-1 with SUVAC-II un-augmented barrel in a single stage configuration: The experimental points are deduced from the magnetic and optical probes. The 4 simulated curves shown correspond to 4 different values used for the mass of the plasma armature. Curve (2) uses the mass of the initial plasma generation package. Curve (4) uses a plasma armature mass which provides the best fit with the experimental points.

Figure 4-8. Velocity profile for Shot CX2-120584-1 with SUVAC-II un-augmented barrel in a single stage configuration. The profiles are obtained from time differentiation of the corresponding position profiles of Figure 4-7. The points indicated as 'experiment' indicate the estimated projectile velocity at the positions where there is a magnetic or optical probe.

Figure 4-9. The breakwire wire screen support structure. Picture taken after shot CX2-120584-1.

Figure 4-10. Muzzle arc together with any accelerated plasma taken during Shot PCX1-030485-1 with a HYCAM high-speed motion framing camera at a speed of approx. 3500 frames per sec..

Figure 4-11. Sample witness plate of the PCX1 series..

Figure 4-12. SUVAC-II Barrel Testing and Commissioning: Showing the molybdenum rails after Shot CX2-120585-1. A peak current of 395 kA was experienced in a bore 9.5 mm wide. The lower rail has been cleaned with acetone to expose the metallic surface..

Figure 4-13. SUVAC-II Barrel Testing and Commissioning: Showing the first 6 inches of the rails from the point of plasma initiation in Shot CX2-120585-1. The plasma generation package was located at 5.75 inches from the end of the rails (5 inches from the point of current injection). Rail current: 415 kA/mm.

Figure 4-14. SUVAC-II Barrel Testing and Commissioning: Showing the middle portion of the rails after Shot CX2-120585-1. .

5. SUVAC-II 2-Stage Launcher Development

The complete SUVAC-II program requires the development of a 3-stage launcher. In Year 2, we focused our attention on the first step of this process, that is the development of the first 2 stages of the 3-stage accelerator. It is essential that we learn how to operate the 2-stage launcher successfully before the operation of the entire 3-stage launcher is attempted.

We report here the current status of this development.

Figure 5-1 shows the fully assembled and installed 2-stage system, comprising:

1. The first-stage power supply (400 kJ) and barrel (6 ft)
2. The second-stage power supply (200 kJ) and barrel (6 ft)
3. The muzzle vacuum seal
4. The muzzle D-block
5. The vacuum tank housing the ballistics instrumentation and the catch tank

SUVAC-II program signifies the beginning of the development of the entire SUVAC distributed power supply system, the basic unit is the 100-kJ capacitor module shown in Figure 5-2. Two of these modules make up the power supply for the second stage.

The 2-stage barrel system can be seen in Figure 5-3. In the figure, the D-block muzzle arc dissipator is shown without its containment structure. Some

of the steel clamps have also been removed to expose the interior of the barrel. The bus work feeding energy into the second stage through the junction can also be seen. The 2 capacitor modules providing the 200 kJ of energy for the second stage can also be seen in the right corner of the picture. The junction with its current injection module is shown in Figure 5-4. The new breech connection to the augmented first stage which represents an upgrade on the previous breech connection is shown in Figure 5-5.

Inter-stage sensing of the projectile and plasma armature and firing of the second stage power supply is a critical element in the successful operation of the 2-stage launcher. The sensing-and-firing system comprises a logical combination of the following signals:

1. A time delay based upon a pre-shot estimate of time-of-arrival of the armature
2. The magnetic signatures of the plasma armature as sensed by the magnetic pick-up loops
3. The optical probe which will sense the optical radiation from plasma armature

The required firing units have been installed.

The 2-stage system is currently ready for testing.

SUVAC-II: A 2-stage launcher system fully assembled ready for testing. Picture shows the ballistics vacuum tank housing the catch tank, the breakwire screen, the D-block muzzle arc dissipator, the two 6-ft barrel sections, the 400-kJ power supply for the first stage (in the back), and the 200-kJ power supply for the second-stage (to the right)..

Figure 5-2. The SUVAC 100-kJ capacitor module - The basic unit of energy in the SUVAC distributed system of power supply..

Figure 5-3. The 2-stage SUVAC-II Launcher System: Showing the two 6-ft barrel joined by a junction. Some of the upper steel clamps have been removed to show the insulators; Also shown are some of the magnetic pick-up loops (B-dot probes). The two 100-kJ capacitor modules feeding the launcher 2nd stage can be seen to the right, together with the associated bus works..

Figure 5-4. The Junction: Showing the bus connection and the current injection module. The inverted U-bar is the jumper for the augmentation winding of the first stage. A similar bar underneath the barrel completes the symmetry of the augmentation current feed..

Figure 5-5. The breech of the first stage and its bus connections to the terminals of the first-stage power supply (400 kJ)..

References

- [1] Y. C. Thio, D. L. Ometz, D. M. York, P. L. Ulerich, and T. J. Dougherty. *Investigation of Electromagnetic Launcher Behavior for Impact Fusion: Progress Report I.* Progress Report DOE/ER/13048-1, Westinghouse R & D Center, Pittsburgh, Pennsylvania, June, 1984.