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(54) Title: MAGNETIC ARMOR SYSTEMS AND METHODS

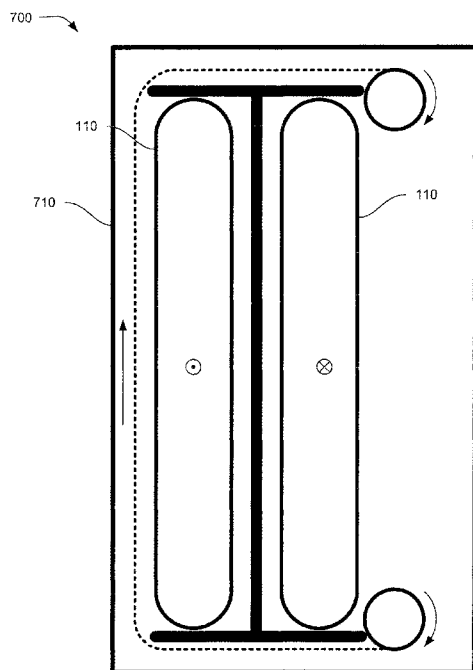


FIG. 7

(57) Abstract: Armor systems for fixed and mobile targets are provided. The armor systems are effective against sustained attacks from projectiles, blasts, and ion beams and offer graceful degradation. The armor systems employ very strong magnetic fields to deflect projectiles. The armor systems employ fence conductors situated within the magnetic field to impart a static charge to projectiles entering the magnetic field. Fence conductors are sacrificial, and can be rapidly replaced.



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- *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

Magnetic Armor Systems and Methods

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The invention relates generally to the field of warfare and more particularly to defenses for moving and stationary targets.

Description of the Prior Art

[0002] Ground, air, and sea vehicles, as well as encampments, buildings, and other structures, are always at risk of attack from projectiles such as gunfire, rockets, missiles, and shrapnel. In addition to projectiles, vehicles and structures can be damaged by high energy ions such as in the plasma generated by a nearby explosion and those generated by ion beam weapons. Current technologies surround potential targets with physical barriers made from materials such as concrete, steel, water, or sand. To be effective, such barriers are often very thick, making the barriers, heavy, time-consuming to erect, and in some instances difficult or impractical to move. In other instances the barriers are intended to be mobile, such as the armor on a ship or tank, but moving the armored vehicle requires substantial energy because of the added weight, and the added weight further constrains maneuverability. Moreover, physical barriers degrade rapidly in the face of a sustained attack, as each attack removes material, eventually leading to penetration.

[0003] What is needed, therefore, is a light weight defense system capable of withstanding a sustained attack.

SUMMARY

[0004] An exemplary armor system comprises a first superconducting magnetic field generator configured to be able to generate a first magnetic field external thereto. The armor system also comprises a first spool disposed proximate to a side of the first superconducting magnetic field generator, a second spool disposed proximate to an opposite side of the first superconducting magnetic field generator, and a fence conductor extending between the first spool and the second spool. When the first external magnetic field is generated, the fence conductor is disposed within the external magnetic field. The fence conductor is also translatable from the first spool to the second spool. The fence conductor can comprise a wire mesh, for example. The armor system can further comprise a second superconducting magnetic field generator disposed approximately parallel to the first superconducting magnetic field generator and configured to generate a second external magnetic field, wherein the first and second external magnetic fields have opposite polarities. The armor system can further comprise a housing enclosing the fence conductor, the first and second spools, the first superconducting magnetic field generator, and the second superconducting magnetic field generator, if present.

[0005] In various embodiments the first superconducting magnetic field generator comprises a support structure, a winding of a superconducting material secured to the support structure, and a cryogenic jacket disposed around the winding. In some of these embodiments the winding comprises loops around a core that is symmetrical around a surface. The surface can be either planar or non-planar, for instance, the core can be symmetrical around a rectangular portion of a plane or a segment of a cylindrical surface. In further embodiments, the winding comprises a coil around a U-shaped core.

[0006] Another exemplary armor system comprises a plurality of armor modules in a side by side arrangement. Here, each armor module comprises an embodiment of the armor systems just noted. In some instances the armor system further comprises a power supply such as a generator or battery system in electrical communication with the windings of the modules, and in some of these embodiments the electrical communication comprises a parallel circuit for each module.

[0007] An exemplary armored vehicle comprises a propulsion system configured to propel the vehicle and generate electricity, a personnel compartment comprising an electrically conductive enclosure, and an armor system comprising an embodiment of the armor systems noted above, where the superconducting magnetic field generator is in electrical communication with the propulsion system. In various embodiments, the propulsion system comprises an internal combustion engine, a turbine, or an air blower configured to generate an air bearing beneath the armored vehicle such that the vehicle comprises a hovercraft.

[0008] An exemplary method for protecting a target from a projectile comprises generating a magnetic field of at least 1T in front of the target, and electrically charging the incoming projectile as the projectile enters the magnetic field such that the projectile is deflected away from the target by the magnetic field. In some embodiments, electrically charging the incoming projectile includes maintaining a fence conductor within the magnetic field at a potential voltage relative to ground. Some of these embodiments further comprise translating the fence conductor through the magnetic field after the projectile has been deflected.

BRIEF DESCRIPTION OF DRAWINGS

[0009] FIG. 1 is a schematic representation of an armor system according to an exemplary embodiment of the present invention.

[0010] FIG. 2 is an exemplary front plan view of the armor system of FIG. 1.

[0011] FIG. 3 is a cross-sectional view through the armor system of FIG. 1 along the line 3-3.

[0012] FIG. 4 shows exemplary bundles of superconducting wires disposed with cryogenic jackets according to embodiments of the present invention.

[0013] FIG. 5 schematically illustrates the embodiment according to FIGs. 1-3 deflecting a projectile.

[0014] FIG. 6 is a schematic representation of a superconducting magnetic according to an embodiment of the present invention.

[0015] FIG. 7 is a schematic representation of an armor system according to another embodiment of the present invention.

[0016] FIG. 8 is a schematic representation of an armor system according to another embodiment of the present invention.

[0017] FIG. 9 is a schematic representation of an armored vehicle according to an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0018] The present invention provides an armor system suitable for defending both fixed and mobile targets against sustained attacks from projectiles, blasts, and ion beams. The armor system is portable and simple to deploy, in various embodiments. The armor system employs a very strong magnetic field to deflect anything with an electrical charge moving therethrough. The armor system also

employs a fence conductor situated within the magnetic field that can impart a static charge to otherwise uncharged projectiles that pass through the fence conductor. The fence conductor is sacrificial, and if damaged can be rapidly replaced. The presently disclosed armor system can be deployed on vehicles for substantial weight savings, permitting highly mobile tanks and armored personnel carriers, for example.

