High Performance Railgun Barrels for Laboratory Use

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Abstract—High performance low-cost, laboratory railgun barrels are now available, based on a technology developed at IAP Research. The barrel is comprised of an inherently stiff containment structure, which surrounds the bore components machined from "off-the-shelf" materials. The shape of the containment structure was selected to make the barrel inherently stiff. The structure consists of stainless steel laminations which do not compromise the electrical efficiency of the railgun. The modular design enhances the utility of the barrel, as it is easy to service between shots, and can be "re-cored: to produce different configurations and sizes using the same structure. We have produced barrels ranging from 15 mm to 90 mm square bore, a 30 mm round bore, and in lengths varying from 0.25 meters to 10 meters long. Successful tests with both plasma and solid metal armatures have demonstrated the versatility and performance of this design.

INTRODUCTION

Electromagnetic railgun technology development is at present primarily taking place in laboratories and test facilities. Specific component research and development is focused within three broad areas: power supplies, launch packages, and launchers. Cost effective development testing requires a reliable and efficient laboratory railgun system. For example, during development testing of a new projectile design, the power supply and barrel should be reliable tools ready to perform. This paper describes the laboratory barrel design which we have developed to support reliable and efficient testing of other railgun components. To develop railgun system components in a cost effective fashion, laboratory railgun barrels must be versatile, highly maintainable, and meet key performance requirements. These requirements are explained in the following paragraphs.

Maintainability

A lab barrel is inherently subjected to new test conditions. Often these conditions can result in rail or insulator degradation or damage during a test. The cost of maintaining a barrel subjected to these conditions must be reasonable to permit the maximum amount of testing on a fixed budget. The two elements required for low cost maintainability are fast, easy core component repair or replacement, and low cost components. Maintenance can be held to a minimum if lab technicians can quickly and easily perform the work with the barrel in-situ (in the test stand) or at least at the test facility. Replacement of part cost can be minimized if "off-the-shelf" stock materials (e.g., stock size rail material) are employed. The combination of low cost materials and low man-hour servicing leads to lower cost development testing for railgun component technologies.

Versatility

A laboratory barrel must be versatile to meet ever-changing test requirements. Examples of development efforts which might be supported by a laboratory barrel include rail thermal management, rail, insulator ablation reduction, and launch package development. A laboratory barrel should be adaptable to a variety of configurations. Bore geometry greatly affects the complexity of launch package development. A laboratory barrel should accommodate both round and square bore configurations by simply changing the core of the barrel structure. This allows for the development of armature technology in the less complex magnetic environment of a square bore configuration before the design is transitioned to a more complex round bore configuration. The barrel should also accommodate a range of bore sizes. Performing both subscale and full-scale testing with the same structure should be possible by changing the insulator and rail core. Finally, the barrel structure should accommodate a variety of diagnostic probes to include pressure, B-dot, voltage, and optical probes.

Performance

Laboratory railgun testing is conducted over a broad range of currents and velocities. This requires good mechanical and electrical performance. The key mechanical

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requirement is high stiffness while the key electrical requirement is high inductance gradient.

High peak currents and plasma armatures generate high pressures in a railgun bore. These operating conditions require that the barrel have high strength, with high lateral stiffness, and tight bore dimensional tolerances. Barrels must often repeatably support electromagnetically generated pressures up to 350 MPa.[1] At these high pressures, the bore dimensions will grow, but must not exceed about 1% of the nominal bore size. Higher bore growth causes high balloting loads and obturation problems.

Inductance gradient is a key factor in barrel electrical performance. Force exerted on the projectile is directly proportional to inductance gradient. Therefore, inductance gradient must be as high as possible to get high acceleration force and projectile kinetic energy from the power supply delivered energy. Barrels that have inductance gradients[2] greater than 0.4 μH/m are generally desired.

A LAMINATED BARREL DESIGN

The laminated barrel design we have developed to meet the needs described above is shown in Figure 1. This basic barrel concept was developed under an IR&D project at IAP in 1987. The two main sub-assemblies of the barrel are the structure and the core. The structure consists of the laminated multiple pair barrel housing and the clamps. The core consists of the rails, the bore insulators, the backing insulators, and the mylar wrap (polyester film). Each of these components is described in the following paragraphs.

