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U.S. Serial No. 934,273, filed 24 Nov 1986  
entitled "ELECTROMAGNETIC RAILGUN WITH A NON-  
EXPLOSIVE MAGNETIC FLUX COMPRESSION GENERATOR"  
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Louis J. Jasper, Jr.  
CECOM Docket No. 4144

ELECTROMAGNETIC RAILGUN WITH A NON-EXPLOSIVE  
MAGNETIC FLUX COMPRESSION GENERATOR

5           The invention described herein may be manufactured, used,  
and licensed by or for the Government for Governmental purposes  
without the payment to me of any royalties thereon.

TECHNICAL FIELD

10           This invention relates generally to railguns and more  
particularly to railguns which utilize the principle of magnetic  
flux compression to generate large current pulses for gun  
operation.

BACKGROUND OF THE INVENTION

15           Conventional guns and projectile launching weapons  
utilize the burning of chemical propellents to achieve high  
projectile velocities. In recent years there has been a renewed  
interest in projectile launchers which utilize electromagnetic  
energy. Generally speaking, electromagnetic launchers promise  
higher projectile velocities than launchers utilizing chemical  
20           propellants. A prior art design currently receiving considerable  
attention is the electromagnetic railgun. The electromagnetic  
railgun utilizes two long parallel rails capable of carrying a  
large current. A sliding, conducting armature is positioned

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between the two rails. The armature is adapted to slide between the two rails along their entire length. Application of a voltage across two ends of the two rails causes a large current pulse to flow through one rail, thence through the armature, and into the other rail. The current generates a magnetic field. The Lorentz force created by the interaction of the magnetic field with the current in the armature causes the armature to be rapidly propelled between the two rails in a direction away from the points of application of the voltage. The armature itself may be projected like a bullet at a target, or the armature may be used to push a bullet-type projectile at high velocity towards a chosen target and the armature ultimately slowed and retained with the device for future shots. A detailed discussion of the principles of operation of an electromagnetic railgun is contained in applicant's co-pending application, titled "Electromagnetic Injector/Railgun," Serial Number 910,915, Filed, Sept 22, 1986, the entire disclosure of which is hereby incorporated by reference. To achieve high projectile velocities, large currents must be provided to the rails of the railgun. It is estimated that a current of at least 225 kiloAmperes (kA) is required to accelerate a two gram projectile to a velocity of 2 kilometers per second in a railgun of 1 meter length. The total weight of such a system is estimated to be between 150 and 200 pounds. The great weight of such a system makes the design of a hand-held railgun problematic.

### SUMMARY OF THE INVENTION

It is an object of the present invention to provide a gun which does not require a chemical propellant.

It is another object of the present invention to provide a simple, compact electromagnetic projectile launcher.

5 A further object of the present invention is to provide a lightweight electromagnetic projectile launcher capable of launching projectiles at high speeds.

A still further object of the present invention is to provide a lightweight electromagnetic projectile launcher which  
10 utilizes high currents produced by magnetic flux compression.

An additional object of the present invention is to provide a hand-held gun which does not require chemically-propelled bullets.

The present invention has three sections: a railgun  
15 section, a magnetic flux compression generator section, and an injector section. The railgun operates, as previously described, by utilizing a large current to drive an armature at high speed between two parallel rails. The armature is the bullet or portion of the bullet which is directed toward a chosen target. The  
20 magnetic flux compression generator (MFCG) section utilizes the principal of magnetic flux compression to provide a large current pulse to energize the rails and propel the armature.

In the MFCG section, a conducting piston slides between two conducting bars. A voltage is applied across the bars.  
25 Current flows in a circuitual path through the piston, through one

bar, through the bullet and finally through the other bar. The current generates a magnetic field and a resultant magnetic flux in the area enclosed by the current's circuital path. The piston compresses the magnetic flux ahead of it as it slides forward  
5 between the bars. The bars are electrically connected to the rails. According to the laws of electrodynamics, magnetic flux compression produces a large current pulse which travels from the bars to the rails.

The injector section serves to inject the piston into the  
10 area between the bars, causing the piston to slide between them and produce the aforementioned magnetic flux compression. The injector section also provides the aforementioned voltage which is applied across the bars. The injector section is powered by a prime voltage source such as a battery and capacitor bank. The  
15 injector section utilizes the operative principles disclosed in the aforementioned co-pending application. Briefly, the injector section features two parallel circular disks arranged at right angles to the aforementioned bars and rails. The disks are electrically connected to the capacitor bank so that they may  
20 carry current in opposite directions. The disks are separated by an insulator. One of the disks has a gap sized to admit the piston. Application of a voltage via the capacitor bank to the disks, causes current to flow in opposite directions through the disks and causes the piston to be rapidly injected into the  
25 magnetic flux compression generator section. As mentioned before,

movement of the piston through the magnetic flux compression generator section generates a large current pulse which causes a bullet to travel rapidly between the rails and thence towards a target.

5

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be more fully appreciated from the following detailed description when the same is considered in connection with the accompanying drawings, in which:

Fig. 1 is schematic perspective view of the inventive  
10 device;

Fig. 2 is a plan cross-sectional view of the device of Fig. 1 cut along the line 2-2 looking in the direction of the arrows;

Figs. 3A-3F are partial cross sectional views in the same  
15 plane as Fig. 2;

Fig. 4 is a graph which qualitatively illustrates the time dependence of current in the magnetic flux compression generator section;

Fig. 5A is an enlarged perspective view of the piston of  
20 the magnetic flux compression generator;

Fig. 5B is a cross-sectional view of the piston of Fig. 5A, cut along the line B-B looking in the direction of the arrows; and

Fig. 6 is a schematic perspective view of the principal  
25 components of the injector section of the inventive device.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the drawings, and more particularly to Fig. 1, wherein like numerals refer to like components throughout, reference numeral 11 designates generally the inventive device.

5 The railgun section of the inventive device includes parallel metallic rails 13 and 15. Grooves 21 and 23 extend along the length of rails 13 and 15 respectively. The grooves 21 and 23 serve to guide the bullet 25 (shown in Fig. 2) as it accelerates between the rails toward the target. Although Fig. 1 discloses

10 rectangular shaped grooves, other shapes, such as circular cross-sectional grooves, are acceptable. The only requirement is that the bullet 25 fit closely between rails 13 and 15. In a preferred embodiment, rails 13 and 15 are made of copper, or a copper alloy such as copper-tungsten. Snubbers 17 and 19 are

15 positioned at the ends of rails 13 and 15. The purpose of the snubbers is to attenuate current remaining on the rails after the bullet leaves the railgun and also to reduce the signature of the railgun. Consequently, the snubbers are made from materials having a much higher resistivity than copper (or whatever other

20 material the rails are made from). The bullet 25 (shown in Fig. 2) has a header section 29 and a body 27. The header 29 has a curved shape which facilitates progress of the bullet between the rails 13 and 15 and also improves the aerodynamic characteristics of the bullet 25 after it leaves the

railgun. The body section 27 of the bullet 25 is metallic and has a cross-section which mates closely with grooves 21 and 23.