[0019] FIG. 1 is a schematic representation of an exemplary armor system 100. The armor system 100 comprises a superconducting magnetic field generator 110 configured to be able to generate a magnetic field that is external to the magnetic field generator 110. The armor system 100 also comprises a fence conductor 120 and first and second spools, 130 and 140. The first and second spools 130, 140 are disposed proximate to opposite sides of the magnetic field generator 110, as shown. The fence conductor 120 extends between the first spool 130 and the second spool 140 and is disposed in front of the magnetic field generator 110. Initially, the fence conductor 110 is spooled around the first spool 130, and as needed, can be translated in front of the magnetic field generator 110 to spool around the second spool 140.

[0020] FIG. 2 shows a front view of the armor system of FIG. 1. The fence conductor 120, in the illustrated embodiment, comprises a wire mesh, though in other embodiments the fence conductor 120 can comprise a number of parallel wires, a metal woven fabric (like a fencing lame), or a thin metal foil, for example. Exemplary wire meshes can be triangular, square, or hexagonal, for instance, with mesh sizes of less than, about, or greater than 1", less than, about, or greater than 2", less than, about, or greater than 3", and less than, about, or greater than 4". The wires in the mesh can be woven in the manner of a chain-link fence. Thicker wires gauges and more open meshes are not as easily deformed by pressure waves and are less likely to melt from the heat of a nearby blast.

[0021] Exemplary dimensions for a panel of the armor system 100 are about 4' high and 8' wide (the dimensions of the frontal view in FIG. 2) and approximately 2' deep. Such a panel can be made to be approximately 200lbs, which can be moved and positioned by two men. While modular armor systems 100 are used herein for exemplary purposes, it will be appreciated that such armor systems need not be modular and can be, instead, a single unit. In some embodiments, such as those illustrated generally with respect to FIG. 9, an armor system can be made integral with a structure such as a vehicle.

[0022] FIG. 3 schematically represents a cross-section through the fence conductor 120 and part of the magnetic field generator 110 along the line 3-3 shown in FIG. 1. As described in greater detail below, the magnetic field generator 110 includes a winding 300 of a superconducting material that can carry an electric current. The two vertical lines for the windings 300 in FIG. 3 represent the loop portion of the magnetic field generator 110 seen in cross-section, which is a winding of a superconducting wire seen end-on, as represented in the two exemplary embodiments illustrated in higher resolution in FIG. 4.

[0023] FIG. 4 shows the two exemplary embodiments of bundles 400 of superconducting wires 410. Each superconducting wire 410 is disposed within a cryogenic jacket 420 or 430, for example. The cryogenic jacket 420 provides a hollow sheath within which the cooling fluid flows. With the cryogenic jacket 430 the cooling fluid flows around and in contact with the superconducting wire 410. More than one superconducting wire 410 can exist in a bundle 400. In some embodiments, multiple bundles 400 are used to form the superconducting magnetic of the magnetic field generator 110. Additional insulation has been omitted from FIG. 4 for simplicity. Exemplary superconducting materials include ceramic

superconductors such as yttrium-barium-copper-oxide (YBCO) and magnesium diboride superconductors, and alloy superconductors such as certain niobium-titanium and germanium-niobium alloys.

[0024] Returning to FIG. 1, in various embodiments the superconducting magnetic field generator 110 includes a support structure 150. The winding 300 of a superconducting material is secured to the support structure 150 to hold the winding 300 in the desired shape against the strong forces generated by the very strong magnetic field. It will be apparent that the shape of the support structure 150 will depend on the particular shape of the magnetic field being projected by the particular magnetic field generator 110 and hence on the shape of the winding 300.

[0025] Referring again to FIG. 3, when properly cooled below the appropriate critical temperature and connected to a power supply, a current flows around the winding 300 in opposite directions on either side of the loop (represented by the symbols $\odot$ $\otimes$). The current flowing through the winding 300 produces a magnetic field, represented by the magnetic field line 310. It will be appreciated, of course, that the generated magnetic field extends around the winding 300 and has a field strength that diminishes with distance from the winding 300. For simplicity, other field lines to illustrate the field on both side of the winding 300 and to show the variation in field strength have been omitted. It will also be appreciated that a current flowing in a superconducting loop encounters zero resistance and can theoretically flow indefinitely. In practice, energy is lost over time from the system, however, maintaining an established magnetic field with the superconducting magnetic field generator 110 requires little energy.

[0026] As illustrated by the magnetic field line 310, the generated magnetic field extends external to the magnetic field generator 110. The fence conductor 120 is

situated within the external portion of the magnetic field, and in some embodiments the greatest field strength is disposed between the fence conductor 120 and the winding 300. In various embodiments, the maximum of the magnetic field strength, also known as the magnetic flux density, **B**, exceeds 1 Tesla (T). In some embodiments, the magnetic flux density is in the range of 8T to 10T. For some applications, a magnetic flux density in the range of 4T to 6T is also suitable.

[0027] As also illustrated by FIG. 3, the fence conductor 120 is held at a potential relative to ground. Essentially, the fence conductor 120 acts as a capacitor, ready to impart an electric charge to anything that comes close enough. In some embodiments, a potential of about 20,000 volts is maintained on the fence conductor 120. Like maintaining the magnetic field, maintaining the charge on the fence conductor 120 requires little energy. It will be appreciated that the fence conductor 120, and all parts of the system 100 that either directly contact, or are situated close to, the fence conductor 120 such as the spools 130, 140 and supports that maintain the shape of the fence conductor 120 in front of the winding 300, need to be electrically insulated from ground. In embodiments such as those illustrated by FIGs. 1-3, a suitable spacing between the fence conductor 120 and the winding 300 is in the range of about 6" to about 8" depending on the voltage applied to the fence conductor 120.

[0028] Omitted from the drawings herein, but understood to be present is sufficient electrical power for generating and maintaining the superconducting field and the charge on the fence conductor 120, as well as a sufficient power reserve to translate the fence conductor 120, for example, as well as sufficient cooling capacity for an adequate time between resupply opportunities at an installed location, or for the length of a required number of operations of approximate duration as used on vehicles. Electrical power can come from batteries or can be generated with an

electric generator, or both, for example. Exemplary electric generators for producing the high current/low voltage requirements of magnetic field generators 110 are homopolar generators.

[0029] Suitable cooling liquids include liquid helium and liquid nitrogen. Liquid nitrogen can be advantageously manufactured from air and does not have to be provided by an external source. Accordingly, in some embodiments, the armor system includes a liquid nitrogen generator. Liquid nitrogen can be produced for modules individually, for groups of modules, or for systems as a whole. Individual modules can include a reservoir with sufficient capacity that interruptions in generation can be tolerated.

