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RAIL CIRCUIT AUGMENTATION

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A concept for an augmented railgun barrel and integrated projectile/armature system is presented. The system makes use of the rail geometry to expose the augmenting rails to the bore, and incorporates dual tandem armatures in the launch package. Benefits include reduced current and power required to launch a given mass and a modest reduction in sabot mass due to creation of multiple tension and compression regions resulting from the use of dual armatures. Radial and axial plasma confinement techniques may be required to take advantage of system benefits. Application to an antiarmor mission is proposed.

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INTRODUCTION

Since electromagnetic launchers have begun to receive serious consideration for use in weapon systems, numerous railgun concepts have been put forth which employ multiple armatures and rails. For example, in 1984 Moldenbauer and Hauze proposed a system using "stacked rails[1]". This report illustrates advantages of a specific arrangement of armatures and rails which could apply to a tactically realizable anti-armor weapon system.

A concept for an augmented railgun barrel and integrated projectile/armature system is presented. Characteristics of the system configuration are high inductance gradiant, reduced current requirements deriving from the use of multiple armatures, reduced ohmic losses, and lower circuit resistance than standard augmented railguns.

RAIL CIRCUIT AUGMENTATION

Standard concepts for series augmented railgun barrels generally feature a simple series circuit with the augmenting rails parallel to the primary rails, situated to their outside, and in close proximity to them to facilitate strong magnetic induction (B) field coupling. The concept presented is referred to as rail circuit augmentation (RCA) and is a modification of the series augmentation concept. Instead of simply providing an additional rail turn to enhance the bore field, however, RCA uses the configuration of the augmenting turn in association with dual projectile armatures to achieve performance advantages for non-transitioning armature- based systems. Use of plasma confinement techniques could enable RCA to work in transitioning systems as well. In lieu of advances in material technology that would result in higher transition velocities, plasma confinement may be important for application of RCA to an antiarmor mission.

The basic configuration for an RCA barrel is shown in cross-section in figure 1. The fundamental difference between this and other augmented barrels is that the RCA augmenting turns curve in to meet the bore. This general configuration has been used before in conventional augmented guns without any exposure of the secondary rails to the bore[2]. The purpose of the c-shaped augmenting turn is to provide strong field

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[1] Moldenbauer, J., (ARES, Inc.) and Hauze, G., (formerly with ARES, Inc.), "Experimental Demonstration of an N-Turn EML," IEEE Transaction on Magnetics, Vol MAG-20, No. 2, March 1984.

[2] Zielinski, A., and Kezerian, J., both formerly of ARDEC, designed a 10 mm square bore augmented railgun with c-shaped augmenting rails, 1986.

coupling between the rail sets and thus a high inductance gradient (L'). An L' of 1.0μH/m is typically associated with barrels of this geometry which incorporate a single armature[3].

The key to the RCA configuration is the armature configuration. The idea is to have, in tandem, two separate and distinct solid armatures integrated with the launch package. The two armatures are electrically connected in series through the rail circuit with one armature conducting current across the primary rail set only and the other armature conducting current across the augmenting rail set only. Schematics of a conventional railgun, a standard augmented railgun, and an RCA railgun are shown in figure 2 along with expressions for resistance as a function of armature position for each system. A resistance versus armature travel function between that of a conventional railgun and a conventional series augmented railgun is a result of the "traveling" nature of the augmented region. A graph of relative rail resistance versus armature position for the three different kinds of systems, illustrating the intermediate resistance function of the RCA concept, is shown in figure 3.

The operation of this design requires minimal radial rotation of the projectile in the bore to ensure alignment of the armatures with the correct rails as well as creation of the desired rail circuit. In practice, radial rotations greater that one degree in round bore railguns have not been observed[4].

A potential difficulty with the RCA gun is operation in the presence of a plasma. Creation of a plasma, without some method of mechanical confinement, could electrically short the gun circuit, possibly leading to degraded system performance. Therefore, any practical application of RCA will more than likely incorporate a plasma confinement scheme in the launch package. At least one railgun maker has initiated efforts in plasma confinement, having fabricated a prototype high-strength filament-wound composite structure designed to physically keep plasma armatures close to the projectile and prevent plasma restrike toward the breech[5]. This axial confinement design consists

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[3] Zielinski, A., BRL, fabricated and made inductance measurements of the 10 mm square bore augmented railgun mentioned previously; also from a finite element analysis of that design by the author, 1987.

[4] Hayden, T., Kaman Sciences and Sink, D., SAIC, private communication, January 1990.