The general principles of railgun operation are well known to those skilled in the art and are also discussed in the above-mentioned co-pending application of the present inventor. Briefly, application of a voltage between rails 13 and 15 causes a large current to flow through rail 13, through the body section 27 of bullet 25, and thence through rail 15. Interaction between the aforementioned current and its self-generated magnetic field produces a Lorentz force which accelerates the bullet 25 between the rails 13 and 15 in a direction away from the points of application of the voltage. In the present invention, the large current required to drive bullet 25 between rails 13 and 15 toward the target is provided by the magnetic flux compression generator (MFCG) section.

The MFCG section is contained within housing 50. The housing 50 is made from insulating material. Two parallel conducting bars 51 and 53 are positioned in housing 50. Bar 51 is electrically connected to rail 13 and bar 53 is electrically connected to rail 15. In a preferred embodiment, the bars may be formed integral with their respective rails and the housing 50, made from an epoxy material, formed about the bars. Bar 51 is completely severed into two sections 57 and 59 by an insulator segment 55. Insulator 55 completely prevents current flow from section 59 of bar 51 to section 57 of bar 51. An insulator pad 61

is inserted into a recess in rail 53 generally opposite insulator 55. As can be seen from Fig. 2, insulating pad 61 does not prevent current flow through bar 53. Two additional insulating pads 63 and 65 are also inserted into recesses of bars 53 and 51 respectively near the railgun end of the MFCG housing 50. As can be seen from Fig. 2, insulating pads 63 and 65 do not prevent current flow through bars 53 and 51. Conducting piston 73 fits closely between bars 51 and 53.

Figs 3A-F are plan cross-sectional views of the MFCG section which illustrate its operation. In Fig 3A, piston 73 is at rest within the injector section (and bullet 25 is at rest between rails 13 and 15 in the railgun section. As will be described subsequently, the injector section, together with a push-catch mechanism serves to inject piston 73 between bars 51 and 53. The injector section also, as will be illustrated in further detail below, produces a voltage across bars 51 and 53. After the piston 73 is launched between bars 51 and 53, a magnetic field (and resultant magnetic flux) is created by the current flowing through the piston 73, bars 51 and 53, and bullet 25. As the piston 73 moves forward between bars 51 and 53, it compresses the magnetic flux trapped in the space interior to bars 51 and 53, piston 73 and bullet 25. Compression of the magnetic flux produces, according to the laws of electrodynamics, a large current pulse in bars 51 and 53. To explain more fully the principle of operation, consider the following sequence of

events: The piston 73 in Fig. 3A is pushed to the position depicted in Fig. 3B by the yet-to-be described push-catch mechanism 400. In Fig. 3B piston 73 contacts disk 302 of the injector section. Presence of Piston 73 within the gap of disk 5 302 causes piston 73 to be forcibly ejected forward to the position depicted in Fig. 3C. Furthermore, as will be described in further detail below, bar 53 and bar section 59 of bar 51 are energized by application of a voltage from the injector section. (Of course, bar section 57 is not energized because insulator 10 segment 55 prevents electrical contact between the two sections.) Fig 3C illustrates the position of piston 73 as its front edge begins to contact insulator segment 55. A large current flows through disk 302, bar section 59, piston 73 and thence through the lower side of disk 302 while the piston 73 is 15 in the position depicted by Fig. 3C.

Fig 3D illustrates the MFCG section as piston 73 begins to pass the location of insulator segment 55. It should be noted that the length of the piston is greater than the length of insulator segment 55. Because the piston is sized so that it is 20 longer than insulator segment 55, current flows from disk 302 of the injector section through bar segment 59, thence through piston 73, through bar segment 57, through body 27 of the bullet and thence through rail 53 and lower side of disk 302, (and ultimately back to the power source to be discussed later). It is possible 25 for current to effectively flow around insulator segment 55 as

long as piston 73 straddles insulator segment 55. Furthermore, it should be noted that the length of piston 73 is less than the length of insulating pad 61 to ensure current flow in the above-described path.

5           When piston 73 has reached the position depicted in Fig 3E, it is effectively short-circuiting bars 51 and 53. Current flows through the circuital path consisting of piston 73, bar section 57, bullet 25, and bar 53. The circuital current flow creates a magnetic field, and hence a magnetic flux, perpendicular  
10 to the plane of the figure. As the piston 73 races forward to the position depicted in Fig 3F, magnetic flux compression occurs. A large current pulse is generated by compression of the magnetic flux by the forward-moving piston, moving at a sufficiently large velocity so as to prevent flux leakage. Because bars 51 and 53  
15 are electrically connected to rails 13 and 15, the current pulse is applied to rails 13 and 15. As previously described, application of a large current to rails 13 and 15 caused acceleration of bullet 25 along rails 13 and 15 and thence toward the target. The MFCG section is thus responsible for producing  
20 the high currents necessary to achieve high bullet velocity. Operation of the MFCG section may be better understood by an examination of Fig 4 in conjunction with Figs 3A-3F. Fig 4 is a graph which illustrates the current flowing through the piston 73 as it reaches the various positions depicted by Figs 3A-3F.  
25 Points labelled A-F on the graph are roughly indicative of

relative current magnitudes at the times when the piston 73 is in the positions depicted by Figs 3A-3F.