[0030] FIG. 5 schematically illustrates the embodiment shown in FIGs. 1-3 deflecting a projectile 500. The projectile 500 initially approaches the system 100 with some surface charge from the rapid passage through air, and as the projectile enters the magnetic field and approaches the fence conductor 120 the projectile begins to experience an acceleration perpendicular to the direction of the magnetic field lines 310. As the projectile 500 encounters the fence conductor 120, whether the projectile 500 passes cleanly through the mesh or contacts the mesh, the fence conductor discharges onto the projectile 500, and the projectile is accelerated much more strongly perpendicular to the direction of the magnetic field lines 310, and away from the target.

[0031] It will be appreciated that the system 100 still must withstand the impulse from repelling the projectile 500, but can absorb the blow over a wider area. Accordingly, it will be appreciated that the system also can include a wall on the side of the magnetic field generator 110 opposite the fence conductor 120. The support structure 150 is secured to this wall, in some embodiments. In other embodiments,

such as when the target is a vehicle, greater weight savings can be achieved by scaling back further on the thickness of the wall, or eliminating the wall entirely, with the trade-off being that the vehicle will recoil in response to the blow.

[0032] Larger projectiles 500 are repelled by the magnetic field similarly. A larger projectile 500, such as a missile, essentially is shredded by the intense sideways acceleration as the projectile 500 passes into the magnetic field, with the electrically charged fragments being readily deflected. Shrapnel thrown by explosions are likewise deflected. Ion beam weapons comprise charged ions which are similarly deflected. It should also be noted that not only are the systems of the present invention effective against projectiles 500 and ion beams, but additionally they cannot be scaled by people.

[0033] After an attack has been deflected, if the fence conductor 120 has been damaged, the fence conductor 120 can be translated to expose fresh fence conductor 120 from the first spool 130 and to wrap the damaged section of fence conductor 120 onto the second spool 140. Various embodiments include pressure sensors or accelerometers to detect hits and possible damage to the fence conductor 120.

[0034] A further advantage of the armor systems of the present invention is that they provide graceful degradation. The ability to provide fresh fence conductor 120 on an as needed basis is one example of graceful degradation. As another example, even if power and cooling systems are both lost, the defense remains viable and dissipates very gradually. As already noted, once current is circulating in the superconducting winding 300, little further current is needed to maintain the generated magnetic field. Loss of that current will cause a very gradual decay of the magnetic field over time. Similarly, once the fence conductor 120 is charged, the voltage source can be removed and the fence conductor 120 will remain charged.

Further, the magnetic field provides a large reservoir of potential energy, and in some embodiments, if power is lost, the magnetic field can be drawn down slightly to charge the fence conductor 120. Moreover, a well insulated winding 300 at a cryogenic temperature well below the critical temperature of the superconducting material will remain below the critical temperature for a considerable time even if the cooling fluid stops circulating.

[0035] The winding 300 can take a variety of topologies of which a loop around a generally planar and rectangular surface is illustrated in FIGs. 1-3 and 5. In another exemplary embodiment, the winding 300 comprises a coil around a U-shaped or horseshoe-shaped core 600 as shown in FIG. 6. As illustrated, the magnetic field lines 610 also project external to the superconducting magnet in this embodiment, and as above, only one exemplary field line 610 is shown here for simplicity. In these embodiments, an exemplary spacing between the fence conductor 120 and the winding 300 is about 3'. The generally planar form noted above is but one example of a core that is symmetrical around a surface. Other exemplary surfaces are non-planar such as cylindrical and spherical surfaces. Electrically insulating stand-offs can be employed to keep the fence conductor 120 at a uniform distance from the winding 300, in various embodiments.

[0036] FIG. 7 illustrates yet another embodiment of an armor system 700 that includes a second superconducting magnetic field generator 110. The two superconducting magnetic field generators 110 are configured so that the polarities of their respective magnetic fields are opposite one another. The effect is that at a significant distance from the system 700 the magnetic fields effectively cancel one another, while remaining substantially strong closer to each magnetic field generator 110. One advantage to a perimeter made out of a number of armor systems 700 is that

any one unit can be switched off independently and moved out of the way to provide a door without losing the protection from the other units.

[0037] The system 700 also includes a housing 710. The housing 710 can be used with any of the previously described embodiments. The housing 710 provide numerous advantages including making the systems of the invention easier to transport and store and improving aerodynamics when the systems are deployed on moving vehicles.

[0038] FIG. 8 shows three systems 100, each a module of an armor system 800, arranged side by side to form a wall segment. Although the armor system 800 is shown as a straight wall, it will be appreciated that enclosures of various dimensions can be readily created. In various embodiments, each system 100 includes independent power and cryogenic supplies, while in other embodiments the several systems 100 share a common power supply and/or a common cryogenic supply. FIG. 8 illustrates an embodiment in which the several systems 100 in electrical communication with a common power supply 810. In various embodiments the windings of the systems 100 are arranged in a series circuit, while in other embodiments the windings are arranged as parallel circuits, as shown in FIG. 8.

[0039] FIG. 9 illustrates an exemplary armored vehicle 900 of the present invention, in this case a hovercraft. The armored vehicle 900 comprises a propulsion system 910 configured to propel the armored vehicle 900 as well as to generate electricity. Exemplary propulsion systems 910 include internal combustion engines and turbines. Either can drive an electric generator to generate electricity. In some embodiments, such as the one illustrated in FIG. 9, the propulsion system 910 comprises one or more air blowers 920 configured to generate an air bearing beneath the armored vehicle 900. The armored vehicle 900 also comprises a personnel

compartment 930. The personnel compartment 930 includes an electrically conductive enclosure 940 to isolate the personnel within the personnel compartment 930 from intense magnetic fields.

[0040] The armored vehicle 900 also comprises an armor system 950 as generally described above with respect to, for example, systems 100 and 700. Here, the armor system 950 includes a superconducting magnetic field generator in electrical communication with the propulsion system 910 to receive electricity in order to generate and maintain the magnetic field. For simplicity of illustration only two armor systems 950 are shown, one within the personnel compartment 930, and one disposed as a ring cantilevered in front of a flexible skirt 960. It will be appreciated that other armor systems 950 can be employed in other locations. It will be further appreciated that armored vehicles 900 achieve substantial weight savings, permitting highly mobile tanks and armored personnel carriers with greater operating ranges, for example.

