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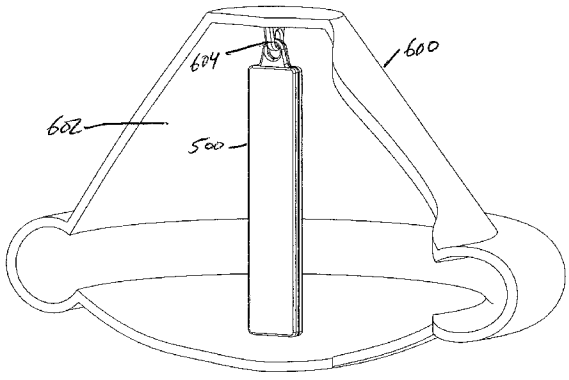
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(54) Title: MOTION-SPECIFIC POWER GENERATOR UNIT AND METHOD OF GENERATING POWER USING SAME



(57) Abstract: A power generator unit is configured to respond to external motion that has a predetermined frequency range. The unit has a first member including one or more magnetic components and a second member including one or more electrical component, such as coils, movable relative to each other such that an electromagnetic interaction between the electrical and magnetic components generates an electrical current in the electrical component. A spring element is coupled to at least one of the first and second members to define a spring-mass system. The spring mass system is configured to reciprocatively move the electrical and magnetic components relative to each other in response to external motion. One or more properties of the first member, the second member, and the spring element are selected and adjusted based on the predetermined frequency range of the motion to maximize the relative movement between the electrical component and the magnetic component.

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MOTION-SPECIFIC POWER GENERATOR UNIT AND METHOD OF GENERATING POWER USING SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the priority benefit of U.S. Provisional Application No. 60/744,814, filed April 13, 2006, and entitled "Vibration Resonant Coupling for Power generator." The foregoing provisional application, as well as each other patent application and/or patent document recited below, are hereby incorporated by reference in their entirety to the extent permitted by law.

BACKGROUND

FIELD OF INVENTION

[0002] The present invention relates generally to power generator, and more particularly, to a motion-specific electrical power generator wherein an electrical component and a magnetic component are movable relative to another.

DISCUSSION OF RELATED ART

[0003] Electrically powered devices that operate with internal to electrical power sources are known. Examples of such devices include portable battery-operated electronic consumer devices which are prevalent in modern society (e.g., mobile phones, personal data assistants, and portable music players (e.g., a CD player, iPod®). These devices may also include a micro-processor and other hardware and software configured to carry out various functions that require the use of electric power provided by the internal power source (i.e., the battery) in order to function. The internal power source may be in the form of a rechargeable power source such as, for example, a rechargeable battery. However, a rechargeable battery generally requires recharging by periodic connection to an external power source such as, for example an electrical socket. This often requires that the entire device be docked or otherwise operatively connected with a device-specific charging apparatus that is itself electrically connected to an external power source. This required periodic connection to dedicated electrical sources via device-specific chargers, however, can often be onerous on users of the devices who may not have access to power outlets (e.g. while commuting to work or traveling) or to the device-specific charging apparatus. Moreover, given the huge number of such devices in

use today, this periodic requirement to connect such devices to dedicated power sources results in a cumulatively significant use of electric power resources.

[0004] Another example of a device that requires a power source is a buoy placed in a body of water (e.g., ocean, lake, etc.) that carries a payload of electronic devices that require the use of electric current in order to function. Like portable electronic devices, buoys and similar devices are subject to external motions. For example, a buoy floating in a body of water is subjected to various forces from wave motion, currents, wind and the like that impart motion to the buoy in various forms including, but not limited to, bouncing, tipping, dipping, spinning or the like. External motions can be categorized as simple and complex motions. A complex motion can be a composite that results from several types of simple motions put together. More complex motions involve more moving parts or more different types of motion occurring concurrently. Exemplary simple motions are translational, traversal or rotational. Translational or traversal motions require passing or move over, along, or through an axis or a path. Rotational motion requires turning or revolving around or about an axis or center point. Each simple motion can occur and be described independently. For example, an object can move along or traverses a path without rotating, or it can rotate without moving along a path.

[0005] A reciprocating or oscillating motion is a complex motion involving a traversal movement along one path in one direction and another traversal motion in the reverse direction along substantially the same path. Bending, stretching, and twisting are somewhat more complicated types of motion. Elastic motions involve rotation and/or translation, with or without reciprocation. Each type of motion is controlled by a different type of force: translation by the net force acting on an object, rotation by torque produced by an off-center force, elastic motion by internal forces between different parts of an object. The strength of the forces can be measured by their effect on the motion of an object.

[0006] Attempts to convert physical motion into a source of electrical power have been made. For example, it is desired to convert the energy created by the movement of an object that is subject to external motion into a source of electrical power. Under normal circumstances, energy created by movement of an object (i.e.,

kinetic energy) is lost to the surrounding environment. Attempts have been made to effectively harness such motion energy and convert it into electrical power by way of interactions with electromagnetic fields. Some common large scale examples of converting physical movement into electrical power include hydroelectric generated power (e.g., a hydroelectric dam), wind generated power (e.g., a wind turbine), and automotive alternators.

[0007] In terms of small scale power generators, attempts have been made to use magnetic transducers with power generating capability. For example, U.S. Patent No. 5,347,186 discloses a linear motion electric power generator that uses a rare earth magnet and a coil that are positioned to move linearly back and forth relative to each other. The movement of the coil in the field of the magnet generates a current in the coil by using the repelling forces of polarized magnets to maintain a quasi-neutral position about which the relative motion occurs. Another example is U.S. Patent No. 5,818,132 which discloses a linear motion electric power generator for generating electric current from motions caused by intermittent force or repetitive forces (e.g., the forces on the heel of a shoe during walking or running). This can be accomplished by a moving magnet confined in such a manner that it can only move with bi-directional linear, or approximately linear, motion through two coils that are spaced apart from each other and connected electrically to produce current in the coils from lower power mechanical forces. The generated electrical current can be used for powering flashlights, alarm systems and communication devices worn around a body or located at places where conventional electric power sources are unavailable.

[0008] The above-described small scale power generators described above are commonly referred to as tubular type power generators. In a tubular type generator, a magnet is fit within a tube, with magnet poles being aligned along the long axis of the tube, which defines the path for the direction of magnet movement. A coil of wire, roughly positioned near the middle of the travel path of the magnet, is wound around the tube and about a coil axis that is in parallel to flux unidirectional path of the magnet as defined its North and South poles. Therefore when the magnet is directly within the coil, its loops are exposed to a substantial portion, if not, all of the available unidirectional flux being generated by the magnet. As the magnet is displaced from the center of the tube toward one end, the coil is exposed to a diminishing magnetic flux density either at

the south pole or north pole. As the magnet reaches a rebound position and begins to return, the coil sees a building magnetic flux change that generates electric power or voltage. The same scenario is repeated as the magnet travels down the other end of the tube. It should be noted that the change in flux density produces the electric power in the coil, not the flux density by itself. Under this arrangement, the unidirectional magnetic flux axis is always in the same parallel direction to the coil axis and flux direction is fixed. In other words, a tubular type power generator presents a unidirectional magnetic flux to one or more coils having coil axes that are parallel to the movement axis of the magnet(s).

[0009] For all electro-motive force (EMF) type power generator units, such as the ones described above, the relevant governing equation of physics is the applied version of Faraday's law. According to Faraday's law , the EMF (i.e., voltage) developed in a coil of wire is equal to the number of turns of the wire in the coil multiplied by the change in the magnetic flux that each loop is exposed to. Therefore, one of the goals of EMF power generator design is to maximize the power output of the generator by maximizing any or all of the terms of Faraday's law individually or in combination, subject to physical and material constraints. However, one of the disadvantages of tubular type power generators is that, due to their basic geometry, they are limited in their power generation potential.