[5] White, M., Sparta Inc., presented to ARDEC personnel during a projectile design review August 1990.

of a bore-fitting pressure vessel attached to the back of the launch package with cutouts to expose the rails, allowing current conduction through the plasma. RCA may require such an axial confinement for both armatures. Radial confinement between them is probably required as well to prevent current conduction between the primary and secondary rail sets. Such a confinement could take the form of thin insulating ribs extending radially, for the length of the inter-armature region, from the outer sabot surface to the bore insulator which separates the primaries and secondaries. The ribs could also serve as sabot structural members (fig. 4).

If a confinement scheme is not incorporated, the design could nonetheless prove workable depending upon the physics of any generated plasma. For example, in a low-temperature (5000 to 7000 K) plasma, the associated resistivity ($\approx$1-5 m$\Omega\cdot$m) would be high and the resulting resistance would allow only a low-current path to be created.

ANTIARMOR APPLICATION

The RCA concept may be used in an antiarmor application. Dual armatures could be configured as mid-riding armatures/sabots or as a combination of base-pushed and mid-riding. The presence of two armatures would reduce the structural requirements on projectile configurations of interest for antiarmor. Multiple tension and compression regions are created, thus reducing overall stress levels in the sabot and projectile. Since the force on the rear armature, due to its deeper immersion in the rail B-field, is roughly three times the force on the forward armature, the sabot structure would be designed around the former with the latter providing some benefit to structural design.

A schematic drawing of a candidate configuration for an RCA railgun-launched antiarmor projectile/sabot is shown in figure 5. This particular concept features dual armatures; the trailing armature is configured as part of the mid-riding sabot structure while the leading armature is integrated with the sabot cup/borerider. Axial plasma confinement devices are located behind each armature. Radial confinement ribs are also visible on the sabot and within the axial confinement devices. Each armature incorporates an obturator to prevent plasma blow-by. The projectile is shown as a bare long rod with an aft flare for flight stabilization.

ADVANTAGES

The nature of the multiple series circuit promises performance advantages over both conventional railguns and standard series augmented railguns. In addition to reducing the structural design requirements on a launch package, the dual armature approach reduces system ohmic power losses by allowing lower currents that the other railgun types (but at the expense of higher rail resistance than a simple railgun), since the same electrical current contributes twice to the armature driving force.

The L for an RCA gun circuit can be shown to be approximately four times that of a simple railgun. Thus, for the same total current, RCA provides four times the total armature force as the simple railgun. This implies that current requirements for an RCA system can be half that of a comparable simple railgun system for the same total armature driving force.

The general expression for the rail action heating is given by

$$\int I^2(t)\,dt \tag{1}$$

and associated ohmic power dissipation is

$$\int I^2(t)\,R(t)\,dt \tag{2}$$

For the rail resistance of a simple railgun compared with that of an RCA gun

$$R(t)_{RCA} = 2\,R(t)_{simple} \tag{3}$$

and the current requirement given by

$$I(t)_{RCA} = 0.5\,I(t)_{simple} \tag{4}$$

the resulting power is

$$I^2(t)_{RCA} = 0.25\,I^2(t)_{simple} \tag{5}$$

Substituting into the power expressions, the ratio of power dissipated in the RCA circuit to power dissipated in the simple circuit is seen to be

$$P_{RCA}/P_{simple} = \frac{\int 0.25\,I^2(t)\,2\,R(t)\,dt}{\int I^2(t)\,R(t)\,dt} = 0.5 \tag{6}$$

The simple rail configuration, therefore, ohmically dissipates twice as much power as the RCA configuration in accelerating the same mass. This neglects power losses due to the additional voltage drop across the extra armature. A similar argument implies corresponding energy savings.

There is some promise for higher solid armature velocities without transitioning to plasma arc contacts, which could obviate the necessity of plasma confinement for RCA. Currently experiments are being made with material approaches to increasing the transition velocities, and multiple armature configurations have been launched from multirail conventional square-bore railguns[6]. Based on calculations of currents moving through the armature due to skin effects, the choice of materials for the rails and the armature could have a significant impact on the projectile velocity at which the contacts begin to arc. For example, there are indications that Cu-Cu contacts would begin arcing at velocities below those of Mo-Al contacts by as much as 1.0 km/s, depending on the actual operating conditions[7]. Also, T. James has described plans to test electrically anisotropic coatings on rail surfaces as a possible method of extending transition velocities to regimes of tactical interest[8].

CONCLUSIONS

RCA represents a tradeoff approach to improved performance for railguns: reduction in power requirements in return for increased system complexity. The concept, however, does not represent a major engineering leap beyond current efforts for either the barrel or projectile package. Single armature mid-riding sabots are being constructed, and a dual armature configuration is not an extreme extrapolation[9]. Radial and axial plasma confinement represents a geometric approach that would take advantage of both high-strength insulators in the bore and sabot as well as ultra-stiff railgun barrel technology.