[0041] In the foregoing specification, the invention is described with reference to specific embodiments thereof, but those skilled in the art will recognize that the invention is not limited thereto. Various features and aspects of the above-described invention may be used individually or jointly. Further, the invention can be utilized in any number of environments and applications beyond those described herein without departing from the broader spirit and scope of the specification. The specification and drawings are, accordingly, to be regarded as illustrative rather than restrictive. It will be recognized that the terms “comprising,” “including,” and “having,” as used herein, are specifically intended to be read as open-ended terms of art.

CLAIMS

What is claimed is:

1. An armor system comprising:
 - a first superconducting magnetic field generator configured to be able to generate a first magnetic field external thereto;
 - a first spool disposed proximate to a side of the first superconducting magnetic field generator;
 - a second spool disposed proximate to an opposite side of the first superconducting magnetic field generator; and
 - a fence conductor extending between the first spool and the second spool and within the first external magnetic field, when generated, the fence conductor being translatable from the first spool to the second spool.
2. The armor system of claim 1 wherein the first superconducting magnetic field generator comprises
 - a support structure,
 - a winding of a superconducting material secured to the support structure, and
 - a cryogenic jacket disposed around the winding.
3. The armor system of claim 1 or 2 wherein the winding comprises loops around a core that is symmetrical around a surface.
4. The armor system of claim 3 wherein the surface is planar.

5. The armor system of claim 3 wherein the surface is non-planar.
6. The armor system of claim 2-4 or 5 wherein the winding comprises a coil around a U-shaped core.
7. The armor system of claim 1-5 or 6 wherein the fence conductor comprises a wire mesh.
8. The armor system of claim 1-6 or 7 further comprising a housing enclosing the fence conductor, the first and second spools, and the first superconducting magnetic field generator.
9. The armor system of claim 1-7 or 8 further comprising a second superconducting magnetic field generator disposed approximately parallel to the first superconducting magnetic field generator and configured to generate a second external magnetic field, wherein the first and second external magnetic fields have opposite polarities.
10. A method for protecting a target comprising:
generating a magnetic field of at least 1T in front of the target; and
electrically charging an incoming projectile as the projectile enters the magnetic field such that the projectile is deflected away from the target by the magnetic field.

11. The method of claim 10 wherein electrically charging the incoming projectile includes maintaining a fence conductor within the magnetic field at a potential voltage relative to ground.
12. The method of claim 10 or 11 further comprising translating the fence conductor through the magnetic field after the projectile has been deflected.
13. An armor system comprising:
 - a plurality of armor modules in a side by side arrangement, each armor module including
 - a superconducting magnetic field generator configured to be able to generate a magnetic field external thereto;
 - a first spool disposed proximate to a side of the superconducting magnetic field generator;
 - a second spool disposed proximate to an opposite side of the superconducting magnetic field generator; and
 - a fence conductor extending between the first spool and the second spool and within the external magnetic field, when generated, the fence conductor being translatable from the first spool to the second spool.

14. The armor system of claim 13 wherein each superconducting magnetic field generator comprises
a support structure,
a winding of a superconducting material secured to the support structure, and
a cryogenic jacket disposed around the winding.
15. The armor system of claim 13 or 14 further comprising a power supply in electrical communication with the windings of the modules.
16. The armor system of claim 13, 14, or 15 wherein the electrical communication comprises a parallel circuit for each module.
17. The armor system of claim 13-15 or 16 wherein each fence conductor comprises a wire mesh.
18. The armor system of claim 17 further comprising a housing enclosing the fence conductor, the first and second spools, and the first superconducting magnetic field generator.

19. An armored vehicle comprising:

a propulsion system configured to propel the vehicle and generate electricity;

a personnel compartment comprising an electrically conductive enclosure; and

an armor system including

a superconducting magnetic field generator in electrical

communication with the propulsion system and configured to

be able to generate a magnetic field external to the

superconducting magnetic field generator;

a first spool disposed proximate to a side of the superconducting

magnetic field generator;

a second spool disposed proximate to an opposite side of the

superconducting magnetic field generator; and

a fence conductor extending between the first spool and the second

spool and within the external magnetic field, when generated,

the fence conductor being translatable from the first spool to

the second spool.

20. The armored vehicle of claim 19 wherein the propulsion system comprises an

internal combustion engine.

21. The armored vehicle of claim 19 or 20 wherein the propulsion system comprises

a turbine.

22. The armored vehicle of claim 19, 20, or 21 wherein the propulsion system comprises an air blower configured to generate an air bearing beneath the armored vehicle.

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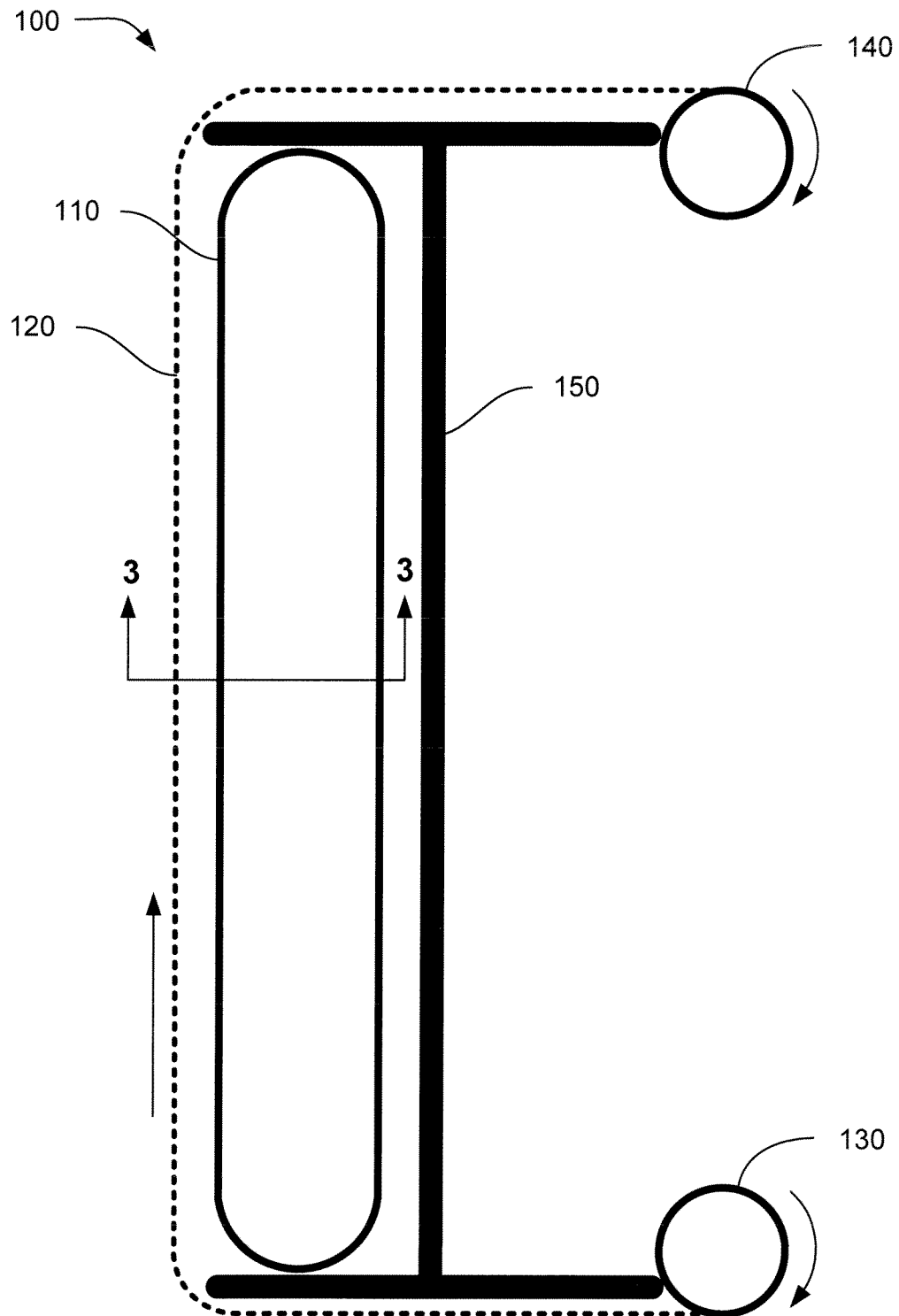