When piston 73 is at its starting position within the injector section as depicted in fig 3A, no current flows through the piston. Point A on the graph of Fig 4 illustrates zero current through the piston. The Piston 73 is pushed forward by the push-catch mechanism 400. When the piston 73 contacts disk 302 of the injector section, as in Fig 3B, current flows through disk 302 and piston 73 and, as will be elaborated further below, the piston 73 is forcibly ejected forward. Point B on the graph of Fig 4 illustrates the relative current flowing through piston 73 as it reaches the position depicted in Fig 3B. As the piston 73 moves forward to the position of Fig 3C, it begins to contact insulator segment 55 and current through the piston 73 falls, as shown by point C in Fig 4. In Fig 3D, the piston 73 straddles insulator segment 55 and current through the piston 73 rises again as shown by point D of Fig 4. In Fig 3E, the current circuitual path which sustains and traps magnetic flux is established through piston 73, bullet 25, and bars 57 and 53. Current through the piston (which is, of course, the same as current through the other components of the circuit) is depicted by point E of Fig 4. As piston 73 continues to rush forward, the trapped magnetic flux is compressed and current continues to rise, as shown by Fig 4. The same current is, of course, transmitted from bars 51 and 57 to rails 13 and 15 to operate the railgun. Finally, as piston 73

comes to rest between insulators 65 and 63, current through the  
piston 73 falls, as shown by point F of Fig 4. Or course,  
although current through piston 73 has diminished, current  
continues to persist on rails 15 and 13 to drive bullet 25 toward  
5 its target.

The following few paragraphs will explain in somewhat  
greater detail the physical principles of magnetic flux  
compression. The MFCG section of the present invention does not  
require the use of chemical explosives--it is a non-explosive  
10 MFCG. Many prior art MFCG devices utilize chemical explosives.  
In general, chemical explosives are used to compress an initially  
established magnetic flux by collapsing part or all of a  
conducting surface which encompasses the flux. Work done by the  
conducting surfaces moving against the magnetic fields results in  
15 an increase in electro-magnetic energy. The energy is supplied by  
the chemical energy stored in the explosives, a part of which is  
transmitted to the moving conductors.

In a perfectly conducting (zero resistance) circuit, a  
well-known electrodynamic result is that the flux is conserved,  
20 or:

$$L_0 I_0 = L_F I_F$$

where  $L_0$  and  $I_0$  are the inductance and current respectively at  
time zero and  $L_F$  and  $I_F$  are respectively inductance and  
current at a subsequent time.

Explosive MFCGs have the ability to produce large energy bursts in time scales not normally available otherwise. Large current and energy multiplications are thus possible for low inductance circuits. However, explosive generators destroy some system components and their use is limited to single shot or at best low repetition rate applications. A detailed discussion of explosive magnetic flux compression generators is contained in: C.M. Fowler, et al. "An Introduction to Explosive Magnetic Flux Compression Generators, Los Alamos scientific laboratory report LA-5890-MS, dated March 1975".

The MFCG of the present invention does not, of course, use chemical explosives. The yet-to-be-described injector section of the present invention accelerates piston 73 until it arrives at the position depicted in Fig 3E. The magnetic flux enclosed by the current path shown in Fig 3E is rapidly compressed by the accelerating piston 73 as it travels toward its resting place depicted in Fig 3F. The conservation of flux equation gives the current  $I$  increase since the inductance  $L$  decreases as the circuit area enclosing the flux decreases. The faster piston 73 moves, the more current gained, because the circuit area will decrease more rapidly before bullet 25 accelerates and in turn causes the circuit area to increase. Also, the flux leakage is minimized by rapid piston velocity. The MFCG section of the present invention is designed to produce energy and current gains in the range of 5 to 10.

Note, that for a rail gun, the force equation is

$$F = \frac{1}{2} L' I^2$$

where  $L'$  is the inductance gradient and  $I$  is the current.

The force increases linearly with inductance and with the square of the current. This means that a MFCG that yields only current  
5 gain and no energy gain is still beneficial because a larger Lorentz force will be generated. The condition of current gain and no energy gain means that the efficiency of the device has been increased. An advantage of the present non-explosive MFCG is that the device may be used over and over again to yield multiple  
10 bullet shots. A subsequent portion of this disclosure will explain how the piston 73 is returned to its starting point for subsequent shots. Of course, the present non-explosive MFCG does not produce energy or current gains as great as those provided by explosive MFCGs. Somewhat lower gains are anticipated for the  
15 present inventive device mainly because the electrically driven piston does not move as fast as an explosively driven piston. An estimate minimum piston velocity is about 300 m/sec.

Fig 3F depicts the piston 73 as it comes to the end of its path between rails 51 and 53. Insulating pads 63 and 65 serve  
20 to prevent current flow, and the piston 73 comes to a stop due to magnetic braking action. Forward progress of piston 73 is also halted, if necessary, by housing 50. For maximum efficiency, piston 73 should just come to rest.

If current flows in the counter clock-wise direction  
25 depicted in Fig 3D, the resulting magnetic field will point upward

from the plane of the figure. The upward-pointing magnetic field depicted in Fig 3D may be augmented by two permanent magnets 83 and 82 (Fig 1), which may be placed above and below the MFCG section. The magnets 83 and 82 must be oriented to create a  
5 magnetic field in the same direction as the magnetic field depicted in Fig 3D, i.e. pointing upward in Figs 1 and 3D for current flow in the counter clockwise direction. Should the magnetic field created by permanent magnets 82 and 83 be  
10 accidentally oriented in a direction opposed to the magnetic field created by the current, the permanent magnets 82 and 83 will be degaussed and be of no use.

The permanent magnets 82 and 83 serve to augment the magnetic field created by current flowing in bars 51 and 53. Magnets 82 and 83 may be made from samarium cobalt, neodymium-  
15 iron-boron or another high energy product magnet material. If magnets 82 and 83 are spaced approximately one-half inch or less between their pole pieces, approximately 1.5 to 2.0 Teslas may be produced. Thus, the permanent magnets 82 and 83 contribute a magnetic field roughly equivalent to the magnetic field generated  
20 at the surface of an infinitely long wire carrying 50 kiloAmperes of current. The permanent magnets 82 and 83 thus augment the magnetic flux between bars 51 and 53 and therefore increase the resulting current pulse  
25 produced. The magnets shown schematically in Fig 1 extend over only a portion of the magnetic flux compression area between bars

51 and 53. However, it is possible, if desired, to make magnets 82 and 83 longer to cover the entire MFCG section. Magnets with extended length have the disadvantage of heavier weight but provide the advantage of greater magnetic field augmentation  
5 between rails 51 and 53 and consequent greater Lorentz Force.