[00010] Other examples include U.S. Patent Nos. 6,768,230; 6,798,090; 6,809,427; 6,812,583; 6,812,598; 6,833,780; and 6,861,772. The foregoing patents describe systems of a related nature and are incorporated herein by reference to the extent permitted by law. In general, these patent documents disclose electromagnetic power generator systems wherein one or more magnets are moved relative to a conductor (e.g., one or more coils of wire) to induce electromotive forces (i.e., a flow of electrons) therein. More specifically, the magnets were moved relative to a stationary conductor so that the magnetic lines of flux radiating from the magnets intersect the conductor at right angles and induce the electromotive forces. An aspect of some of these designs is that the moving magnets can be disposed on an ultra-low friction ferrofluid bearing system. This allows construction of a power generator system wherein the magnets move in response to simple motions (low force – low input energy). The addition of the ultra-low friction bearing fluid (ferrofluid) allowed the generators to become feasible, whereas

prior to this, the inherent internal friction(s) of these devices prevented the starting movement of the system and, therefore, no action was subsequently possible.

[00011] While methods or devices for generating electricity from kinetic energy are known in the art, known systems still encounter losses and inefficiencies due to friction, vibration, and the like.

[00012] As mentioned above, objects in remote locations face the problem of finding ways to power electronic devices that are attached to or disposed within those objects. A buoy floating in the middle of the ocean is not able to simply plug a power cord into a wall socket in order to meet the electrical energy needs of the electronic devices attached to or disposed within the buoy. Therefore, there is a need for alternative means of providing charge power to devices that are in remote locations without easy and/or simple access to a power supply external to the object. There is a further need to provide a kinetic energy power generator that is connectable to electronic devices within a remotely located object in order to constantly charge these devices. Therefore, there exists a need to maximize power generator efficiency derived from external motion.

SUMMARY

[00013] Briefly, according to the embodiments of the present invention, power generator efficiency due to external motion is increased by maximizing the relative movement between coupled electrical and magnetic components through selection or adjustment of system component properties based on a predetermined frequency range exhibited by external moving objects.

[00014] More specifically, an exemplary power generator unit of the invention is configured to be subjected to an external motion that has a predetermined frequency range. The exemplary power generator unit has a first member comprising a magnetic component and a second member comprising an electrical component. The magnetic component and the electrical component are movable relative to one another, whereby an electromagnetic interaction between the electrical and magnetic components generates an electrical current in the electrical component. The exemplary power generator unit of the invention further comprises a spring element coupled to at least one of the first and second members to define a spring-mass system configured to reciprocatively move the

electrical and magnetic components relative to each other in response to the external motion. (e.g., linear motion, circumferential motion, radial motion or any combination thereof). One or more properties of the first member, the second member, and the spring element may be selected and adjusted based on the predetermined frequency range of the motion to maximize the relative movement between the electrical component and the magnetic component. Also note that multiples and combinations of each of the components are possible.

[00015] In another embodiment of the invention, the external motion to which the power generator unit may be subjected comprises a plurality of external motions each having a predetermined frequency range. The spring element may comprises a plurality of spring elements that define a plurality of spring-mass systems configured to reciprocatively move the electrical and magnetic components relative to each other. Also, means of modifying the properties of the spring element itself can allow the system to be "tuned" to the external motion. An example of this is for a simple spring mass system, where along the length of the spring, several fixing points can be made to exist. The fixation of the remaining length of spring results in a different spring rate, and thus a different preferred response of the system. Realize of course that changing the sprung mass would produce a similar effect, but mechanical hardships make this option while workable for some situations, less desirable for most.

[00016] In still another embodiment of the invention, an exemplary method for generating power with a power generator unit is provided. The power generator unit comprises a first member comprising a magnetic component, a second member comprising an electrical component coupled to the magnetic component, and a spring element coupled to at least one of the first and second members to define a spring-mass system. The method requires 1) subjecting the power generator unit to an external motion having a predetermined frequency range; 2) reciprocatively moving the electrical and magnetic components relative to each other in response to the external motion; 3) generating an electrical current in the electrical component; 4) selecting one or more properties of the first member, the second member, and the spring element based on the predetermined frequency range of the motion; and 5) adjusting the one or more selected properties to maximize the relative movement between the electrical component and the magnetic component.

[00017] According to some of the more detailed features of the embodiments of the

present invention, a fluid bearing containing ferro-magnetic particles is used to facilitate the movement of the electric and magnetic components relative to each other. The external motion can comprises a plurality of external motions each having a predetermined frequency range and the spring element can have a plurality of spring elements that define a plurality of spring-mass systems configured to reciprocatively move the electrical and magnetic components relative to each other. The spring element can be a linear spring element or non-linear spring element. Examples of a linear spring elements include a coiled wire or mechanical spring that has a constant spring coefficient. Nonlinear spring element can be repelling magnets, e.g., rebound magnets, that have exponential spring constants.

[00018] According to other more detailed features of the embodiments of the present invention, the first member ("mag rack") has a first surface and a second surface that are spaced from and oppose each other to define a gap . In an exemplary embodiment, the second member comprises a flat blade or carrier having opposing sides that carries one or more coils sized to allow the flat carrier to fit within the gap of the first member to allow first and second member to move relative to each other in a reciprocal manner slidably along a movement axis defined by the second member (blade/carrier). The gap has opposing surfaces, both inwardly facing, corresponding opposing sides of the blade or carrier. According to other more detailed features of the embodiments of the present invention, the first member has a first surface and a second surface that are spaced from and oppose each other to define a gap. In an exemplary embodiment, the second member comprise a flat blade having opposing sides that carries one or more coils sized to allow the flat blade/carrier to move slideably within the gap of the first member in a reciprocal manner along a reciprocal movement axis. The gap has opposing surfaces, both facing corresponding opposing sides of the blade/carrier.

[00019] A first array of magnets are disposed on the first surface and a second array of magnets are disposed on the second surface such that the magnetic flux generated by the magnetic component is substantially perpendicular to the reciprocal movement path of the one or more electric components. Each magnet in each of the first and second array of magnets has a magnetic polarity facing the movement path. Adjacent magnets in each array of magnets are oriented to have sides with opposite polarities (N or S) sequentially inwardly facing the movement path within the gap of the one or more coils. Each pair of opposing magnets on the first and second support surfaces are also oriented to have opposite polarities with respect to each other inwardly facing the movement path within the gap and thus since

all magnets are dipoles, the outwardly facing array must be of opposite poles as well A first magnetic yoke of high magnetic permeability material, e.g., mu metal or more simply soft iron, covers and magnetically links the outwardly facing side of the magnets of the fist array of magnets. Similarly, a second magnetic yoke of high magnetic permeability material magnetically covers and links the other outwardly facing side of the magnets of the second array of magnets.. In this way, a concentrated magnetic field is generated by the magnetic component with alternating magnetic flux directions that are substantially perpendicular to the movement axis. As the magnet moves and magnetic flux crosses the coil, an electrical current is induced in the coil. The faster the magnet moves in relation to the coil, the more electric energy is generated. Either of the first and second members can define a longitudinal movement axis along which the reciprocative movement of the electrical and magnetic components relative to each other can take place. In this example it is the second member (blade/carrier) that defines the motion axis.

[00020] In one exemplary power generator unit, the magnetic component in the fist member comprises an array of opposing magnet pairs that with alternating flux paths or reversing direction from one opposing magnet pair to another. The electrical component of the second member comprises one or more coils positioned between the array of opposing magnets with their respective coil axes perpendicular to their movement axis. Unlike a tubular conventional type power generator, which presents a unidirectional flux to a coil, the coils of the second member are exposed to alternating and bidirectional magnetic flux paths. From one end, as the array of opposing magnet pairs approaches the coil, the coil is subjected to an increasing magnetic flux in one direction as the first opposing magnet pair approaches the coil. . The magnetic flux appears at an instantaneous maximum when the first pair of magnets is directly over center of the coil. . The flux experienced by the coil then abruptly drops off as the first magnet pair departs. Then, as the second opposing magnet pair approaches the coil, the coil experiences an abruptly building flux in the opposite direction as was from the first magnet pair. Again, there exists an instantaneous maximum flux in the opposite direction experienced by the coil, as the second pair of magnets is substantially over center of the coil. As the magnet second pair of magnets depart the coil, the coil experiences a diminishing magnetic flux. It should be noted that in both conventional tubular type power generators and the exemplary embodiments described herein, the coils are exposed to an increasing and diminishing magnetic flux as the magnetic component approaches or departs from the electrical component during movement.