FIG. 1

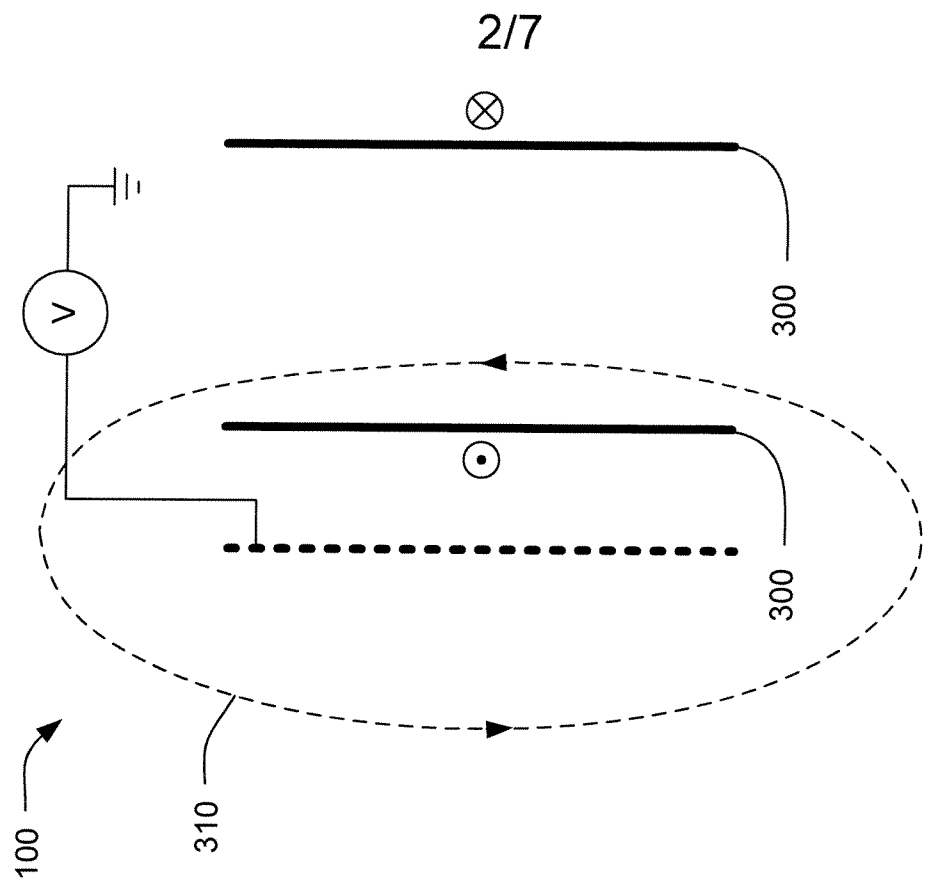


FIG. 3

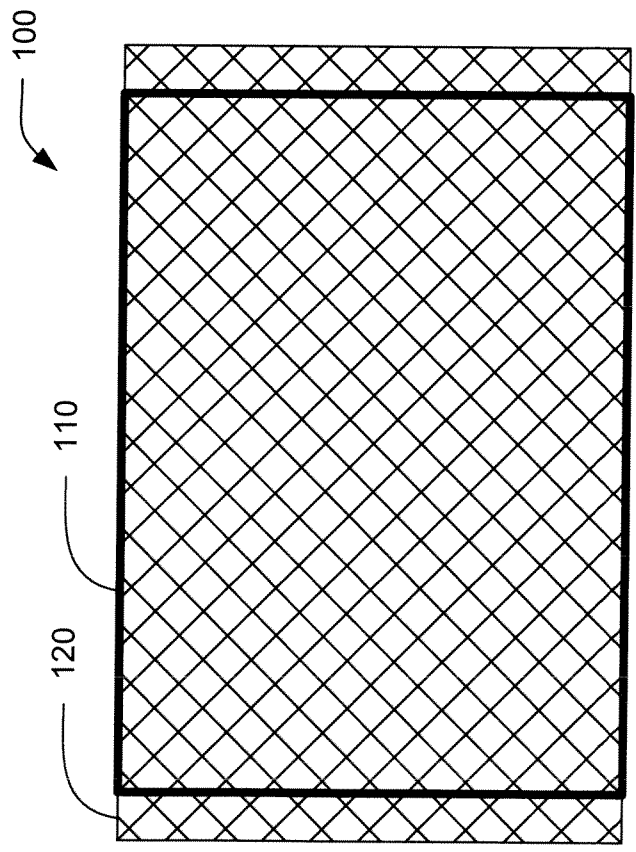


FIG. 2

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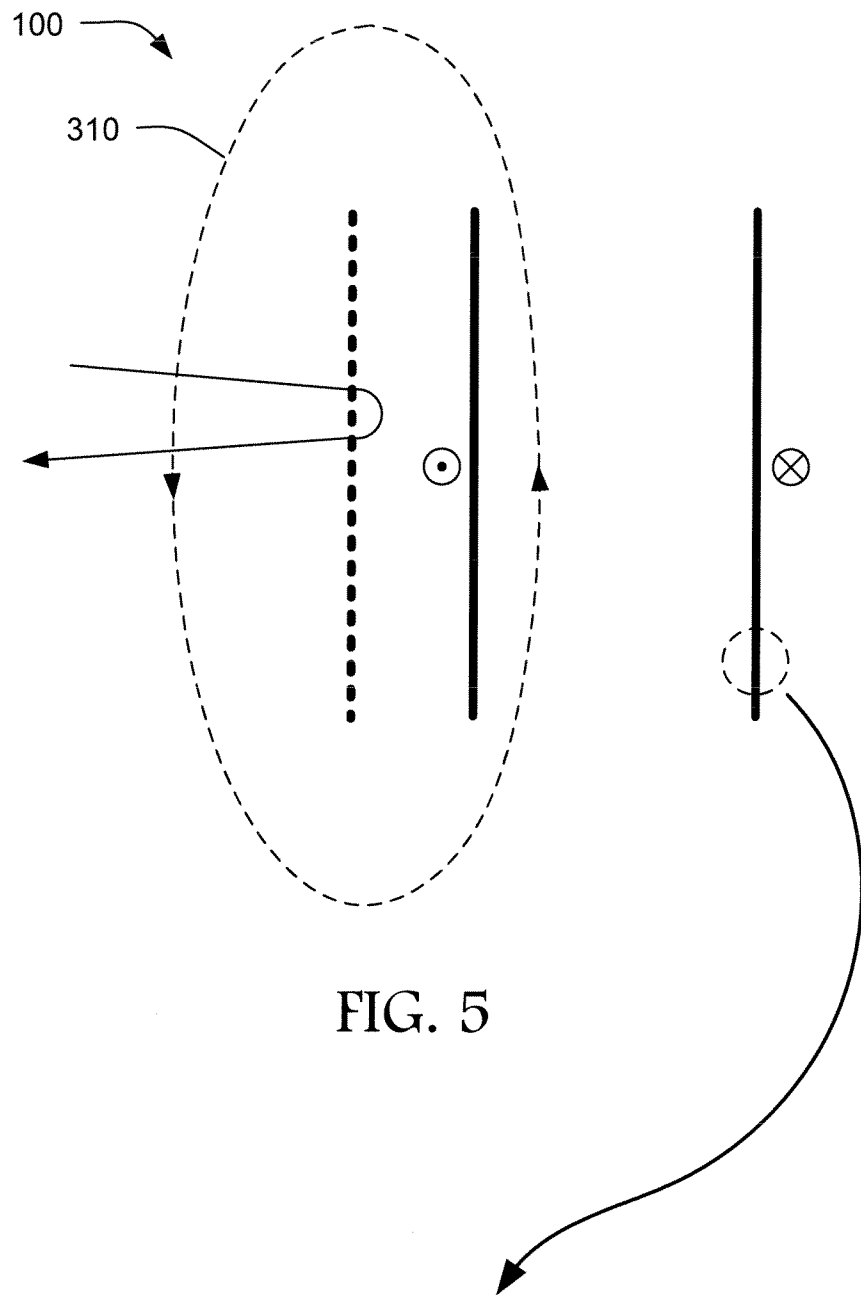