Thus, what has been described so far is the railgun section of the present inventive device which propels a bullet toward a chosen target with the application of a large current pulse to its rails 13 and 15. The current pulse necessary to  
10 energize the railgun is provided by the non-explosive MFCG which utilizes piston 73 injected between bars 51 and 53 to compress a resulting magnetic flux and provide the needed current pulse. Piston 73 is initially launched at high speed between bars 51 and 53 by the injector section which is described below:

15 The injector section is most easily understood by reference to Figs 1, 2, and 6. The injector section of the present invention utilizes the electromagnetic principle that oppositely directed currents flowing in parallel conductors tend to force those conductors apart. Briefly, disks 302 and 305 are  
20 oriented parallel to each other, separated by an insulator 304. The disks 302 and 305 are arranged so that current from a battery/capacitor bank 200 flows in opposite directions through them. Piston 73, originally at rest within an insulated gap 323 in disk 305 is ejected by a push-catch mechanism 400 into a gap in  
25 disk 302. Presence of the

piston within the gap in disk 302 permits current to flow through both disks and causes the piston 73 to be ejected between rails 51 and 53.

Disk 302 is generally circular in shape. Disk 302 is  
5 split in two halves 310 and 311 by gaps 314 and 315. Disk 305 is split by gap 320 into two halves 505 and 504. Connector 313 connects the lower portion of half-disk 311 and the lower portion of half-disk 505. Connector 312 is attached to the lower portion of half-disk 310 and connector 320 is attached to the lower  
10 portion of half-disk 504. Notches 317 and 316 are located adjacent gap 314 and disk halves 311 and 310 respectively. Notches 317 and 316 are shaped and spaced apart so that piston 73 fits closely within them. It is necessary that piston 73 fit closely enough that it forms an electrical connection for the  
15 conduction of current between the disk half 310 through piston 73 to disk half 311. For example, side 81 of piston 73 (Fig 5) touches notch 317 and side 80 of piston 73 touches notch 316.

Disk 305 is split by gap 320 at its bottom. A hole 323 is located in the top of disk 305. The hole 323 does not sever  
20 disk 305, i.e., it is possible for current to flow through the disk material above and below hole 323. Hole 323 is defined on all sides by an insulating insert 324. Hole 323 is dimensioned to closely receive piston 73. However, the presence of insulating insert 324 prevents any current which may flow through disk 305  
25 from flowing through piston 73.

Insulator 304 has the same circular dimensions as disks 305 and 302 and is sandwiched between them. Insulator 304 has a hole through which piston 73 may pass as it travels from disk 305 through disk 302. Except for the hole, there need be no other gaps or holes in insulator 304.

In operation, leads 312 and 321 are connected to opposite sides of a capacitor bank/battery combination 200. The capacitor bank is denoted by reference numeral 501; the battery or other power supply by numeral 503. A trigger switch 502 is positioned between them. Piston 73 is initially at rest within hole 323 of disk 305. The piston 73 must be short enough so that it does not protrude into or contact any portion of disk 302. Consequently, thickness of disk 305 plus the thickness of insulator 304 must equal or exceed the length of piston 73. Push-catch mechanism 400 contains an actuator which may be electrically or mechanically powered. The actuator serves to push the piston 73 from its resting place in hole 323 into the gap defined by notches 317 and 316 of disk 302. Presence of the piston 73 within the gap defined by notches 317 and 316 of 302 causes current to flow through disks 302 and 305 in opposite directions. The sandwich of disks 305 and 302 and insulator 304 is firmly held together within an epoxy coating 300. Consequently, disks 305 and 302 cannot move apart despite the strong force created by the oppositely-moving currents. Piston 73 is forcibly ejected from the space defined by notches 317 and 316 to a position between bar 59 and 53 as shown

in Fig 3C. Disk half 310 is electrically connected to rail 53 and they may be formed integrally if desired. Disk half 310 is electrically connected to bar segment 59 and they may be formed integrally if so desired. Operation of the magnetic flux  
5 compression generator section after piston 73 has been ejected into the position depicted in Fig 3C and the ultimate ejection of bullet 25 have already been described.

After piston 73 finally arrives at a position depicted in Fig 3E between insulating pads 63 and 65, current generation  
10 ceases. It is necessary to somehow return piston 73 to its starting place within hole 323 of disk 305 so that another bullet may be fired. The following paragraphs describe how piston 73 is returned to its starting position in anticipation of the next shot. Piston 73, shown in enlarged detail in Fig 5, has two  
15 insulating inserts 82 and 83 located in sides 80 and 81 respectively. In forward-operation, such as is depicted in Figs 3A-3F, current flows through piston 73 from side 81 to side 80. Side 81 of piston 73 is contiguous to the side of bar 51 and side 80 is contiguous to the corresponding side of bar 53. However,  
20 when piston 73 arrives between insulating pads 63 and 65, the insulating pads prevent current from flowing between the sides of the bars and the sides 80 and 81 of piston 73. However, magnets 83 and 82 together with metal plates 91 and 90 are utilized to create a Lorentz force which serves to return piston 73 to its  
25 starting position in hole 323 of disk 305. Plates 90 and 91 are positioned above and below the plane of Fig 3E. Plate 91 is

positioned so that it contacts the top surface 94 of piston 73. Plate 90 is positioned so that it contacts the bottom surface 95 of piston 73. Leads 92 and 93 are attached to plates 91 and 90 respectively. Plates 90 and 91 are located within the gap between  
5 the pole pieces of magnets 82 and 83. Leads 92 and 93 are connected to leads 402 and 403 of disk 302. Leads 92 and 93 are twisted together as they extend from disk 302 to plates 91 and 90 so that the repulsive forces exerted on the wires are reduced. When piston 73 comes to rest at the position shown schematically  
10 in Fig 3E, the top of piston 73 contacts plate 91 and the bottom of piston 77 comes in contact with plate 90. The leads 92 and 93 are connected so that current flows through the piston 73 from the top surface 94, in the general direction from side 80 to 81, and thence through bottom surface 95, into plate 90. It should be  
15 observed, that the principle direction of horizontal current flow through piston 73 caused by contact with plates 91 and 90 is opposite to the direction of current flow depicted in the forward-moving snapshot of Fig 3D. The portion of the current through piston 73 which is parallel to the magnetic fields between  
20 magnets 82 and 83 does not contribute to a Lorentz force capable of returning the piston 73. However, the horizontal component of current flow, proceeding generally from side 80 to side 81 interacts with the magnetic field created by permanent magnets 82 and 83 to produce a Lorentz force which pushes the piston backward  
25 towards its starting position in hole 323 of disk 305. Thus, the

piston 73 is returned to its initial starting point from whence it may begin another cycle.