The utility of the RCA concept lies in performance improvements manifested in reduced electrical current requirements due to augmentation, in conjunction with the use of dual armatures. The twin armatures, in turn, allow reduction of the structural requirements in railgun weapon system antiarmor launch packages.

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[6] Barber, J., IAP Research Inc., presented to ARDEC personnel during a technology briefing.

[7] Sink, D., SAIC, private communication, October 1990.

[8] James, T., Culham Laboratories (U.K.), in a briefing to ARDEC personnel, c. 1988.

[9] Single armature mid-riding projectile/sabot/armature launch packages are being built under the ARDEC SLEKE (Sabot Launched Electric gun Kinetic Energy) projectile contracts with Kaman Sciences Corp. and LTV Corp.

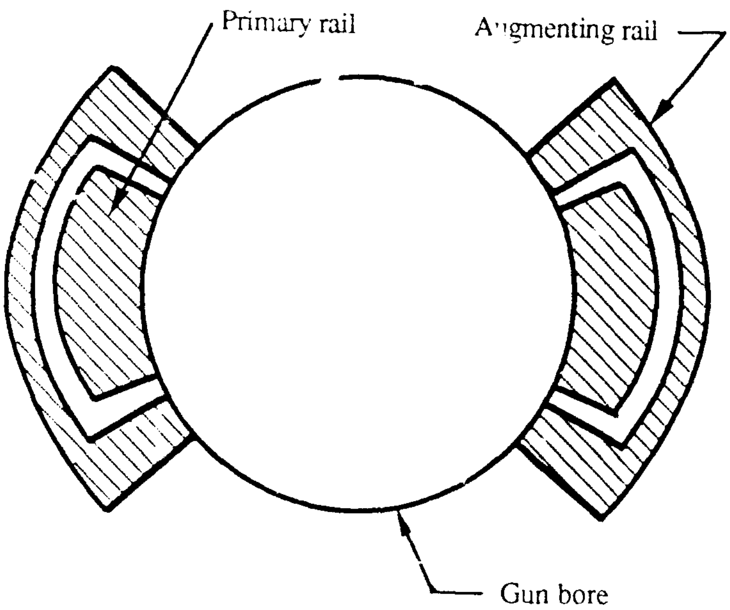
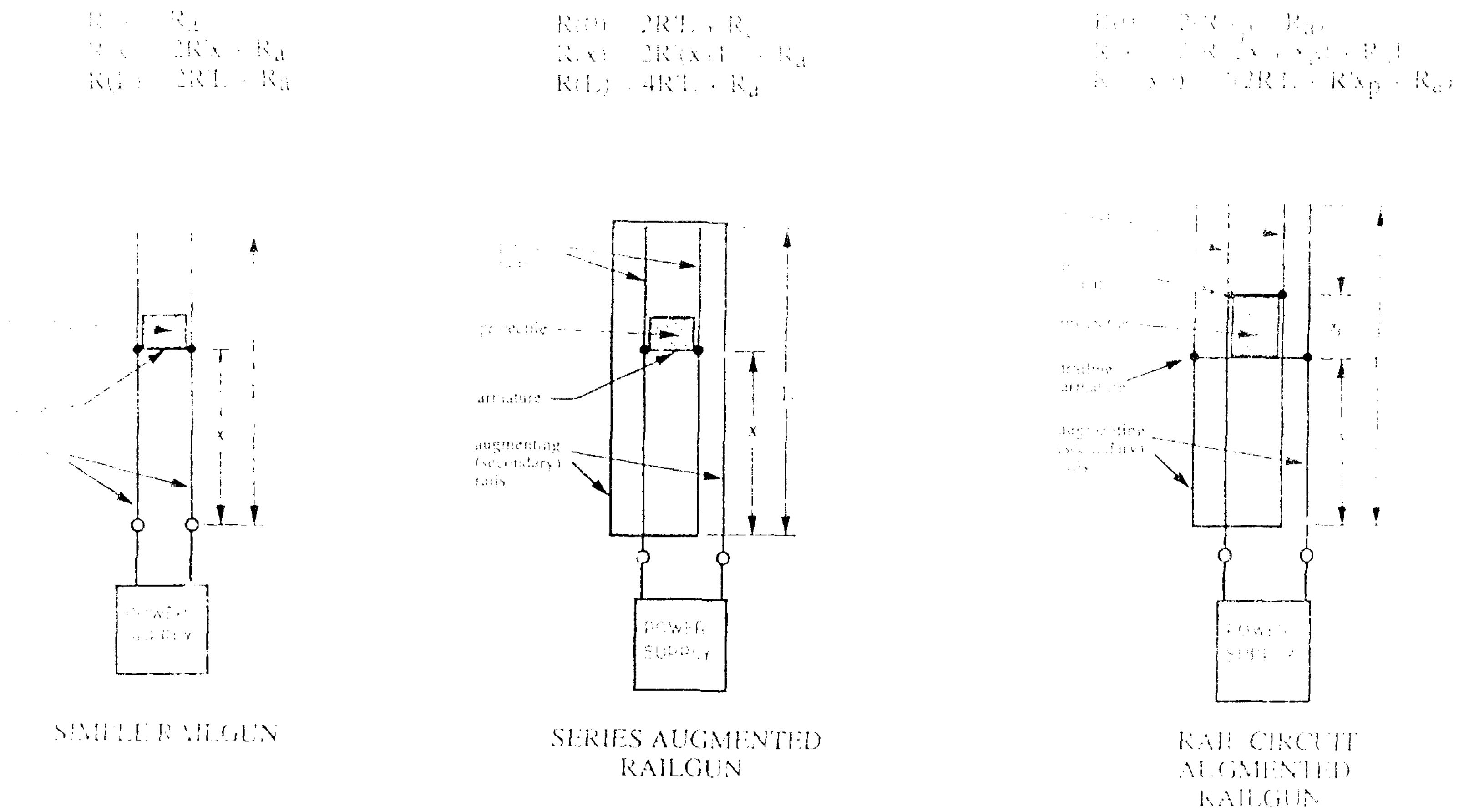