FIG. 5

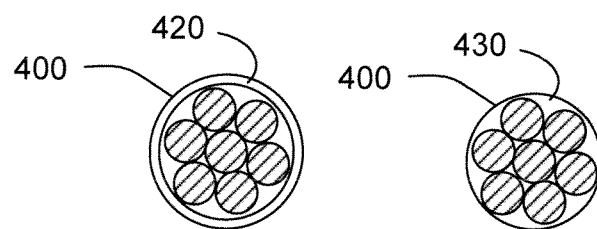


FIG. 4

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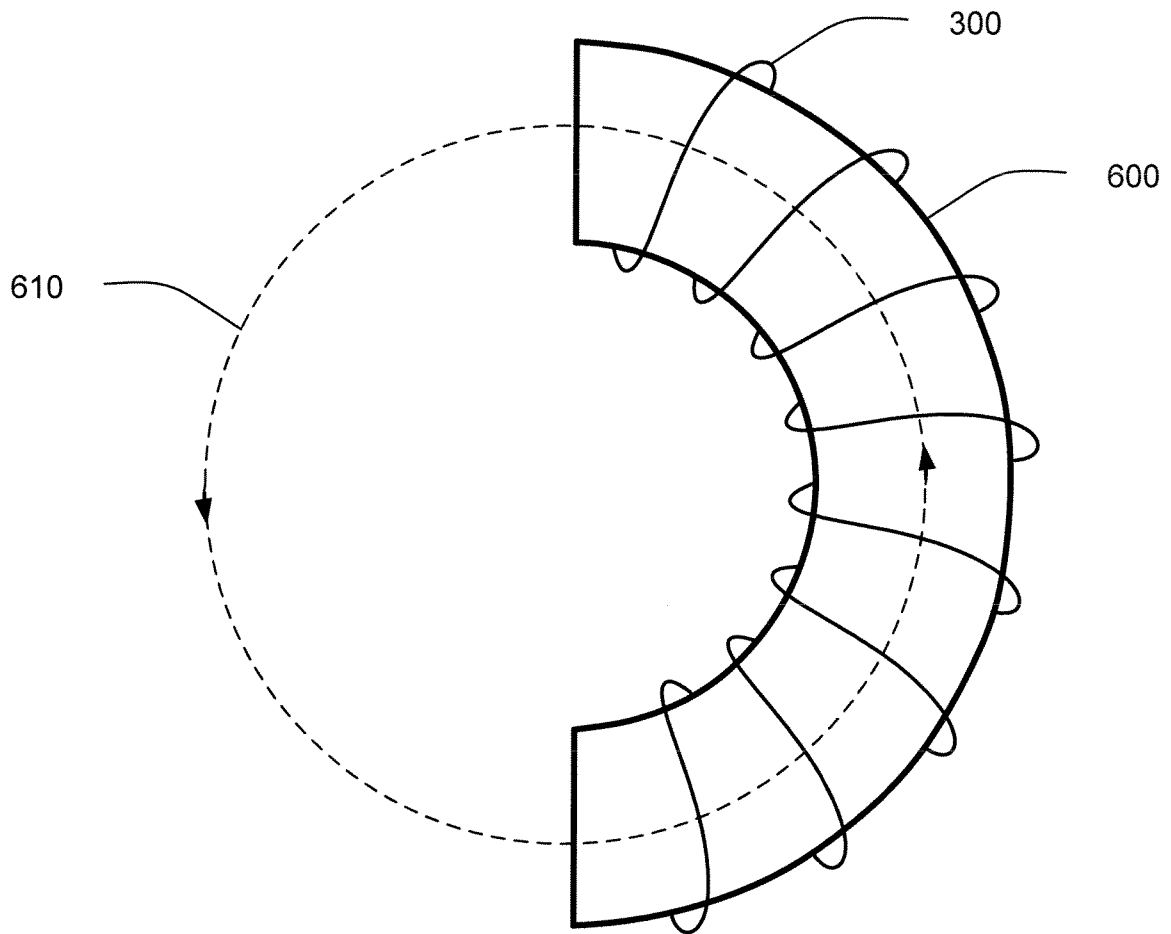