The Structure

The structure is comprised of the barrel housing and the clamps. A housing is a stainless steel laminated structure, consisting of alternating stainless steel and glass-epoxy laminations. The housing segments are fabricated by laying-up the laminations on an assembly mandrel which has been machined to precise tolerances. The laminations and mandrel are then placed in an oven to cure the epoxy, to form a single housing. Since each housing section is cured on the same mandrel, each has the identical internal dimensions. These internal dimensions are critical since they determine the core dimensions and tolerances.

The housing design is a key feature of this barrel. During a railgun launch, the electromagnetic (rail) bursting forces are reacted by the barrel housing itself. This is illustrated in Figure 2. Since the barrel housing material is located closely to the rails, thin insulator pieces can be used to insulate the rails from the structure. This results in lateral high stiffness, and the clamps which join the upper and lower barrel housing do not significantly add to the structure stiffness of the barrel. The wedge loaded C-clamps do not take significant loads. Many laboratory railgun barrels (capable of disassembly), have relied on the clamping bolts to react the electromagnetic bursting forces.[1] The result is that these barrels have low stiffness (and high bore deflection). In our laminated barrel, the structure reacts the bursting forces.

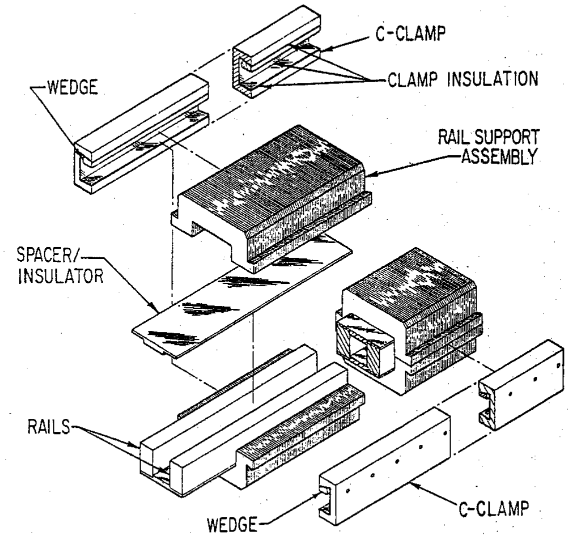

Fig 1. The laminated barrel consists of the core and the structure.

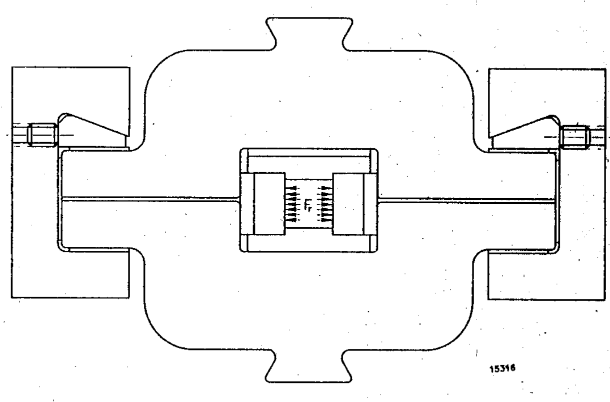

Fig. 2. The structure reacts the rail bursting forces and not the clamps.

The clamps consist of the clamp block, the clamp wedge, and the clamp insulators. A clamp assembly for our 90 mm structure is shown in Figure 3. The clamp block "pre-loads" the tabs on the upper and lower barrel housing by driving the wedge block forward with 1/2" set screws located 5 inches apart along the lay of the clamp block. During peak loading conditions, the "bursting forces are reacted through the structure to the wedge and finally to the clamp block. The clamp insulators insulate the wedge block and the clamp block from the stainless steel laminations avoiding electrical shorting of the laminates.