Figure 1. Rail circuit augmented (RCA) rail cross-section



L	Barrel length	R_a	Armature resistance (presumed equal for dual armatures)
R	Total circuit resistance	x	Armature distance from breech
R'	Rail resistance gradient (presumed constant)	x_p	Dual armature separation distance

Figure 2. Railgun schematics

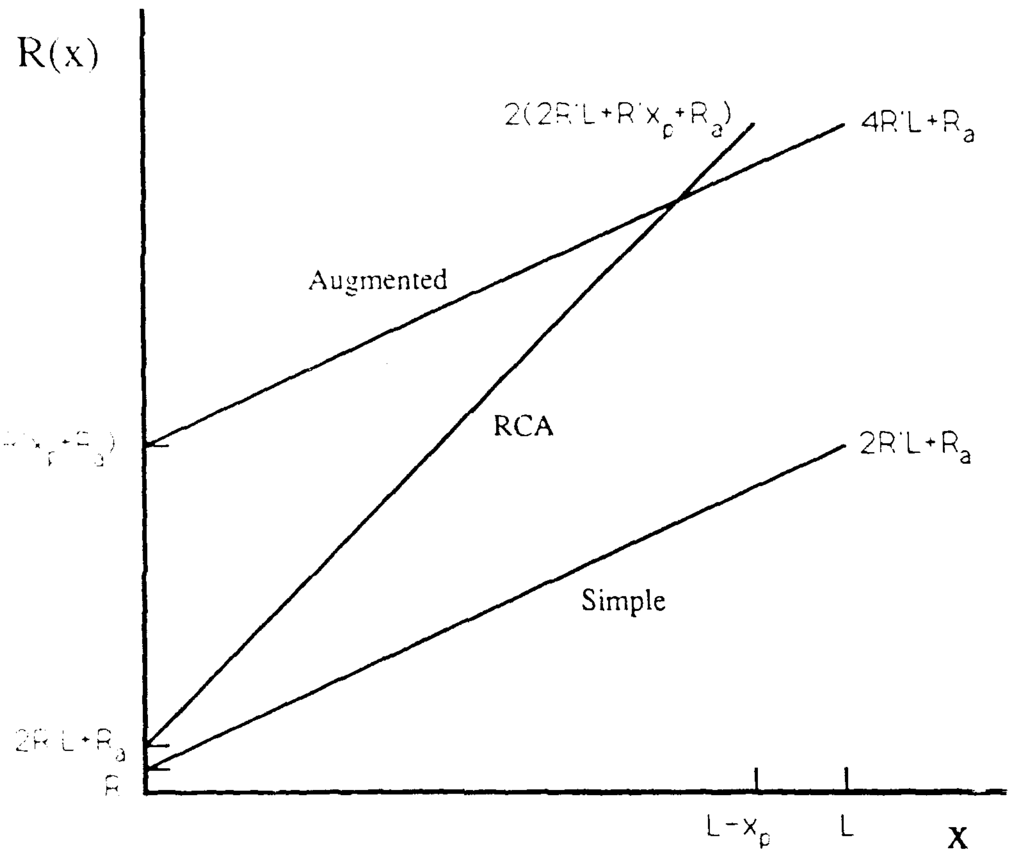


Figure 3. Relative resistances of the railgun types

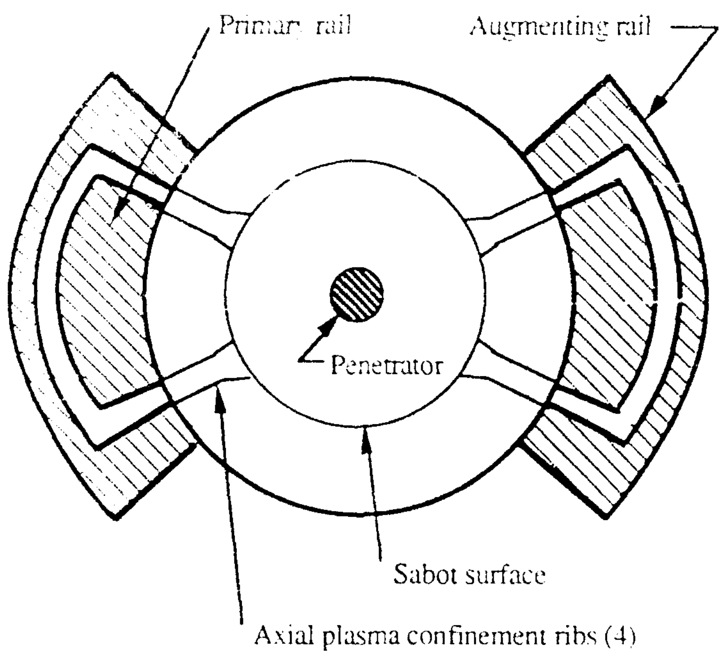


Figure 4. Axial plasma confinement

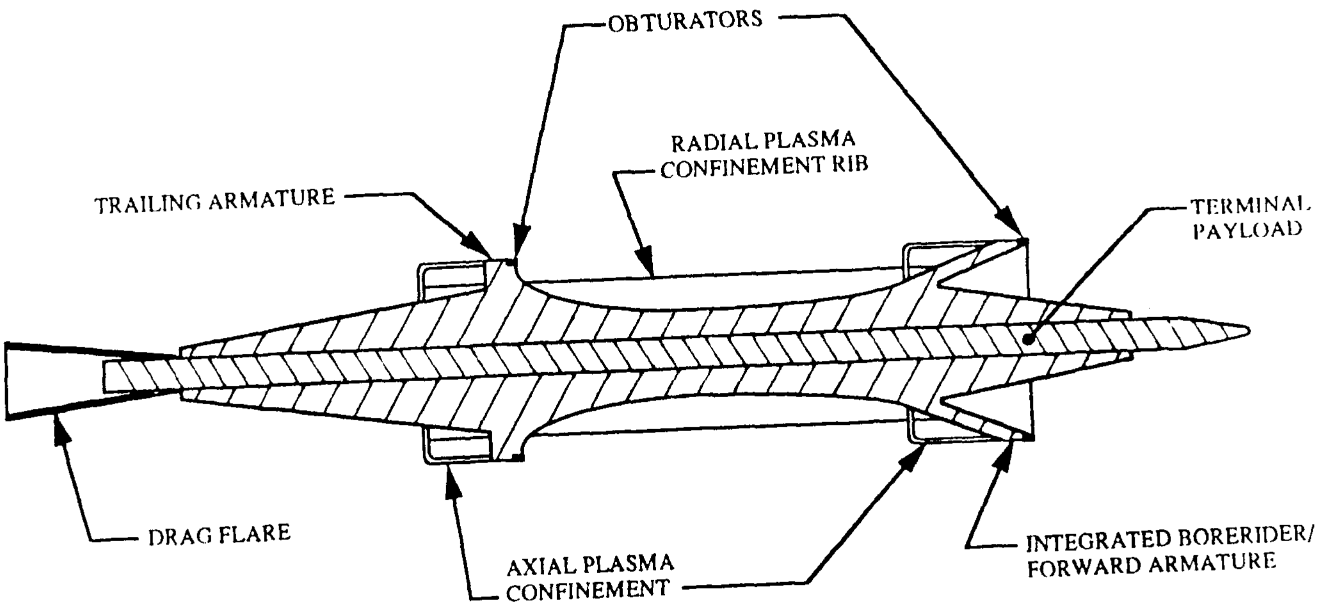


Figure 5. Cutaway schematic of a dual armature projectile package

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