A major purpose of the Technical Information Center is to provide the broadest dissemination possible of information contained in DOE's Research and Development Reports to business, industry, the academic community, and federal, state and local governments.

Although a small portion of this report is not reproducible, it is being made available to expedite the availability of information on the research discussed herein.

LA-UR -86-942

CONF-860414 /

Received by OSTI

APR 07 1986

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

MASTER

TITLE: A Launcher Barrel for the Lethality Test System Railgun

LA-UR--86-942

DE86 008739

AUTHOR(S) James R. Sims
Kirk E. Christensen
Charles E. Cummings
Noel C. Calkins

SUBMITTED TO: 3rd Symposium on Electromagnetic Launch Technology,
April 22-24, 1986, Austin, Texas

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy.

Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

A LAUNCHER BARREL FOR THE LETHALITY TEST SYSTEM RAILGUN

J. R. Sims, K. E. Christensen, C. E. Cummings, N. C. Calkins

Abstract - A reusable plasma armature railgun barrel design is described. This barrel was designed and is being fabricated at the Los Alamos National Laboratory for use in a kinetic energy lethality test system. The performance goals for this barrel are (1) that it be able to withstand the loads generated when accelerating a 30-g projectile to a velocity of 15 km/s without sustaining permanent damage, (2) that it have multiple shot capability, and, (3) that it be capable of being repaired and/or modified.

The barrel consists of a multipiece modular core contained in an outer structural shell. The core assembly, composed of rails and insulators, is accessible for repair or replacement. The outer structural shell is designed to allow access to the core and is used to preload the core compressively. The barrel design incorporates various features that will allow the use of stronger and stiffer materials such as structural ceramics and reinforced coppers as they become available.

INTRODUCTION

Los Alamos is designing and building a kinetic energy lethality test system (LTS). A plasma-armature railgun with a light-gas gun injector will be used to accelerate 30-g projectiles to velocities of 15 km/s. Multiple shot capability between major refurbishments is required of this railgun. A launcher barrel for this railgun is described in this paper. The LTS launcher barrel must meet the following requirements: (1) it must be able to withstand the rail force resulting from the magnetic field and plasma arc pressure loads generated in accelerating 30-g projectiles to 15 km/s without sustaining catastrophic damage, (2) it must be capable of firing single-shot experiments 10 to 12 times between major refurbishments, and (3) it must be capable of being refurbished and/or easily modified.

To meet these requirements, we chose a barrel with a high inductance gradient, a high structural stiffness and toughness, and a modular bolted construction. Because a light-gas gun will be used to inject projectiles into the railgun, a round bore is necessary. The round bore also makes repair of minor bore damage easier. Bore sidewall inserts of low atomic weight material are also used to help minimize the growth of the plasma arc mass from ablation of bore walls.

Numerical modeling of the LTS railgun system indicates that the acceleration of 30-g projectiles to 15 km/s may generate plasma arc pressures of 380 MPa in the bore and a magnetic force of 5.9×10^6 N/m acting to separate the rails. If the railgun barrel is to function efficiently, it must contain these loads, provide electric isolation of the rails, and not deform near the projectile. The poor structural characteristics of currently available insulating materials make this task difficult to accomplish. The high rail loads also make rail design a challenge because high strength, high conductivity ($>75\%$ IACS) anneal-resistant rail materials are not readily available.

Manuscript received March 17, 1986.

The authors are with Los Alamos National Laboratory, P. O. Box 1663, Los Alamos, NM 87545.

A barrel design has been developed that mitigates some of these material problems by compressively preloading the insulators and rails. This design also provides a reasonable inductance gradient of 0.329 $\mu\text{H/m}$ and allows the barrel to be easily repaired and modified.

BARREL DESCRIPTION

When completed, the launcher barrel will be 22 m long and will have a nominal bore diameter of 25 mm. It will be made of 1.85-m-long modules split horizontally and mounted on a structural support. Each module consists of two 210-mm-high by 420-mm-wide containment pieces (anvils), which are bolted together using 57-mm-diameter studs (see Fig. 1). The mating surface of each of these anvils has a 100-mm-deep 90° longitudinal groove that contains the rails and insulating material or core of the barrel. This core has a 152-mm-square cross section and typically contains 20 individual insulator, rail, and bore side-wall pieces as shown in Fig. 1. The core parts are typically 38 mm square and they are as long as material availability allows. The core is compressively preloaded by tensioning the studs that hold the anvil together.

ANVILS

The containment or anvils are mounted end-to-end using alignment supports on a beam consisting of two 610-mm rolled, wide flange sections welded together side by side. The anvils were designed and sized to provide a preloading force of 2.8×10^7 N/m along the barrel length. This force is sufficient to preload any known commercially available high-strength high-conductivity rail material to compressive yielding failure. The anvils are made from AISI 4340 steel forgings that are heat-treated to a hardness of Rockwell C-36. The anvils are machined and ground in pairs. The v-notch surfaces are ground to an 0.80 μm finish. The anvils are plated with electroless nickel plating for corrosion protection. The geometry of the anvils and the location of the studs that pull the anvils together minimize lateral bending moments at the bottom of the v-notches. The anvils contain various cavities and hole and notch penetrations to allow for the passage of electrical power-feed bus bars and diagnostic sensor leads and cables.