However, the exemplary embodiment of the present invention exposes the electrical component to alternating reversals of magnetic flux direction within short distances of travel resulting in rapid flux changes experienced by the coil which substantially increases its power generation capability. Any physical, electrical or magnetic parameters can be selected and adjusted for tuning the resonant coupling of the power generating unit to external motion in order to maximize power generation efficiency.

BRIEF DESCRIPTION OF THE DRAWINGS

[00021] Examples for some embodiments of the invention will be described with respect to the following drawings, in which like reference numerals represent like features throughout the figures, and in which:

[00022] FIG. 1 is a diagrammatic perspective view of an exemplary power generator unit according to an embodiment of the invention;

[00023] FIG. 2 is a diagrammatic cross-sectional view of a yoked magnet array of the power generator unit of FIG. 1 taken along line 2-2;

[00024] FIG. 3 is a diagrammatic cross-sectional view of the power generator unit of FIG. 1 taken along line 3-3;

[00025] FIG. 4 is a diagrammatic top view of the yoked magnet array of the power generator unit of FIG. 2;

[00026] FIG. 5 is a diagrammatic cross-sectional view of the power generator unit of FIG. 1 taken along line 5-5 illustrating the use of ferrofluid bearings;

[00027] FIG. 6 is a diagrammatic side view of an example power generator unit with a fixed second member according to an embodiment of the invention;

[00028] FIG. 7 is a diagrammatic side view of an example power generator unit with a fixed first member according to an embodiment of the invention;

[00029] FIG. 8 depicts an example flowchart for the process of tuning a power generator unit based on a predetermined frequency range of a particular motion to maximize the relative movement between elements of the power generator unit;

[00030] FIG. 9 shows a simplified model of a structure that is coupled to a linear spring-mass system;

[00031] FIG. 10 shows the spring-mass system of FIG. 9 coupled to a system of magnets and coils;

[00032] FIG. 11 is a graph showing the relationship between the speed of the

magnet and generation of electricity;

[00033] FIG. 12 shows various model spring-mass configurations having pluralities of degrees of freedom; and

[00034] FIGS. 13A-C are various exploded and cross-sectional views of an embodiment of a power generator unit having pluralities of degrees of freedom;

[00035] FIGS. 14A-C are various exploded and cross-sectional views of an embodiment of a power generator unit having pluralities of degrees of freedom;

[00036] FIGS. 15A-C are various exploded and cross-sectional views of an embodiment of a power generator unit having pluralities of degrees of freedom; and

[00037] FIGS. 16A-D are various exploded and cross-sectional views of a buoy within which is disposed a power generator unit having pluralities of degrees of freedom;.

DETAILED DESCRIPTION

[00038] In describing the example embodiments illustrated in the drawings, specific terminology is employed for the sake of clarity. However, the invention is not intended to be limited to the specific terminology so selected. It is to be understood that each specific element includes all technical equivalents that operate in a similar manner to accomplish a similar purpose.

[00039] In the following description of some of the example embodiments of the invention, directional words such as “top,” “bottom,” “upwardly,” and “downwardly” are employed by way of description and not limitation with respect to the orientation of the power generator unit and its various components as illustrated in the drawings. Similarly, directional words such as “axial” and “radial” are also employed by way of description and not limitation.

DEFINITIONS

[00040] The term "couple" (and variations thereof), as used herein, means something that relates or links two things together.

[00041] The term "electrical component," as used herein, means an element or member relating to, producing, or operated by electricity.

[00042] The term "external," as used herein, means acting or coming from the

outside.

[00043] The term "frequency," as used herein, means the number of occurrences of a repeated motion per unit of time. Non-limiting examples of frequency include .5 Hz, 1 Hz, 2 Hz, 5 Hz, etc.

[00044] The term "magnetic component," as used herein, means any of one or more elements or members having magnetic properties or relating to magnetism or magnets, such as, for example, permanent magnets of any shape.

[00045] The term "motion" means any simple or complex movement from a first position to a second position. Non-limiting examples of motion may include those caused by walking, running, ocean waves, and the like.

[00046] The term "oscillate" (and variations thereof), as used herein, means to move back and forth or to cause to move back and forth.

[00047] The term "oscillator," as used herein, means an apparatus establishing and maintaining oscillations of a frequency determined by its physical constants.

[00048] The term "power generator unit," as used herein, means any unit that generates electrical power. Non-limiting examples of a power generator unit may include battery chargers and power supplies.

[00049] The term "predetermined," as used herein, means to settle or decide in advance.

[00050] The term "property" (and variations thereof), as used herein, means any attribute or characteristic.

[00051] The term "range," as used herein, means an amount or extent of variation between two values such as, for example, the difference or interval between the smallest and largest values in a frequency distribution.

[00052] The term "reciprocative," (and variations thereof), as used herein, means to oscillate.

[00053] The term "spring element," as used herein, means any element that exhibits resilience or elasticity. A spring element can be a linear spring element or non-linear spring element. Examples of a linear spring elements are a coiled wire or any mechanical spring that has a constant spring coefficient. Nonlinear spring element have non-linear, e.g., exponential spring constants. Examples include repelling magnets, e.g., rebound magnets, that have exponential spring coefficients.

[00054] A "spring-mass system," as used herein, means any system which, when

displaced from its equilibrium position, experiences a restoring force proportional to the displacement. Non-limiting examples of a spring-mass system may include a simple harmonic oscillator, a driven harmonic oscillator, a damped harmonic oscillator, and a driven damped harmonic oscillator.

[00055] The term "yoke" (and variations thereof), as used herein, means something that binds, unites, couples, or connects at least two physical objects.

DESCRIPTION OF THE EXEMPLARY EMBODIMENTS

[00056] FIG. 1 illustrates a power generator unit 1 having first and second members 10, 18. The first member 10 defines a longitudinal axis A and has a pair of parallel spaced opposing sides 11, 13 defining an internal gap 12 between the sides 11, 13 (see FIG. 2). The first member 10 also includes a magnetic component defined by two spaced arrays of magnets 20, 30 respectively disposed on opposing surfaces of the sides 11, 13. Due to the presence of the magnet arrays 20, 30, the first member 10 is also referred to as the magnet rack or mag rack. Each array 20, 30 includes, respectively, one or more magnets 20a-20e, 30a-30e. For purposes of illustration, only five magnets are shown in each array 20, 30 but the number of magnets in each array 20, 30 can be as few as a single magnet to as many magnets as can be arranged on the array 20, 30. Magnets can be arranged on each array linearly (e.g., single, in pairs, etc.). Where a plurality of magnets 20a-e, 30a-e are provided in the magnet array 20, 30, a high permeability magnetic yoke 16 (discussed further below) may serve to couple and link together the magnets disposed in the same magnet array 20, 30. The second member 18 (carrier or "blade") includes an electrical component 24 that may come in various forms including, but not limited to, one or more electrical coils 24a-e. For purposes of illustration, only five coils 24a-e are shown associated with the second member 18, but the number of coils in each second member 18 can be as few as a coil to as many coils as can be arranged on the second member 18. The first and second members 10, 18 are moveably disposed relative to one another. In one exemplary embodiment, the second member 18 comprises a generally flat elongated coil carrier 22 having two opposing surfaces that face, respectively, the sides 11, 13 of the first member 10. The electrical component 24 is embedded within, laminated on, potted within, extends through and/or is otherwise disposed on the carrier 22. For example, one more coils (e.g., coils 24a-24e) are inserted

within the carrier 22. The first member 10 is structured to define a rectangular gap 12 sized to allow the flat carrier 22 to slideably move within the gap 12 in a reciprocal manner along a reciprocal longitudinal movement axis that is generally co-axial with the longitudinal axis A.