The push catch mechanism 400 is not shown in detail and is well known in many arts. The functions of the push catch mechanism are twofold: to push the piston 73 from its initial position in hole 323 of disk 305 into the gap defined by notches 317 and 316 of disk 302, thus causing conduction through disk 302 and ejection of piston 73, and to catch and hold piston 73 after it is returned by the above-described Lorentz force return mechanism. As mentioned before, ejection of the piston 73 may be accomplished by a variety of actuators well known to those skilled in many arts, such as solenoid-actuated actuators or spring-loaded actuators. The catching mechanism may be either a spring-loaded hook or an electromagnet.

Ammunition clip 405 is positioned generally beneath bullet 25. Ammunition clip 405 may be a spring-loaded clip selected from a variety of designs well-known to those skilled in the art. The purpose of the ammunition clip 405 is to provide additional bullets 25 for multiple shots. If desired, the ammunition clip may be accompanied by a sensor which prevents a new bullet from being inserted between rails 13 and 15 while the previous bullet is still traveling between them.

Performance of the inventive device may be enhanced by constructing housing 50 to be air tight. Such an assembly might require that magnets 82 and 83 be located outside housing 50 and might also require feed throughs for bars 51 and 53 and leads 92

and 93. The interior of housing 50 could be filled with an arc suppressing gas such as sulfur hexafluoride at a pressure of a few atmospheres. An alternative embodiment features a housing evacuated to a very low pressure on the order of  $10^{-6}$  to  $10^{-8}$  Torr. This embodiment would possess the advantages of reducing arcing between piston 73 and rails 51 and 53, providing less friction for moving piston 73 and, possibly allowing the use of superconducting metals or metal temperature reduction techniques to enhance efficiency and lower circuit resistance. If the inventive device were to be adapted for pod-mounted or vehicle-mounted applications, the use of a compact cryorefrigerator capable of reducing the temperature of the copper rails from room temperature to  $-140^{\circ}\text{C}$  would be feasible.

The inventive device may be fired by using a trigger. The trigger is connected to several of the aforementioned components of the inventive device. The trigger is connected to activate the push-catch mechanism 400, while simultaneously energizing disks 302 and 305 via switch 502.

The illustrative embodiment herein is merely one of those possible variations which will occur to those skilled in the art while using the inventive principles contained herein. Accordingly numerous variations of the invention are possible while staying within the spirit and scope of the invention as defined in the following claims.

ELECTROMAGNETIC RAILGUN WITH A NON-EXPLOSIVE  
MAGNETIC FLUX COMPRESSION GENERATOR

ABSTRACT OF THE DISCLOSURE

A lightweight, portable, electromagnetic railgun. The  
5 invention features a conventional railgun coupled to a magnetic  
flux compression generator (MFCG) section and an injector section.  
The conventional railgun has two parallel metallic rails (13,15)  
with a bullet (25) slidably positioned between them. The bullet  
is rapidly projected between the rails toward a chosen target when  
10 a current flows between the rails (and through the bullet). The  
MFCG section provides a source of high current to the rails. The  
MFCG section has a piston (73) which moves between two energized  
bars (51,53). A magnetic field is created by current flowing in a  
circuit through the piston, (73) the bars (51,53) and the bullet  
15 (25). The associated magnetic flux is rapidly compressed as the  
piston moves between the bars. Compression of the magnetic flux  
produces a large current pulse which is coupled to the rails  
(13,15) to propel the bullet (25). The injector section injects  
the piston (73) into the space between the bars (51,53) to begin  
20 the magnetic flux compression sequence.

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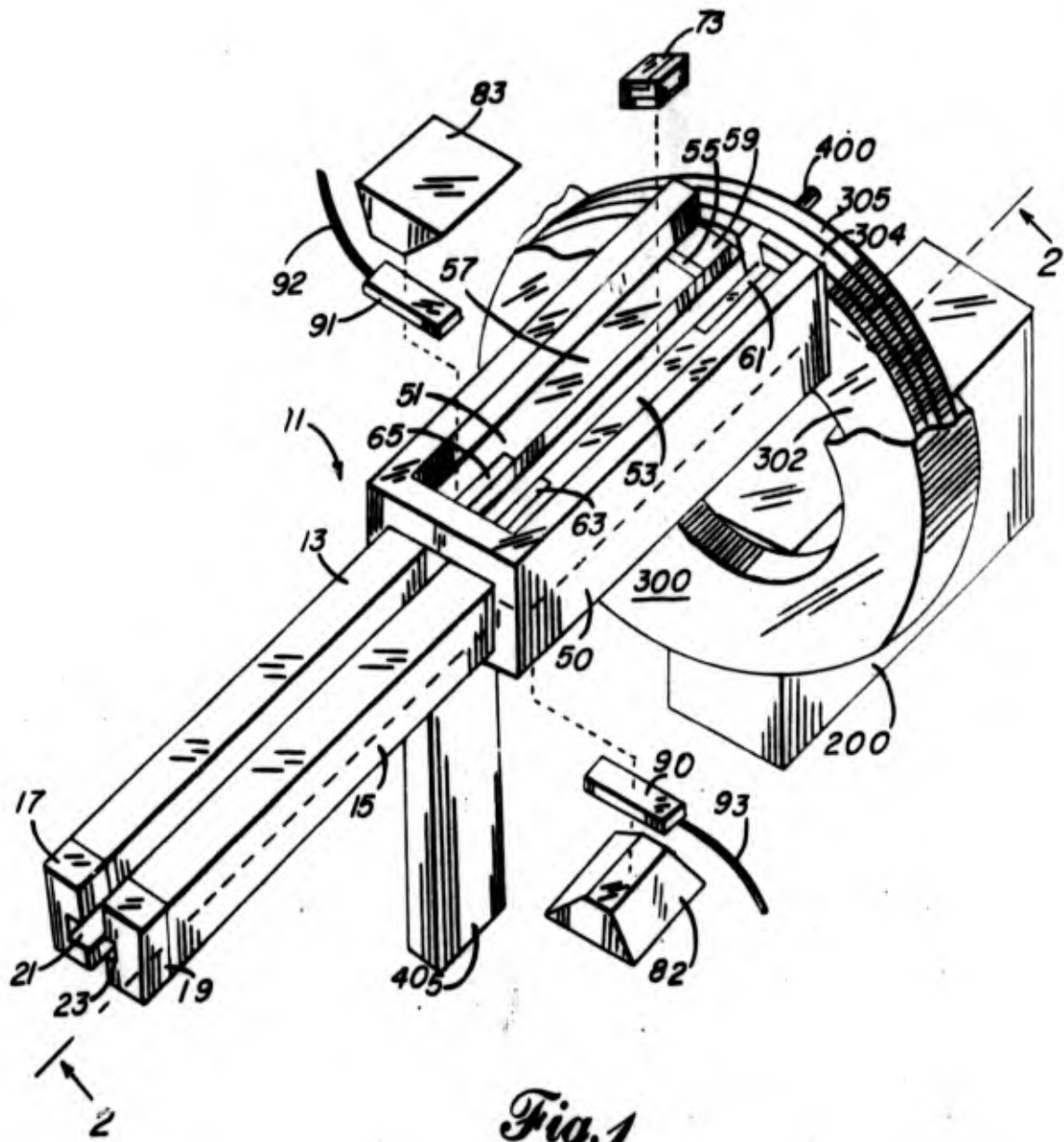