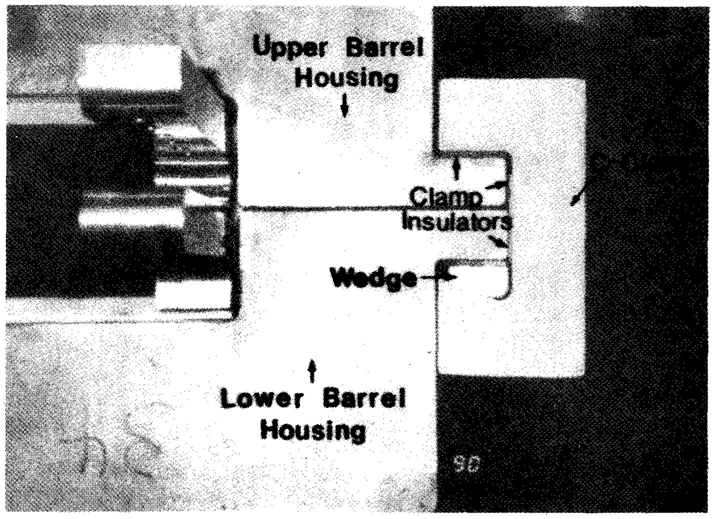

Fig. 3. Wedge loaded C-clamps hold the upper and lower barrel housing together.

The Core

The core consists of the rails, the bore insulators, the backing insulators, and the mylar wrap. For most testing requirements, "off-the-shelf" rail bar stock can be used. "Off-the-shelf" rail bar stock has very little variation on nominal dimensions over the length of the bar. The only machining required is to cut bars to the length, and to machine for connection to the power supply. Our approach to using "off-the-shelf" rails is a cost effective method for obtaining a relatively high precision bore (+/- a few thousandths of an inch variation over a length of several meters) without the added cost of machining the entire rail.

Our core is designed to use insulators that are machined from "off-the-shelf" bar or sheet. G-10 or Lexan provide excellent performance for most testing needs. The most significant dimension of the insulators is the width of the "land." This dimension and its associated tolerances determine the bore width and variation. Most all other dimensions on the bore insulator are not significant. Since the bore insulators are precision machined over the entire length, they are the most expensive (replacement) component of the gun.

The backing insulators are "off-the-shelf" pieces of insulation (G-10 or phenolic) which fit between the rails and the mylar wrap. The rail bursting forces are transmitted through the backing insulators (and the mylar wrap) to the barrel structure. The thickness of the backing insulators is minimized to reduce the amount of total bore deflection when the low modulus backing insulator is compressed.

The mylar wrap has two functions. The first is to insulate the rails from the stainless steel structure. The second is to shim between the bore components and the barrel structure. Since we use "off-the-shelf" rails, we do not always know the precise width of the core components when assembled. The mylar wrap shims any gap that may exist in the assembly. Usually more than one piece of mylar is used to improve insulation. The mylar thickness is generally about 0.25 mm.

APPLICATIONS AND TEST RESULTS

Our laminated barrel has met or exceeded our requirements for testing in the areas of armature, launch package, rail materials, and bore insulator materials development. The barrel is extremely easy to maintain and inexpensive to operate. In the following paragraphs, we describe some of the applications and test results which illustrate the laminated barrel performance.

Maintainability

The laminated barrel is very easy to assembly, operate, and service. The barrel can be maintained by technicians with very little training using basic laboratory tools. For example, a 3 m long, 50 mm barrel has been tested, disassembled, the core replaced and reassembled in the same day. This effort was accomplished by two technicians working less than eight hours each. Of course, if there is no damage to rails and insulators, then the barrel can be cleaned out and re-tested in a much shorter time. The maintainability of this barrel allows the user to concentrate on the pertinent research being conducted, and not on maintaining the barrel. It also allows for more flexibility in testing. For larger guns that are difficult to disassemble, test must be conducted on rails or insulators that are in less than optimum conditions. The low maintenance requirements for our barrel make it feasible to change out the core without dramatic cost implications.

Versatility

We have fabricated and tested barrels in a wide variety of core components, geometries, and lengths. A 50 mm laminated structure has been re-cored into a 30 mm round bore for development testing of a armature and sabot for a railgun launched anti-armor penetrator shown in Figure 4. We have also fitted this structure with a square geometry multiple rail system for development testing of an advanced concept for launching long rod penetrators in railguns (See Figure 5). We currently have two 50 mm structures, 3 m in length and conduct an average of two to three tests per week at currents to 1 MA.