[00057] As shown in FIG. 1, the first member 10 includes a number of support posts 14 extending across the gap 12 through a pair of guide slots 26 in the carrier 22 (i.e., the second member 18) that extend longitudinally along the carrier 22. The guide slots 26 extend substantially parallel to and offset from the longitudinal axis A (i.e., the reciprocal movement axis) and, in conjunction with at least the support posts 14, serve to guide the longitudinal movement of the first and second members 10, 18 relative to one another. The posts 14 may also serve to provide support to the opposing sides 11, 13 of the first member 10 in resisting magnetic forces spanning the gap 12 (see, e.g., FIG. 2). The guide slots 26 and/or support posts 14 reduce rattle and extraneous vibration. An electromagnetic interaction is created between the magnetic and electrical components 20, 30, 24 that serves to produce an electrical current in the electrical component 24 when the magnetic and electrical components 20, 30, 24 are moved relative to one another. A similar device is disclosed in U.S. Application No. 11/359,671, filed February 21, 2006, (published as U.S. Patent Application Publication No. 2007-0052302 on March 8, 2007), the disclosure of which is hereby incorporated by reference.

[00058] At least one of the first and second members 10, 18 may be arranged to be subjected to a simple or complex motion or motions of one or more external objects (not shown) either directly or indirectly through a housing (see FIGS. 8A, 8B and 14). Furthermore, a spring element (not shown in FIG. 1; see FIGS. 6-7) may be provided in the power generator unit 1 and disposed to reciprocatingly move the first and second members 10, 18 relative to one another in response to simple or complex external motions. The spring element will be discussed in more detail below. The first and second members 10, 18, either alone or in combination, define a longitudinal movement axis along which the reciprocative movement of the electrical and magnetic components 20, 30, 24 relative to each other can take place. As mentioned above, the reciprocal longitudinal movement axis is generally co-axial with the longitudinal axis A.

[00059] As illustrated in FIG. 2, the two yoked magnet arrays 20, 30 of the first

member 10 of the power generator unit 1 include the first magnet array 20 having, for example, magnets 20a, 20b, 20c, 20d, and 20e, which are spaced apart from, and respectively correspond with, magnets 30a, 30b, 30c, 30d, and 30e, of the second magnet array 30. Although each magnet array 20, 30 is shown as having five magnets 20a-e, 30a-e, the number of magnets in each array 20, 30 may vary depending on space requirements and based on particular applications of the power generator unit 1. The magnets in each array 20, 30 may be made from various types of magnetic materials including, but not limited to grade 38 NdFeB (neodymium iron boron), rare earth magnets or the like.

[00060] As can be seen in FIG. 2, the polarity of each respective magnet 20a-e in the first magnet array 20 is arranged such that it is attracted to the corresponding magnets 30a-e in the second magnet array 30 across gap 12. The pole-indication arrows shown in FIG. 2 for each respective magnet point towards the north-seeking pole of the respective magnet (hereinafter north pole or north magnetic pole). For example, the pole indication arrow for magnet 20a indicates that the magnet's north pole is adjacent to the gap 12 and facing the south pole of magnet 30a. Furthermore, each magnet 20a-e, 30a-e in a given array 20, 30 is oriented to have a polarity orientation opposite to that of any immediately adjacent magnets in the same given magnet array 20, 30. That is, the polarities of magnets in a given magnet array alternate. Additionally, a respective magnet 20a-e, 30a-e in a given magnet array 20, 30 may have a magnetic strength that is the same as or different from each other magnet 20a-e, 30a-e in the same magnet array 20, 30.

[00061] The first array 20 of magnets is disposed on the first side 11 of the first member 10 and the second array 30 of magnets is disposed on the second side 13 of the first member 10 such that the magnets 20a-e, 30a-e of the two arrays 20, 30 face each other across the gap 12. In this configuration, the magnetic flux generated by the magnetic component 20, 30 is substantially perpendicular to the reciprocal movement path of the one or more electric components 24. Each magnet 20a-e, 30a-e in each of the first and second arrays 20, 30 has a magnetic polarity facing the movement path. Adjacent magnets 20a-e, 30a-e in each array 20, 30 are oriented to have sides with opposite polarities (N or S) sequentially facing the movement path within the gap 12 of the one or more coils 24a-e forming the electrical component 24. Each pair of opposing magnets 20a-e, 30a-e on the first and second sides 11, 13 are also oriented to have

opposite polarities with respect to each other facing the movement path within the gap 12. The first and second sides 11, 13 of the first member 10 must be made of a sufficiently strong material so as not to buckle or bow in response to the attractive forces of the magnets 20a-e, 30a-e across the gap 12. Given that the attractive forces between the magnets 20a-e, 30a-e are related exponentially to the distance of the gap 12, a slightly larger gap 12 can be used to reduce the attractive forces and reduce the tendency for the sides 11, 13 to distort. It may be desirable to use a light-weight material for the first member 10 including, but not limited to, strong organic polymers (e.g., plastic including, but not limited to, polycarbonate, polysulfone or the like); high strength, lightweight metallic alloys; and ceramics or other more dense materials (e.g., glass, brass, tungsten, etc.). As discussed below, it is also possible to construct the power generator unit 1 with support posts 14 spanning the gap 12 through slots 26 in the carrier 22 of the second member 18 to ensure structural rigidity.

[00062] As shown in FIGS. 1-2, each magnet 20a-e, 30a-e in a given magnet array 20, 30 is coupled and linked to the other magnets 20a-e, 30a-e in the same magnet array 20, 30 by a yoke 16 having a high magnetic permeability. The yoke 16 may be made of any high magnetic permeability material including, but not limited to mu (μ) metal, various nanomagnetic materials, Permalloy, steel (e.g., 1010 iron steel), Back Iron, or the like. Mu metal is a special iron nickel alloy that has extremely high magnetic permeability and is often used to provide magnetic shielding. Ideally, the yoke 16 would be configured to effect complete magnetic shielding so that the strong magnet fields of the magnet arrays 20, 30 will not exist outside of the power generator unit 1. Furthermore, due to the high magnetic permeability of the yoke 16 and the fact that adjacent magnets 20a-e, 30a-e in each magnet array 20, 30 are arranged in alternating orientations, magnetic lines of flux from each magnet 20a-e, 30a-e can be very efficiently conducted to neighboring magnets 20a-e, 30a-e in the same given magnet array 20, 30.

[00063] As shown in FIGS. 1-2, the magnets 20a-e, 30a-e are depicted as being cylindrical. However, the magnets 20a-e, 30a-e may come in various shapes including, but not limited to, cubed (i.e., square sides), bar-shaped (i.e., rectangular sides) or other geometric shape. Furthermore, the size of the gap 12 between the parallel opposing sides 11, 13 of the first member 10 is exaggerated in the figures for illustration purposes.

[00064] FIG. 3 illustrates the carrier 22 of the second member 18 movably disposed in the gap 12. Attached to, or embedded within, the carrier 22 includes the electrical component 24 comprising one or more conductive coils 24a-e (i.e., coils 24a, 24b, 24c, 24d, and/or 24e). Any one of the coils 24a-e can be formed from conductors wound about a respective coil axis 28a-e. As illustrated, the conductors forming, respectively, the coils 24a-e are wound about their respective coil axes 28a-e. In the embodiment shown in FIG. 3, the coil axis 28a-e is perpendicular to the movement axis or path taken by the first and second members 10, 18 as the first and second members 10, 18 move relative to each other. Although each electrical component 24 is shown as having five coils 24a-e, the number of coils in the electrical component 24 may vary depending on space requirements and based on particular applications of the power generator unit 1. As stated above, each coil 24a-e defines a coil axis 28a-e about which the turns of the respective coil 24a-e are disposed. Each coil axis 28a-e is oriented substantially parallel with the magnetic flux lines of the magnets 20a-e and perpendicular to the longitudinal axis A.