Fig. 1

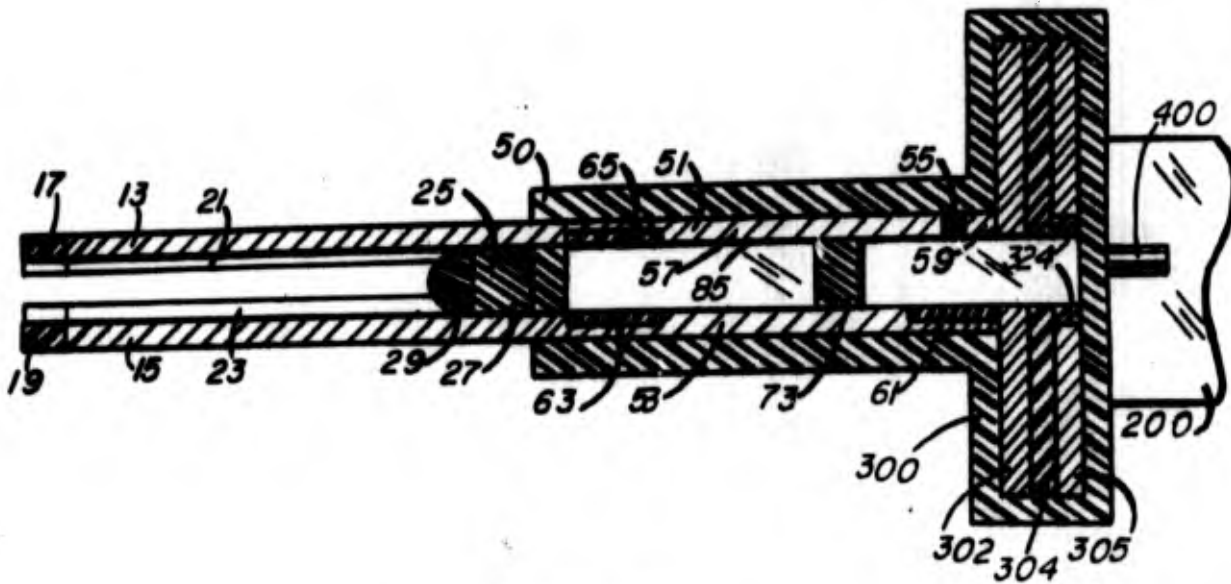


Fig. 2

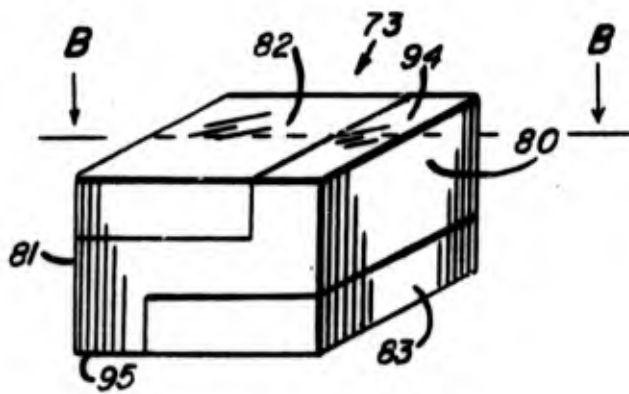


Fig. 5A

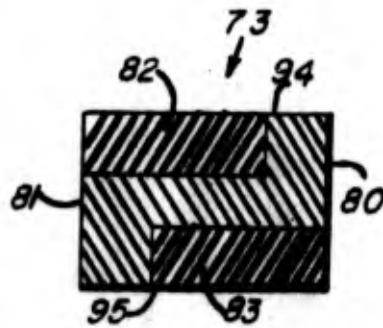
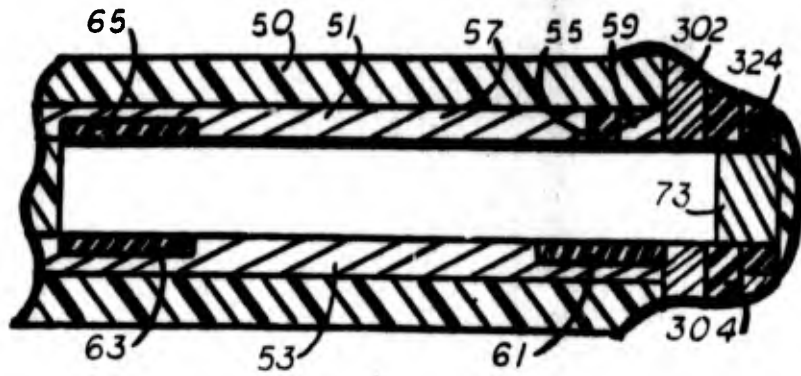
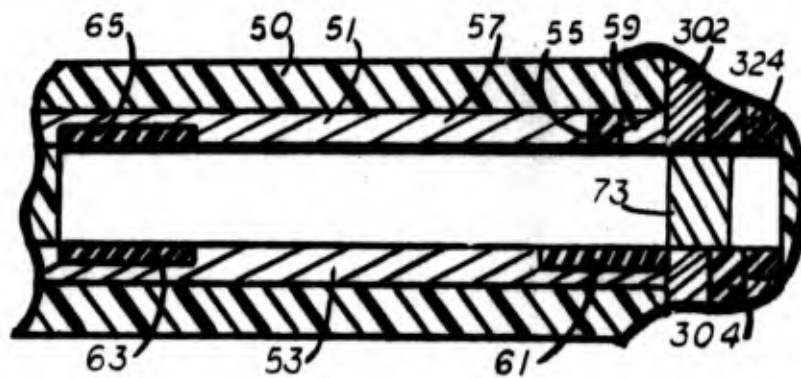