FIG. 6

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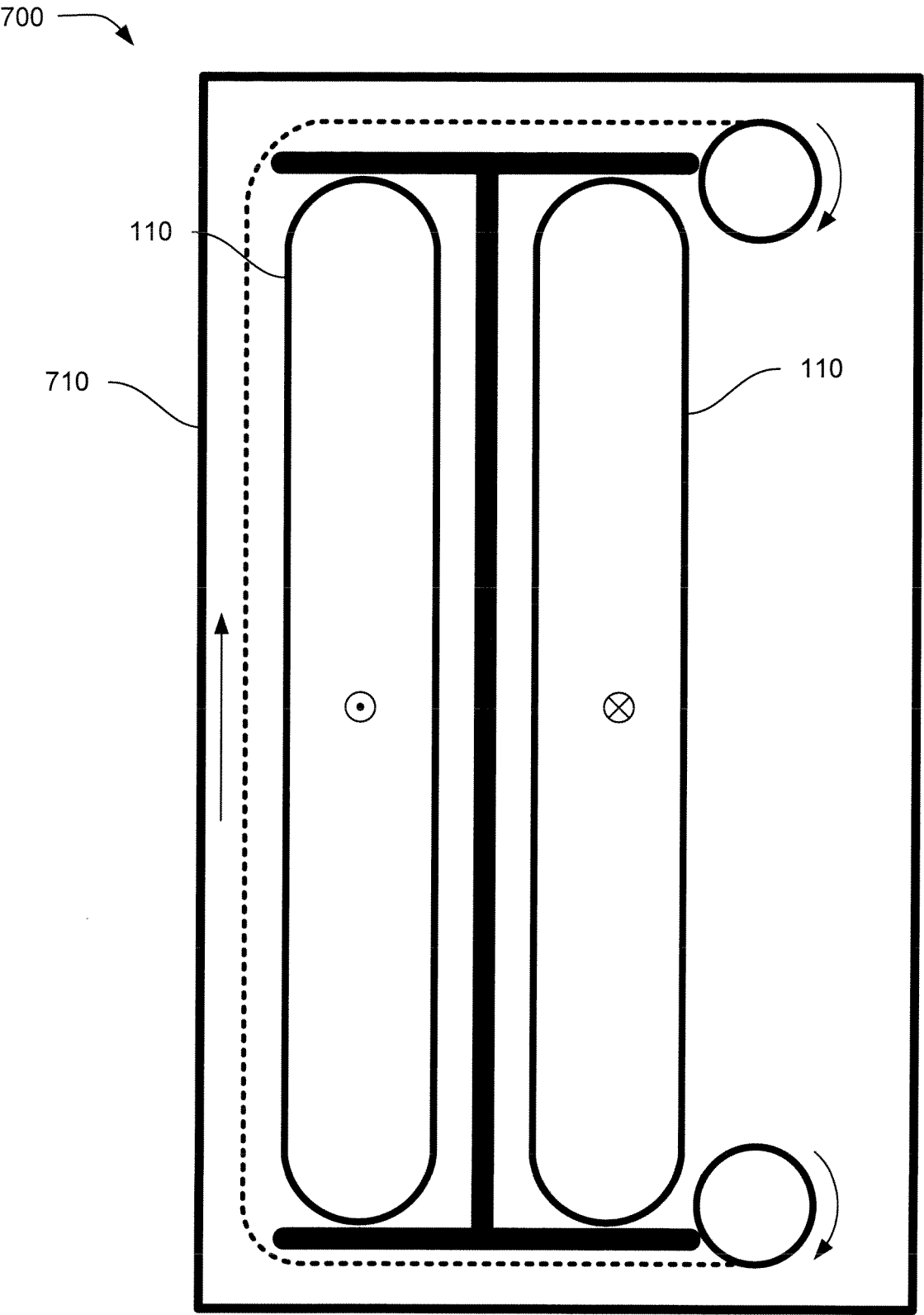


FIG. 7

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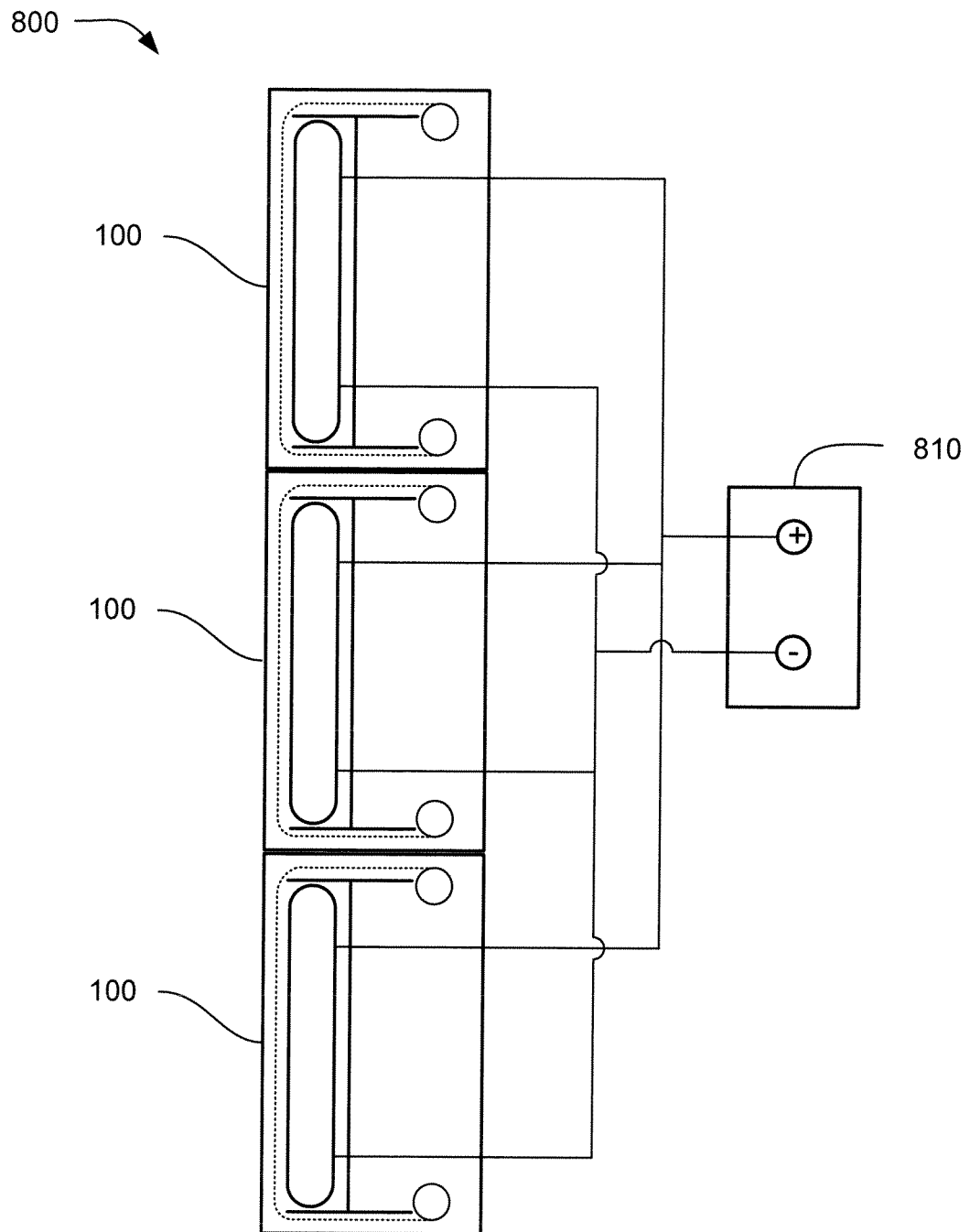