[00065] During movement between the first and second members 10, 18, any given coil 24n will be intersected by magnetic flux lines of the opposite polarity as compared to the immediately adjacent coil 24a-e because of the alternating polarity orientations of respective adjacent magnets 20a-e, 30a-e in the magnet arrays 20, 30. Thus, the direction of current flow in one coil 24a-e will be opposite to the direction of current flow in an adjacent coil 24a-e. The additional benefits of wiring of the coils either in parallel or series versus wiring each coil independently of the other coils, is usually dictated by the respective geometry of the placement of the coils with respect to the magnets. In some cases, wiring of the coils 24a-e independently has the most advantage, as when a magnet pair is not interacting with a coil (end stroke) that coil is essentially providing no benefit while if connected in any way directly to the other coils, provides a loss path. Independent connection of the coils, at least the end coils, eliminates this downfall. Parallel and series wiring of the coils 24a-e are most useful when the coils 24a-e are experiencing magnetic flux from the magnets 20a-e, 30a-e and/or when the pitch of the coils 24a-e and magnets 20a-e, 30a-e are equal. If the coils 24a-e are wired in parallel or series, and if a coil 24a-e becomes exposed (i.e., is not covered by the arrays 20,30), the coil 24a-e is non-energized and acts as a resistor to the

system since the voltages from the coils 24a-e are combined. However, if the coils 24a-e are independently wired, this issue is eliminated. One of the benefits of series wiring is that higher voltages can be generated. Alternatively, diodes and other semiconductor devices known in the art can be used to effectively condition the power outputs of the coils 24a-e. As seen in FIG. 1, the coils 24a-e are connected electrically and/or mechanically to an electrical conductor 31, such as a wire, cable or the like, that can be operatively connected (mechanically and/or electrically) to an electronic device (and, by extension, to the rechargeable power source of the electronic device).

[00066] In one exemplary embodiment, the coils 24a-e are immersed in a ferrofluid and force is applied (for example, mild centrifugation or evacuation) to facilitate infiltration. The point of the infiltration is to allow the coil 24a-e to exhibit some properties like that found in a coil wrapped around a ferrite core. A "doughnut hole" formed in the center of the coil 24a-e allows ferrofluid to flow through the center of the coil 24a-e (i.e., through the hole). Once the fluid has evenly penetrated the coil's intricacies the ferrofluid liquid can be evaporated to leave the nano-ferrite particles (approximately 5-10 nm in diameter) within the coil 24a-e. In another embodiment, the particles are suspended in super critical carbon dioxide which can readily evaporate following infiltration. In one embodiment, the ferromagnetic particles are fixed on the one or more electric components 24 (e.g., the coil) according to a desired direction. The ferromagnetic particles can be oriented by exposure to magnetic fields, for example, via external magnets or by energizing the coil 24a-e with electricity during evaporation. In order to prevent movement or orientation of the ferrite particles, a trace of a soluble resin can be added to the ferrofluid so that the nano-ferrite particles are "glued down." Alternatively, a dense solution of nano-ferrite particles in a polymerizable matrix can be used so that after the coil has been completely infiltrated, the matrix can be polymerized to leave the particles "frozen" in place. The addition of ferrofluid to the coil 24a-e or any slightly ferro-magnetic material provides improved flux transmission. In the alternative, another way of impregnating coils 24a-e is accomplished by mixing the nano-particles in epoxy resin, then using the resulting slurry to encapsulate the conductor used to form the coil 24a-e as the conductor is wound to form the coil 24a-e. The conductor used to form the coil 24a-e may come in various forms, including, but not limited to, an iron-clad wire.

[00067] FIG. 4 illustrates a diagrammatic top view of the yoked magnet array 20 of the first member 10 of the power generator unit 1 and shows two magnetic bearing arrays 32, 34 having bearing magnets 32a-d and 34a-d, respectively, which may be employed in the power generator unit 1 to reduce friction resulting from relative movement between the first and second members 10, 18. The magnets 20a-e associated with the side 11 are indicated in phantom to show their position beneath the yoke 16. FIG. 5 illustrates the power generator unit 1 as seen in a direction parallel to the longitudinal axis A and illustrating the use of magnetic ferrofluid bearings (as shown in FIG. 4). The spaced apart magnetic bearing arrays 32 and 34 are aligned with narrow side edges of the carrier 22 of the second member 18. Small drops 36 of ferrofluid placed proximate each of the bearing magnets 32a-d, 34a-d allow the first and second members 10, 18 to move relative to one another in an essentially friction-free manner. The use of ferrofluid bearings is described in U.S. Patent Nos. 6,768,230; 6,809,427; and 6,812,583, which are hereby incorporated by reference. Alternatively, or in combination with the foregoing side-positioned ferrofluid-based magnetic bearing arrays 32, 34, each of the magnets 20n, 30n of the magnet arrays 20, 30 may be provided with ferrofluid 42 which forms a meniscus 43 at a surface interface between the first and second members 10, 18. The ferrofluid meniscus 43 tends to center the carrier 22 within the gap 12 which reduces the chance of any possible friction that could result from contact of the carrier 22 with any side 11, 13 of the first member 10 that defines the gap 12. The self centering phenomena also is evident in the cross wise direction, though in this example of lesser degree due to the lesser sized edge magnets. Additionally, the meniscus 43 acts as a lens and further focuses the magnetic lines of flux from magnets 20a-e, 30a-e on the coil 24a-e.

[00068] FIG. 6 illustrates a power generator unit 100 having a first member 110 and a second member 118 arranged to move relative to one another, in accordance with another embodiment of the invention. The first member 110 defines longitudinal axis A and includes a magnetic component having a first magnet arrays 120 and a second magnet array (not shown) on an opposite side of the first member 110 from the first magnet array 120. The first member 110 is "stationary" relative to the second member 118 in that fasteners 112 connect the first member 110 to a housing (not shown) or other object (not shown) to which the power generator unit 100 is affixed and does not move

relative to that housing or object. The second member 118 includes an electrical component 124 that may come in various forms including, but not limited to, one or more electrical coils, movable relative to one or more magnetic components (i.e., the magnet arrays 120) such that an electromagnetic interaction between the one or more electrical and magnetic components (124,120) generates an electrical current in the electrical component 124. In FIG. 6, a spring element 128 moveably couples the first member 110 to a carrier 122 of the second member 118 to define a spring-mass system such that when the first member 110 is subjected to external motion M, the spring element 128 causes the second element 118 to reciprocatingly move relative to the first member 110 and thereby generate an electrical current in the coils 124. The embodiment depicted in FIG. 7 is substantially the same as that depicted in FIG. 6 except that a second member 218 of a power generator unit 200 is subjected to the external motion M such that the spring element 228 causes a first member 210 to reciprocatingly move relative to the second member 118 and thereby generate an electrical current in the coils 224. The second member 118 is "stationary" relative to the first member 110 in that the second member 118 is connected to a housing (not shown) or other object (not shown) to which the power generator unit 100 is affixed and does not move relative to that housing or object. In both FIGS. 6 and 7, the spring element (128, 228) may be a mechanical coil spring or other spring elements or, alternatively, a system of rebound magnets, springs or other spring elements forming a non-linear spring mass system arranged to reciprocatingly move the magnet array 120, 220 away from respective ends of the second member 118, 218 as disclosed in U.S. Patent Application Publication No. 2007-0052302, published March 8, 2007, hereby incorporated by reference. Furthermore, assuming the power generator units 100 and 200 are oriented vertically, a spring element (not shown) attached between a bottom of the second member 118, 218 and a bottom edge of the first member 110, 210 could provide a similar effect (likewise if a spring element was attached on both the bottom and top sides of the second member 118, 128 and respective bottom and top sides of the first member 110, 210). In one embodiment, the power generator unit 1, 100, 200 may contain rebound springs, magnets, or elastomeric bumpers (not shown) for over travel protection. In FIGS. 6 and 7, at least one of the first and second members 110, 210, 118, 218 is generally fixed in position relative to the other member 118, 128, 110, 210.

[00069] The external motion can comprises any type of simple or complex motion or a plurality of external motions each having a predetermined frequency range and the spring element can have a plurality of spring elements that define a plurality of spring-mass systems configured to reciprocatingly move the electrical and magnetic components relative to each other. Each spring element can be a linear spring element or non-linear spring element. Examples of a linear spring elements are coiled wire or mechanical springs having constant spring coefficients. Nonlinear spring elements can be repelling magnets, e.g., rebound magnets, that have exponential spring coefficients. Floating bodies, such as buoys, are modeled as spring elements as well. The shape of the hull of the floating body essentially determines the restorative force due to buoyancy. A long slender tube represents a near linear spring element, while other shapes represent non-linear, and possibly complex variable spring element characteristics.