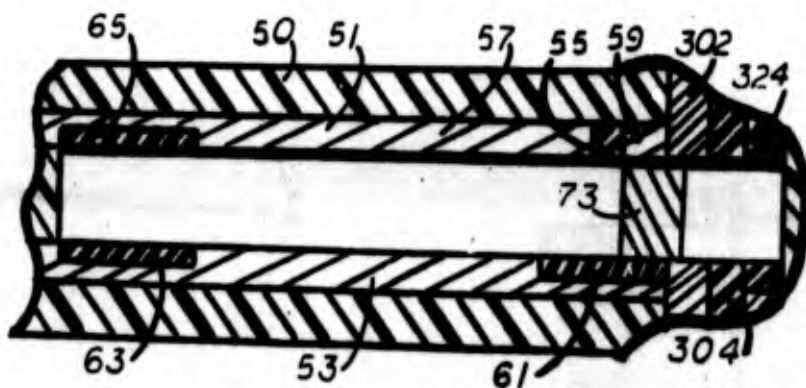
Fig. 5B



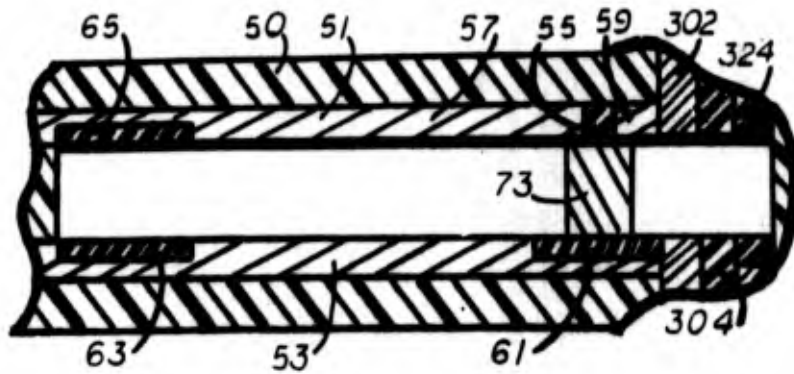
*Fig. 3A*



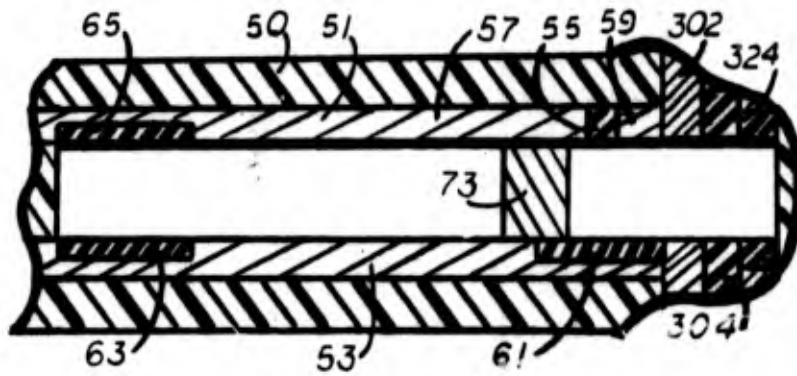
*Fig. 3B*



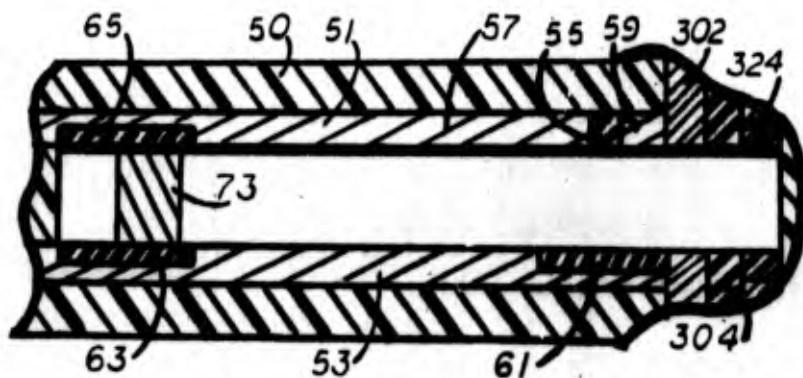
*Fig. 3C*



*Fig. 3 D*



*Fig. 3 E*



*Fig. 3 F*

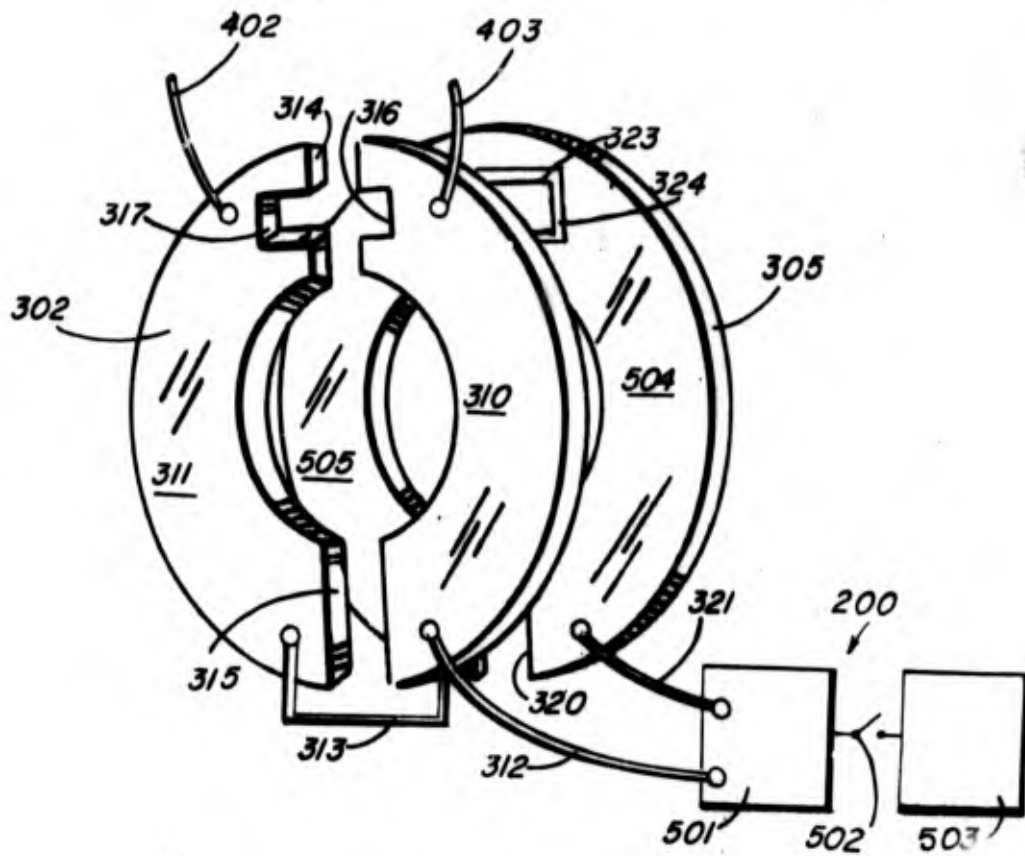


Fig. 6

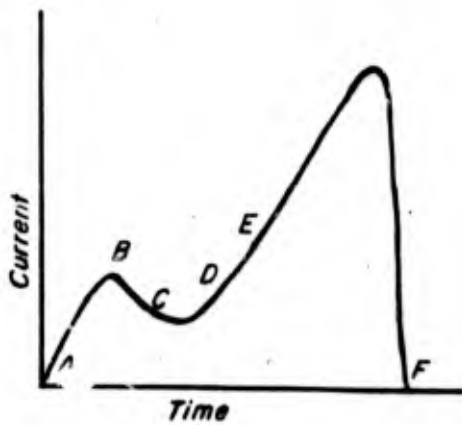


Fig. 4

IN THE UNITED STATES PATENT AND TRADEMARK  
OFFICE COMBINED DECLARATION AND  
POWER OF ATTORNEY

ATTORNEY'S DOCKET NO.  
CECCM D-4144

As a below named inventor, I hereby declare that:  
My residence, post office address and citizenship are as stated below next to my name.  
I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint  
inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on  
the invention entitled ELECTROMAGNETIC RAILGUN WITH A NON-EXPLOSIVE MAGNETIC FLUX COMPRESSION  
GENERATOR

the specification of which

(Check one)  is attached hereto.  
 was filed on \_\_\_\_\_ as  
Application Serial No. \_\_\_\_\_  
and was amended on \_\_\_\_\_  
(if applicable)

I hereby state that I have reviewed and understand the contents of the above identified specification, including the  
claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accord-  
ance with Title 37, Code of Federal Regulations, § 1.51(a).

I hereby claim foreign priority benefits under Title 35, United States Code, § 119 of any foreign application(s) for  
patent or inventor's certificate listed below and have also identified below any foreign application for patent or in-  
ventor's certificate having a filing date before that of the application on which priority is claimed.

PRIOR FOREIGN APPLICATION(S)

APPLICATION NUMBER	COUNTRY	DATE OF FILING (day, month, year)	PRIORITY CLAIMED
_____	_____	_____	<input type="checkbox"/> YES <input type="checkbox"/> NO
_____	_____	_____	<input type="checkbox"/> YES <input type="checkbox"/> NO
_____	_____	_____	<input type="checkbox"/> YES <input type="checkbox"/> NO

I hereby claim the benefit under Title 35, United States Code, § 120 of any United States application(s) listed below  
and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States  
application in the manner provided by the first paragraph of Title 35, United States Code, § 112.1 a, acknowledge the  
duty to disclose material information as defined in Title 37, Code of Federal Regulations, § 1.56(a) which occurred  
between the filing date of the prior application and the national or PCT international filing date of this application.