Our railgun barrel technology is also used by several research organizations in the U.S. The Electromagnetic Launcher Technology Branch at U.S. Air Force Wright Laboratories Armament Directorate at Eglin AFB, Florida uses a 10 m long, 90 mm laminate structure designed and fabricated by IAP for their hypervelocity research.[3] This barrel, as shown in Figure 6, has been in service for approximately two years. A smaller 15 mm structure has been in service at the U.S. Army Ballistic Research Laboratory (BRL) for nearly five years.

Performance

We have analytically computed and experimentally measured the inductance gradient for our laminated barrel technology. A electromagnetic finite element analysis of our geometry has been performance yielding an L' of 0.40 μH/m. This value has been validated from actual pulsed current testing using the high frequency component of the pulse.

Our laminated barrel has excellent mechanical stiffness. We have computed and measured the bore deflection with respect to rail pressure. The results are provided in Figure 7. We measured the bore growth under hydrostatic pressure (on the rails), and during a current pulse using two interferometric techniques. The tests all give similar results and correlate very well with our analytical model. The bore growth is about 1% of bore size at a rated rail current of 30 KA/mm.

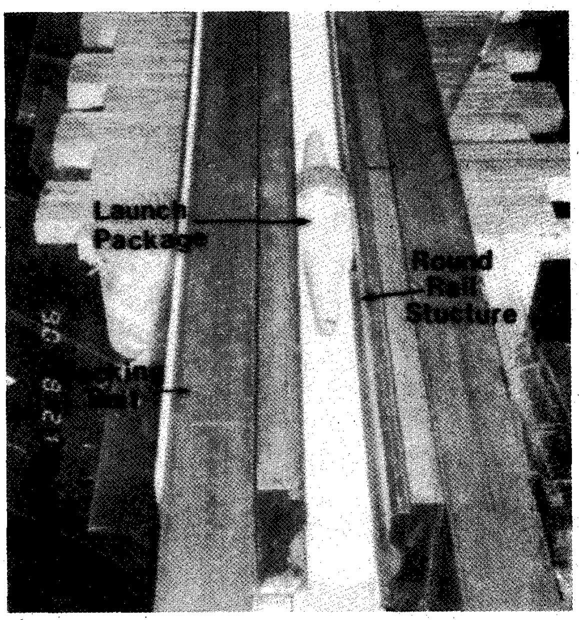

Fig. 4. A 50 mm structure was re-cored for 30 mm round bore tests.

Planned Improvements

We have identified several areas for improvement of our laminated barrel technology. The first is that we are currently investigating the feasibility of welding the laminate structure. We will eliminate the glass-epoxy insulation by coating the stainless steel laminates directly with an electrostatic-applied epoxy paint. The individual laminates will be formed into a barrel housing section by welding. We have performed analysis and testing to determine the optimum placement and size of the welds. This process will significantly lower the fabrication cost of our barrel.

We have also developed an approach for pre-stressing the bore insulator materials. This approach utilizes a mechanical wedge system eliminating the need for a complex hydraulic system. This wedge system can be easily adapted to the existing design.