[00070] The magnetic component of the power generating unit described above thus generates a concentrated magnetic field with alternating magnetic flux directions that are substantially perpendicular to the movement axis of the coils of the electrical component. As the magnets move and magnetic flux crosses each coil, an electrical current is induced in the coil. The faster the magnet moves in relation to the coil, the more electric energy is generated. The magnetic component in the first member comprises an array of opposing magnet pairs that with alternating flux paths or reversing direction from one opposing magnet pair to another. The electrical component of the second member comprises a number of coils positioned between the array of opposing magnets with their respective coil axis perpendicular to their movement axis.

[00071] Unlike a tubular type power generator, which presents a unidirectional flux to a coil, the one or more coils of the electrical element 24 of the second member 18 are exposed to alternating and bidirectional magnetic flux paths. From one end, as each opposing magnet pair (e.g., magnet pairs 20a/30a, 20b/30b, 20c/30c, 20d/30d, 20e/30e, etc.) of the arrays 20, 30 approaches a respective coil, the coil is subjected to an increasing magnetic flux in one direction as a first opposing magnet pair (e.g., a magnet pair comprising magnets 20b, 30b) approaches the coil. The magnetic flux appears at an instantaneous maximum when the first pair of magnets is directly over a center of the coil. The flux experienced by the coil then abruptly drops off as the first magnet pair departs. Then, as the second opposing magnet pair approaches the coil, the coil

experiences an abruptly building flux in the opposite direction as was from the first magnet pair. Again, there exists an instantaneous maximum flux in the opposite direction experienced by the coil, as the second pair of magnets is substantially over center of the coil. This flux reversal repeats for as many pairs of magnets are made to be within the first member 18 (i.e., the mag rack). As the last pair of magnets departs the coil, the coil experiences a diminishing magnetic flux. It should be noted that the coils are exposed to an increasing and diminishing magnetic flux as the magnetic component approaches or departs from the electrical component 24 during movement. However, the exemplary embodiment of the present invention exposes the electrical component 24 to alternating reversals of magnetic flux direction within short distances of travel resulting in rapid flux changes experienced by the coil which substantially increases its power generation capability.

[00072] In another exemplary embodiment, for each opposing magnet pair, only one magnet can be positioned somewhere in the flux circuit and the flux could be directed to the coil with shaped ferro-magnetic materials, such as iron, where the magnet exposes the coil to magnetic flux and the ferro-magnetic material forms a conduit for alternatingly reversing magnetic flux direction. Such magnetic flux direction reversal comprises the change in flux with respect to time as a parameter for maximizing generated voltage under Faraday's law. Any physical, electrical or magnetic parameters can be selected and adjusted for tuning the resonant coupling of the power generating unit to external motion in order to maximize power generation efficiency.

[00073] In view of such predetermined frequency ranges for various bodies in motion, adjustments and/or modifications may be made to the power generator unit that effectively optimize the unit and enable greater power output. For example, the following properties of various components in the above-described power generator units may be modified alone, or in combination, to "tune" the unit based on the movement of a particular external body or environment and its predetermined frequency range: the properties of the spring element, the weight of the first member, the weight of the second member, the number of magnets in a given array, the relative spacing of magnets in a given magnet array, magnet thickness, magnet strength, gap size, the number of coils, the relative spacing of adjacent coils on the second member, coil thickness, the number of turns in a coil, and the like. The primary dominant elements above are the modifications

to the mass and spring properties. By adjusting one or more of the foregoing properties of the elements and components of the power generator unit, the unit is tuned such that the inherent natural, or "resonant", frequency of vibration of the first and second members relative to one another equals, or nearly equals, the one or more common frequencies of the external motion. In this way, the relative motion between the magnetic and electrical components can be maximized, thus resulting in additional power output of the unit in comparison to un-optimized units.

[00074] FIG. 8 depicts an exemplary flowchart for the process of tuning a power generator unit based on a predetermined frequency range of a particular external motion to which the power generator unit is subjected to maximize the relative movement between magnetic and electrical elements of the power generator unit. As shown in FIG. 8, the process 250 may begin with the step of selecting one or more properties of a first member of the power generator unit, a second member of the power generator unit, and a spring element based on the predetermined frequency range of an external motion as shown in block 251. The external motion may be a motion common to a particular body or object in a given type of application or activity. Next, as shown in block 252, the method may include adjusting one or more of the selected properties to maximize relative movement between an electrical component of the second member and a magnetic component of the first member of the power generator unit. The power generator unit may then be subjected to the external motion having the predetermined frequency range, as shown in block 253. Block 254 shows the step of reciprocatively moving the electrical and magnetic components relative to each other in response to the external motion. Block 255 shows the step of generating an electrical current in the electrical component. Ideally, the electrical current generated in step 255 is greater than it otherwise would be without having performed the steps of the process.

[00075] Additionally, in one embodiment of the invention, additional degrees of freedom may be created in the power generator unit such that the device can be tuned and optimized for various frequencies or frequency ranges of one or more external motions. The degrees of freedom of a spring-mass system defined in a power generator unit by the spring element and at least one of the first and second members, can be increased, for example, by adding a coupled spring and mass to the existing spring-mass system. In a spring mass system with multiple degrees of freedom, the mass, or masses, move with more complexity. The net effect is that a spring-mass system with more

natural or resonant frequencies. The ability to expand the degrees of freedom of a power generator unit allows resonance coupling to a multitude of external motion, thereby widening the type of motions that can be exploited. This can be useful in coupling to excitations that appear random, such as walking, jogging, or ocean waves. By tuning the system to the predominant frequencies of low, mid and high frequency movements, significant power can be produced over all amplitudes and multiple frequencies.

[00076] From the foregoing description it will be appreciated that the embodiments of the present invention relate to a kinetic energy power generator tuned to provide resonant coupling to external motion. The tuning of the kinetic energy power generator results in improved electric power generation from the kinetic energy of the device. In addition, the degrees of freedom of the kinetic energy power generator may be expanded such that the device can be tuned to various frequencies of external motion. A power generator unit is configured to be subjected to an external motion that has a predetermined frequency range. The power generator unit has a first member comprising one or more magnetic components and a second member comprising one or more electrical component, such as coils, movable relative to one or more magnetic component such that an electromagnetic interaction between the one or more electrical and magnetic components generates an electrical current in the electrical component. A spring element is coupled to at least one of the first and second members to define a spring-mass system. The spring mass system is configured to reciprocatively move the electrical and magnetic components relative to each other in response to the external motion. One or more properties of the first member, the second member, and the spring element are selected and adjusted based on the predetermined frequency range of the motion to maximize the relative movement between the electrical component and the magnetic component. In this way, the power generator unit described in the embodiments of the present invention efficiently generates electric power by capturing lost kinetic energy by tuning the power generator unit to one, or several, common frequencies of motion. The advantage of this approach is that the power generator may generate electricity from a small amplitude input motion.

[00077] Another aspect of the present invention relates to a method for generating power with a power generator unit, such the one described above, which method includes subjecting the power generator unit to an external motion having a predetermined frequency range and reciprocatively moving the electrical and magnetic components of the unit relative to each other in response to the external motion to generate an electrical current in the

electrical component. One or more properties of the first member, the second member, and the spring element are selected based on the predetermined frequency range of the motion and adjusted to maximize the relative movement between the electrical component and the magnetic component.

[00078] As explained above, one embodiment of the exemplary power generator unit of the present invention is composed of a support structure/casing, a spring mass system, and a system of magnets and coils. The systems are arranged such that the oscillation of the support structure/casing results in relative movement between the magnets and coils. The relative movement between the magnets and coils results in the generation of electric current. In an embodiment of the present invention, a mass is coupled to the support structure/casing of the device via one, or several springs. FIG. 9 shows a simplified model of a structure that is coupled to a linear spring mass system. This spring mass system is tuned such that the inherent natural, or "resonant", frequency of vibration of the suspended mass equals, or nearly equals, one or several common frequencies of the device's motion. As the housing of the device moves, the kinetic energy of the housing is transferred to the spring and mass system. The energy stored in the system oscillates between kinetic and spring potential.