FIG. 8

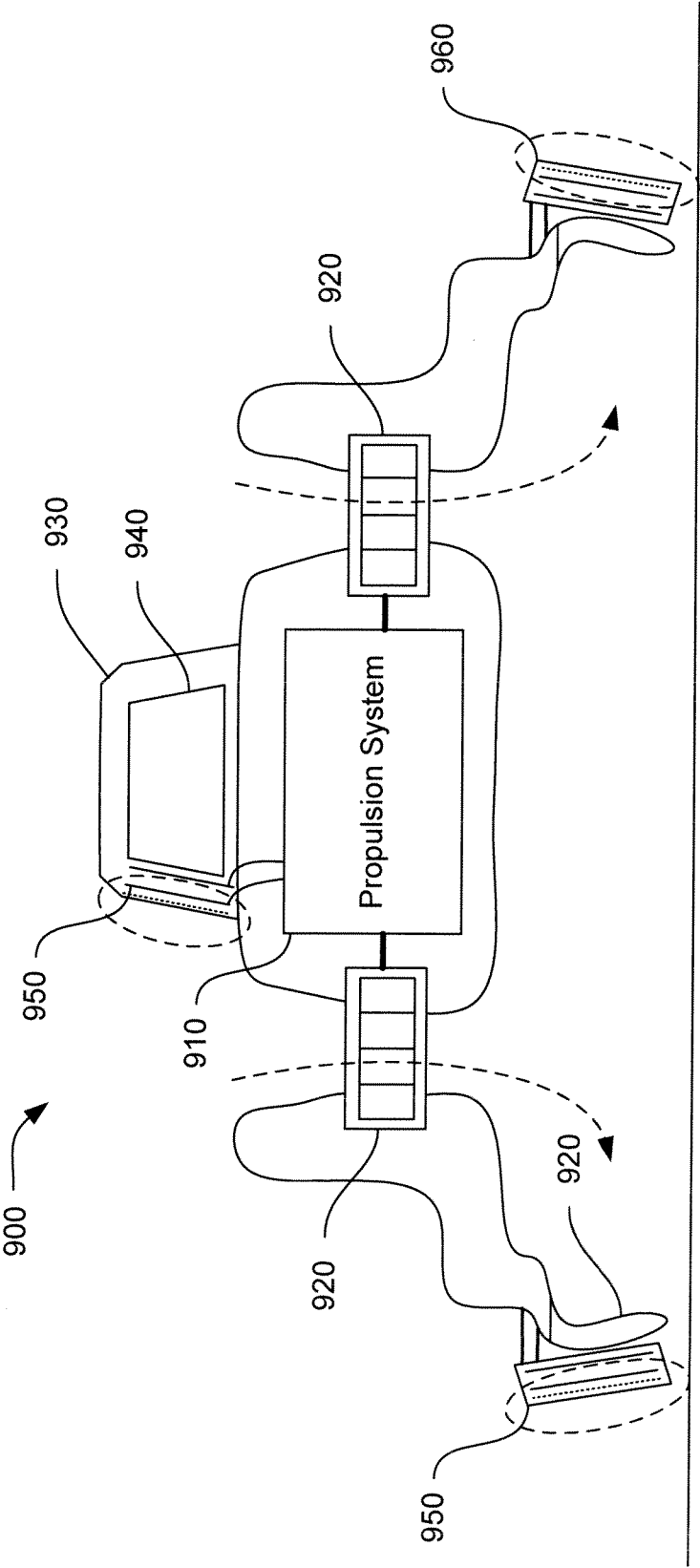


FIG. 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 10/30686

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F41H 5/00 (2010.01)

USPC - 89/36.01

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

USPC: 89/36.01

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

USPC: 89/36.01, 36.02, 36.04, 36.07, 36.12; 335/216

(keyword limited; terms below)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PubWEST (PGPB, USPT, EPAB, JPAB); Google

Search terms: superconduct, magnet, coil, field, armor, shield, protect, bullet, projectile, mesh, screen, fence, et al.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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P	US 7,819,050 B1 (MacDougall) 26 October 2010 (26.10.2010), entire document	1-5, 10-15, 19-21
P	US 7,730,823 B1 (Fullerton) 08 June 2010 (08.06.2010), entire document	1-5, 10-15, 19-21
P	US 2009/0302982 A1 (Putman et al.) 10 December 2009 (10.12.2009), entire document	1-5, 10-15, 19-21



Further documents are listed in the continuation of Box C.



* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

14 December 2010 (14.12.2010)

Date of mailing of the international search report

21 DEC 2010

Name and mailing address of the ISA/US

Mail Stop PCT, Attn: ISA/US, Commissioner for Patents
P.O. Box 1450, Alexandria, Virginia 22313-1450

Facsimile No. 571-273-3201

Authorized officer:

Lee W. Young

PCT Helpdesk: 571-272-4300
PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 10/30686

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☒ Claims Nos.: 6-9, 16-18, and 22
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.