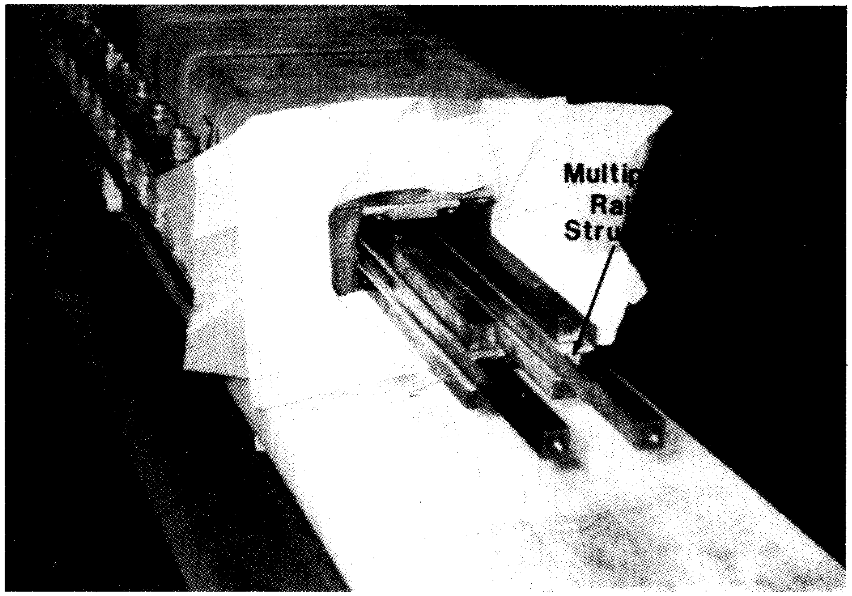

Fig. 5. We have tested advanced multiple rail concepts in our basic 50 mm structure.

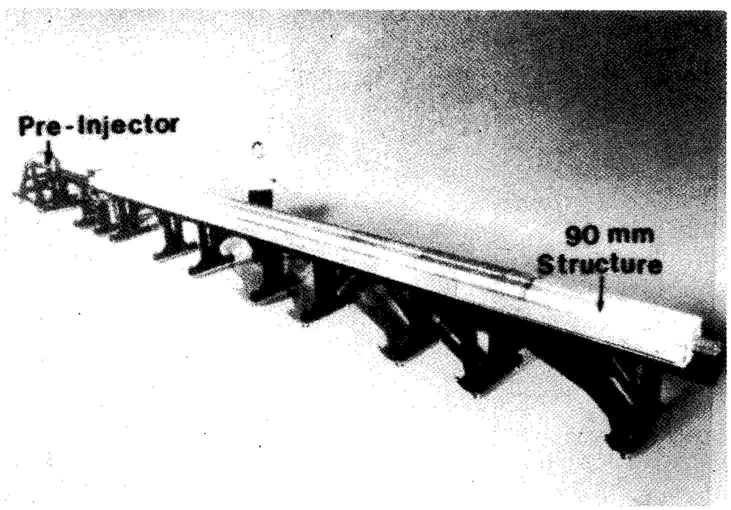

Fig. 6. We have fabricated barrels up to 10 m long.

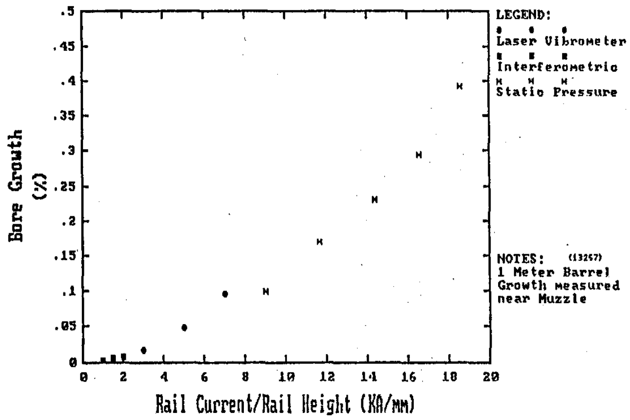

Fig. 7. Bore growth is less than 1%.

CONCLUSIONS

We have developed a laminated railgun barrel for laboratory use. This barrel is easily maintained by lab technicians. Inexpensive, "off-the-shelf" materials can be used as the replaceable core components. The barrel can be reconfigured in a variety of geometries and lengths. The assembled barrel is stiff and has a high inductance gradient (0.43 μH/m). Our barrel has proven to be an effective tool for conducting railgun component research and development.

REFERENCES

[1] Rosenwasser, S.N., "Recent Advances in Large Railgun Structures and Materials Technology," IEEE Transactions on Magnetics, Vol. 27, No. 1, January 1991.

[2] Ibid.

[3] Launcher Equipment, Contract No. SDIO 84-88-G-0002-0003, IAP Research, Inc., Final Report.