[00079] At the upper and lower most extent of the mass travel, the energy is stored in the spring only and is given by:

$$E = 1/2k(\Delta x)^2$$

Alternatively, at the mid stroke the energy is stored in the moving mass only and is given by:

$$E = \tfrac{1}{2}MV^2$$

Where k is the spring constant, M is the mass, and V is the midpoint velocity.

[00080] For each oscillation of the device's housing, the energy is additively stored in the spring and mass system. FIG. 10 shows the spring mass system is in turn coupled to a system of magnets and coils. In an alternate embodiment, the mass of the spring mass system is the magnet, or magnets, of magnet coil system.

[00081] One exemplary power generator unit is based on a dynamic system that uses multiple magnets of different strength in polar opposition to each other within a support structure/casing that surrounds one or more coils. In order to induce an electrical signal in the coil, the magnets interact with each other to oscillate (i.e. move back and forth) in

response to the oscillation of the support structure/casing. An ultra low friction interface can be obtained by use of nanofluid (i.e. ferrofluid) bearings. As a result, very slight movements of the support structure/casing trigger significant magnet movement, resulting in power generation.

[00082] In one embodiment of the present invention, the magnet is also the mass in the spring mass system. As the magnet moves and magnetic flux crosses the coil, an electrical current is induced in the coil. The faster the magnet moves in relation to the coil, the more electric energy is extracted. The relationship between the speed of the magnet and generation of electricity is not linear. FIG. 11 is a graph showing the relationship between the speed of the magnet and generation of electricity. The transference of kinetic energy to electric energy results in a resisting force on the mass in the direction opposite of the movement. The combination of resisting force at high speeds and the dominance of resonance coupling at low speeds tends to keep the system moving within a band of operation, as shown in Figure 11, for a given input movement range. In one embodiment of the present invention, the support structure/casing may contain rebound springs, magnets, or elastomeric bumpers for over travel protection. The rebound springs conserve the energy of the system by preventing the spring mass system from transferring energy back to the support structure/casing and outside environment. In addition, the device is protected from mechanical damage due to the contact between the spring mass system and the support structure/casing.

[00083] As stated above, the degrees of freedom of a spring mass system can be increased by adding a coupled spring and mass to an existing spring-mass system. As shown in Figure 11, a one degree of freedom spring-mass system has one spring and one mass, whereas a two degree of freedom spring-mass system has a first mass coupled to a first spring and a second mass coupled to a second spring. In a spring-mass system with multiple degrees of freedom, the mass, or masses, move with more complexity. The net effect is that a spring-mass system with more degrees of freedom has more natural or resonant frequencies. For a simple two (2) degree of freedom system, the natural frequency of the first mass is mostly dependent on the first spring. Similarly, the natural frequency of the second mass is mostly dependent on the second spring. Together, the system will exhibit two fundamentally different natural frequencies. This trait is continued for multiple degree of freedom systems. The ability to expand the degree of freedom of the present invention allows resonance coupling to a multitude of input excitations, widening the type of motions

that can be exploited. This can be useful in coupling to excitations that appear random, such as walking, jogging, or ocean waves. By tuning the system to the predominant frequencies of low, mid and high frequency movements, significant power can be produced over all amplitudes and multiple frequencies. FIG. 12 shows various model spring-mass configurations having a plurality of degrees of freedom.

[00084] The input vibration to power generating devices in the environment described above is generally passive (i.e., the power generator unit receives kinetic energy from the outside environment based only on ambient conditions). A power generator is designed to maximize the cumulative effects of these vibrations. Each "mass" can be tuned to capture a different frequency of vibration so that the power generator is able to take advantage of as many motions as possible that are being experienced in order to generate current. The spring constant k allows a user to capture multiple frequency bands. Thus, there is a need for a user to be able to select an appropriate spring constant k to match the "mass". For example, when dealing with ocean buoys, a designer seeks to match the type of buoy hull used to the environment the buoy will be in and factor in the buoyancy of the buoy (e.g., changing the shape of the buoy hull changes the buoyancy at different amplitudes) and this affects the type of motion being experienced by the buoy, and thus the amount of electric current that can be generated by a power generator(s) disposed within the buoy. Therefore, it would be desirable to be able to adjust the endpoint of the spring elements in a power generator as adjusting the endpoint of the spring elements, affects the spring constant k which, in turn, affects the natural frequency (e.g., a long spring has a low spring constant k while a short spring has a high spring constant k). This allows for a wider bandwidth at response (i.e., more magnetic flux is experienced by the coil during relative movement between the magnetic and electrical elements).

[00085] As has been discussed previously, the operational enhancements of the vibration coupled devices are utilizing the phenomena where if the internal spring mass system is tuned, within some range of course, to the same frequency of the external vibratory motion, the internal mass will begin to vibrate, where the amplitude of vibration builds, e.g. capturing and thus storing this energy on the oscillatory spring mass system. The nature of the electromagnetic elements in conjunction with the above system serves to transform the energy within the spring mass to electrical energy.

[00086] A simple spring mass system, tuned to some natural frequency, will respond to some range of input vibration frequencies, roughly centered about the home natural

frequency. If on the other hand, the input frequency is outside of the inherent range, the internal mass will not respond accordingly e.g. shaking the housing very fast but the weight remains substantially still with respect to the (outside world). While this situation can be exploited to gain some useful power, much more can be derived if the spring mass system were made to oscillate at resonance. If the input frequency bandwidth is sufficiently narrow so as to allow the system to operate within it's capture range, no further provision is required, but this is not usually the case, For example, with ocean waves the range of input frequencies is very broad. Therefore there is a need to be able to widen the bandwidth that the spring mass system will respond. Below are several methods of achieving this.

[00087] FIGS. 13A and B illustrate, respectively, exploded and cross-sectional views of a power generator unit 300, similar to the power generator unit 200 of FIG. 7, having a first member 310 and a second member 318 arranged to move relative to one another, in accordance with another embodiment of the invention. The first member 310 defines longitudinal axis A and includes a magnetic component having a first magnet arrays 320 and a second magnet array 330 on an opposite side of the first member 310 from the first magnet array 320. Each magnet array 320, 330 comprises a number of individual magnets 332, as seen in the exploded view of the first member 310 in FIG. 13C. The first member 310 also includes a yoke 334 similar in structure and/or function to the yokes described above. The first and second members 310, 318 are disposed within a housing 302. The second member 318 is inserted through a gap 304 in the first member 310, in a manner similar to that described above with respect to other illustrations of power generator units. A pair of spacers 306 are used to secure the ends of the second member 318 within the housing 302 (each spacer 306 has a gap 316 through which an end portion of the second member 318 at least partially passes). The second member 318 is "stationary" relative to the first member 310 in that the second member 318 is connected to and stationary relative to the housing 302 and/or other object (not shown) to which the power generator unit 300 is affixed and does not move relative to that housing 302 or object. The housing 302 is a two-piece housing comprising two sub-housings 302a, 302b. The second member 318 includes an electrical component 324 that may come in various forms including, but not limited to, at least one electrical coil, which is stationary relative to the one or more magnetic components (i.e., the magnet arrays 320, 330) that move with the first member 310 such that an interaction between the one or more electrical and magnetic components (324, 320, 330) generates an electrical current in the electrical component 324. A spring element 308, 314 moveably

couples the first member 310 to a carrier 322 of the second member 318 to define a spring-mass system such that when the housing 302 is subjected to external motion M, the spring element 308, 314 causes the first member 318 to reciprocatingly move relative to the "stationary" carrier 322 of second member 318 and thereby generate an electrical current in the coil(s) of the electrical component 324 due to the electromagnetic interaction. The spring element 308, 314 comprises two sets of a series of mechanical coil springs 312; each series of springs 312 being fixed to the housing 302 (via the spacer 306) on one end and fixed to the first member 310 at the other end. Adjacent springs 314 of each set 312 are connected by solenoid engagement collars or cylinders 326. Each engagement cylinder 326 is generally aligned with a solenoid mechanism 328 that can engage the engagement cylinder 326 when activated and hold the engagement cylinder 326 in a fixed position. Each spring set 312 (comprising a series of individual springs 314) can be viewed as a single spring having a particular spring constant. However, as each individual spring 314 has its own spring constant, the spring constant of the spring set is determined by the cumulative spring constants of the "active" springs 314 in the spring set 312.. When a solenoid 328 engages one of the cylinders 326, the solenoid effectively "inactivates" one of the springs and thus changes the spring constant of the spring set 312. When the spring constant changes, this changes the rate at which the first and second members 310, 318 will reciprocatingly move relative to each other (and thus have an effect on the amount of magnetic flux change experienced which, in turn, effects the amount of electric current generated).