Each anvil pair is pulled together by 32 of the 57-mm-diameter studs. The studs are fabricated to conform to ASTM standard A354 grade BD. A hydraulic tensioning system is used to tension the studs (one at a time) in lateral pairs. Tension in the studs is measured by an ultrasonic extensometer. Stresses in the upper anvil of a pair are measured at the apex of the v-notch and on the upper outside surface immediately above the v-notch (see Fig. 2) at several locations along the length of the barrel. Electrical-resistance-type strain gages are used at these locations to monitor the upper anvil stresses during barrel assembly and core preloading.

CORE

The objectives of the design of the insulators and rails, that is, the core of the LTS railgun launcher barrel, is to compressively preload the core parts immediately surrounding the bore and still

Fig. 1. LTS railgun launcher barrel cross section.

provide a reasonable inductance gradient. The square geometry shown in Figs. 1 and 2 allows the core parts to shift and distort under load and to transmit forces from the anvils to the bore. The surfaces of the core pieces are smoothly finished and lubricated with silicone grease to promote movement into equilibrium under load. The core parts that form the bore are preloaded to slightly below the compressive failure point (275 MPa) by the outer core parts and the anvils.

Rail end joints are made using a lap joint. Any gaps in the joint are filled with a urethane elastomer. Sidewall inserts in the bore are spliced end-to-end using a glued lap joint. The insulator bore-forming parts have a small chamfer on the surfaces that contact the rail. This chamfer causes the compressive preloading stress to be more uniform along the rail and insulator joint. The preloading of the

core raises the capability of the bore-forming core parts to withstand the tensile and rail separating forces generated during firing.

Core insulating pieces are made from NEMA grade G-10CR (cryogenic grade) laminate, with the lamination oriented as shown in Figs. 1 and 2. The lamination orientations that are used optimize the compressive load capability of the G-10CR. The bore-lining sidewall inserts and corner-filling blocks are made of polycarbonate. Polycarbonate was used because of its tough plastic behavior, and in the case of the inserts, because of the low atomic weight of its constituents and some plasma arc modification effects that may occur from the small (<100 ppm), but finite halogen content. Core rails are made of full-hard CDA 110 copper (electrolytic tough pitch). This copper was selected because of its high conductivity, ease of machining, and availability. The compressive

Fig. 2. LTS railgun barrel diagnostics.

strength of the CDA 110 copper is adequate to match that of the NEMA G-10CR with which it will be used.

Several diagnostic sensors are incorporated into the LTS launcher barrel core as shown in Fig. 2. These sensors are preload-measuring electrical resistance strain gages, magnetic-field measuring sensors (B probes), and fiber-optic photonic sensors for measuring rail and bore sidewall movement during gun firing. The assembly preload-measuring strain gages are mounted on polycarbonate spool pieces to form small load cells. These load cells are placed in a NEMA G-10CR bore-forming piece (Fig. 2) where they will bear against the copper rail and measure the pressure at the rail/sidewall joint. The B probes are custom made wire loops and are placed periodically along the core in an outer G-10CR core piece, also shown in Fig. 2. These probes are used to monitor the plasma arc armature as it moves down the barrel. The photonic sensors use light and a fiber optic cable to measure the displacement of the back of the rails at center of the sidewalls. The displacement signals are transmitted optically to a photo-transducer.

quiet control room. Once they reach the quiet control room, the signals are processed and recorded. Typical locations of the photonic sensors are shown in Fig. 2.

By modeling the gun loads, we determined that the launcher barrel could open up along joints in the G-10CR regions of its core before the design goal of 30 g at 15 km/s is attained. An alternative core, using the same basic design as described above but with different materials, is being fabricated and tested for possible future barrel performance enhancement. The alternative core is described in the next section.

BARREL REFURBISHMENT AND FUTURE ENHANCEMENTS USING CERAMIC MATERIAL

The previously outlined barrel design allows minor bore damage to be repaired easily. The bore of the gun after assembly and preload is finished to its initial size by a pull-type reamer system powered by air motors. This reamer system also removes minor bore damage caused by the plasma arc armature and

projectiles. After the bore has sustained enough minor damage to be unusable it can be reamed to the next incremental size and used again. If major bore damage occurs or the bore becomes too large through repeated refurbishing, the gun barrel may be disassembled, and damaged or excessively worn parts may then be replaced. The alternative core mentioned in the previous section is made of sialon ceramic insulators and aluminum oxide dispersion-strengthened copper rails. The sialon ceramic being used has a 5.8 GPa compressive strength, 400 MPa tensile strength, 303 GPa modulus of elasticity, and 7.5 MPa $\sqrt{m}$ fracture toughness. This ceramic is isostatically pressed to rough shape, fired, and

diamond-ground to final form. The copper being used for the rails has a tensile yield strength of 550 MPa, a modulus of elasticity of 137 GPa, and an IACS conductivity of 78%. This alternative core will be made up of 38-mm-square by 305-mm-long sialon prisms and dispersion-strengthened copper bars held together in clusters of four by metal and ceramic-filled epoxy. The cross section of this core is similar to that shown in Fig. 1 except in this case there are only four individually assembled cluster pieces plus the bore sidewall inserts. A numerical model of the alternative core indicates that it will withstand full design-goal loads with some minor local tensile release-wave failures possible.