(Application Serial No.)	(Filing Date)	(Status) (patented, pending, abandoned)
_____	_____	_____
_____	_____	_____

And I hereby give irrevocable control of this application for Letters Patent to the Government of the United States,  
as represented by the Secretary of the Army, and appoint  
**SHELDON KANARS, #20,693; JEREMIAH G. MURRAY, #20,533; JOHN T. REHBERG, #29,207**

or any of them, our attorneys or agents, with full power of substitution and revocation, to prosecute this applica-  
tion, to make alterations and amendments therein, to sign the drawings, to receive the patent, and to transact all  
business in the Patent and Trademark Office connected therewith.

Direct telephone calls to **John T. Rehberg (201) 532-3187**

Direct correspondence to **Commander, U.S. Army Communications-Electronics Command,  
ATTN: ANSEL-LG-1S, Fort Monmouth, N.J. 07703-5000**

Wherefore I pray that Letters Patent be granted to me for the invention or discovery described and claimed in the  
foregoing specification and claims, and I hereby subscribe my name to the attached specification and claims, declara-  
tion, power of attorney, and this petition.

DECLARATION CONTINUATION FORM  
(Use this form as a continuation page)

CECOM D-4144

201	FULL NAME OF INVENTOR	LAST NAME JASPER, JR.	FIRST NAME LOUIS	MIDDLE NAME J.
	RESIDENCE & CITIZENSHIP	CITY OR OTHER LOCATION OCEAN	STATE OR FOREIGN COUNTRY NEW JERSEY	COUNTRY OF CITIZENSHIP USA
	POST OFFICE ADDRESS	POST OFFICE ADDRESS 16 WOOLLEY WAY	CITY OCEAN	STATE & ZIP CODE/COUNTRY N.J. 07712
<del>202</del>	<del>FULL NAME OF INVENTOR</del>	<del>LAST NAME</del>	<del>FIRST NAME</del>	<del>MIDDLE NAME</del>
	<del>RESIDENCE &amp; CITIZENSHIP</del>	<del>CITY OR OTHER LOCATION</del>	<del>STATE OR FOREIGN COUNTRY</del>	<del>COUNTRY OF CITIZENSHIP</del>
	<del>POST OFFICE ADDRESS</del>	<del>POST OFFICE ADDRESS</del>	<del>CITY</del>	<del>STATE &amp; ZIP CODE/COUNTRY</del>
<del>203</del>	<del>FULL NAME OF INVENTOR</del>	<del>LAST NAME</del>	<del>FIRST NAME</del>	<del>MIDDLE NAME</del>
	<del>RESIDENCE &amp; CITIZENSHIP</del>	<del>CITY OR OTHER LOCATION</del>	<del>STATE OR FOREIGN COUNTRY</del>	<del>COUNTRY OF CITIZENSHIP</del>
	<del>POST OFFICE ADDRESS</del>	<del>POST OFFICE ADDRESS</del>	<del>CITY</del>	<del>STATE &amp; ZIP CODE/COUNTRY</del>

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

SIGNATURE OF INVENTOR 201 <i>Louis J. Jasper Jr.</i>	SIGNATURE OF INVENTOR 202	SIGNATURE OF INVENTOR 203
DATE 20 Nov 86	DATE	DATE