[00088] FIGS. 13A-C illustrate a simple spring mss system generator, where at two points along the spring, cylinders or collars are affixed, and solenoids are mounted to the housing to selectively engage the collars. The purpose of the cylinders/collars is such that when the solenoid (pair in this case) engages the collar, it affectively fixes the collar, thus pinning the spring. This is analogous to having simply a smaller – stiffer spring (k= increased), and as has been discussed, the natural frequency of response will be changed by this change in spring stiffness. By placing several sets of fixing points along the length of the spring, one can tune the system to be resonant over several “home frequencies. For the example shown, the system has three choices of natural frequencies; full length spring, first fixing point (somewhat higher natural frequency), and second fixing point (highest natural frequency). By judiciously selecting these fixing points it is possible to achieve resonance coupling to the targeted external vibratory inputs over a wide range. Of course, more fixing points will allow for finer adjustment.

[00089] Alternatively, the first member 310 could also be connected to another spring element (not shown) that is itself attached to an opposite side of the housing 326 from the side connected to the series of springs 336. This spring element would be similar, if not identical, to the spring element 328 in both form and function. In one embodiment, the power generator unit 300 may contain bumper or rebound springs, magnets, or elastomeric bumpers (not shown) for over travel protection..

[00090] FIGS. 14A and B illustrate, respectively, exploded and cross-sectional views of a power generator unit 400, similar to the power generator units 200, 300, having a number of first members 410 and a single second member 418 arranged to move relative to one another, in accordance with another embodiment of the invention. The first members 410 define a longitudinal axis A and each includes a magnetic component having a first magnet arrays 420 and a second magnet array 430 on an opposite side of the first member 410 from the first magnet array 420. Each magnet array 420, 430 comprises a number of individual magnets 432, as seen in the exploded view of the first member 410 in FIG. 14C. Each first member 410 also includes a yoke 434 similar in structure and/or function to the yokes described above. The first and second members 410, 418 are disposed within a housing 402. The second member 418 is inserted through a gap 404 in each of the first members 410, in a manner similar to that described above with respect to other illustrations of power generator units. A pair of spacers 406 is used to secure the ends of the second member 418 within the housing 402 (each spacer 406 has a gap 416 through which an end portion of the second member 418 at least partially passes). The second member 418 is "stationary" relative to the first members 410 in that the second member 418 is connected to and stationary relative to the housing 402 and/or other object (not shown) to which the power generator unit 400 is affixed and does not move relative to that housing 402 or object. The housing 402 is a two-piece housing comprising two sub-housings 402a, 402b. The second member 418 includes an electrical component 424 that may come in various forms including, but not limited to, at least one electrical coil, which is stationary relative to the one or more magnetic components (i.e., the magnet arrays 420, 430) that move with the first members 410 such that an interaction between the one or more electrical and magnetic components (424, 420, 430) generates an electrical current in the electrical component 424. A spring element 408 moveably couples the first members 410 to a carrier 422 of the second member 418 to define a spring-mass system such that when the housing 402 is subjected to external motion M, the spring element 408 causes the first members 418 to reciprocatingly

move relative to the "stationary" carrier 422 of second member 418 and thereby generate an electrical current in the coil(s) of the electrical component 424 due to the electromagnetic interaction. The spring element 408 comprises two sets of a series of mechanical coil springs 412; each series of springs 412 being fixed to the housing 402 (via the spacer 406) on one end and fixed to the first member 410 at the other end. Adjacent springs 414 of each set 412 are connected by solenoid engagement cylinders 426. Each engagement cylinder 426 is generally aligned with a solenoid mechanism 428 that can engage the engagement cylinder 426 when activated and hold the engagement cylinder 426 in a fixed position. Each spring set 412 (comprising a series of individual springs 414) can be viewed as a single spring having a particular spring constant. However, as each individual spring 414 has its own spring constant, the spring constant of the spring set is determined by the cumulative spring constants of the "active" springs 414 in the spring set 412.. When a solenoid 428 engages one of the cylinders 426, the solenoid effectively "inactivates" one of the springs and thus changes the spring constant of the spring set 412. When the spring constant changes, this changes the rate at which the first and second members 410, 418 will reciprocatingly move relative to each other (and thus have an effect on the amount of magnetic flux change experienced which, in turn, effects the amount of electric current generated). In this embodiment, there are multiple first members 410 and the spring element 408 extends to both longitudinal ends of the housing 402. The use of multiple first members 410 allows for additional fine tuning (via the solenoids and cylinders/collars) in order to maximize the use of the vibrational input to the power generator unit 400.

[00091] FIGS. 15A and B illustrate, respectively, exploded and cross-sectional views of a power generator unit 500, similar to the power generator units 200, 300, 400, having a number of first members 510 and a single second member 518 arranged to move relative to one another, in accordance with another embodiment of the invention. The first members 510 define a longitudinal axis A and each includes a magnetic component having a first magnet arrays 520 and a second magnet array 530 on an opposite side of the first member 510 from the first magnet array 520. Each magnet array 520, 530 comprises a number of individual magnets 532, as seen in the exploded view of the first member 510 in FIG. 15C. Each first member 510 also includes a yoke 454 similar in structure and/or function to the yokes described above. The first and second members 510, 518 are disposed within a housing 502. The second member 518 is inserted through a gap 504 in each of the first

members 510, in a manner similar to that described above with respect to other illustrations of power generator units.

[00092] A pair of spacers 506 is used to secure the ends of the second member 518 within the housing 502 (each spacer 506 has a gap 516 through which an end portion of the second member 518 at least partially passes). The second member 518 is "stationary" relative to the first members 510 in that the second member 518 is connected to and stationary relative to the housing 502 and/or other object (not shown) to which the power generator unit 500 is affixed and does not move relative to that housing 502 or object. The housing 502 is a two-piece housing comprising two sub-housings 502a, 502b. The second member 518 includes an electrical component 524 that may come in various forms including, but not limited to, at least one electrical coil, which is stationary relative to the one or more magnetic components (i.e., the magnet arrays 520, 530) that move with the first members 510 such that an interaction between the one or more electrical and magnetic components (524, 520, 530) generates an electrical current in the electrical component 524. A spring element 508 moveably couples the first members 510 to a carrier 522 of the second member 518 to define a spring-mass system such that when the housing 502 is subjected to external motion M, the spring element 508 causes the first members 518 to reciprocatingly move relative to the "stationary" carrier 522 of second member 518 and thereby generate an electrical current in the coil(s) of the electrical component 524 due to the electromagnetic interaction.

[00093] The spring element 508 comprises two sets of a series of mechanical coil springs 512; each series of springs 512 being fixed to the housing 502 (via the spacer 506) on both longitudinal ends. Adjacent springs 514 of each set 512 are connected either to each other by their connection to a first member 510. Each spring set 512 (comprising a series of individual springs 514) can be viewed as a single spring having a particular spring constant. However, as each individual spring 514 has its own spring constant, the spring constant of the spring set is determined by the cumulative spring constants of the "active" springs 514 in the spring set 512.. When the spring constant changes, this changes the rate at which the first and second members 510, 518 will reciprocatingly move relative to each other (and thus have an effect on the amount of magnetic flux change experienced which, in turn, effects the amount of electric current generated). In this embodiment, there are multiple first members 510 and the spring element 508 extends to both longitudinal ends of the housing 502. The use of multiple first members 510 allows for additional fine tuning (via the solenoids and

cylinders/collars) in order to maximize the use of the vibrational input to the power generator unit 500. In this case, the several first members 510 (or "masses") are hung in a chaining arrangement, the key being that a spring element is present connecting from mass to mass. Additional spring elements could have been placed to the housing 502 from each first member 510 but the inherent properties are similar. In this example, the central first member 10 is suspended by the action of the springs above and below. As the unit 500 is exposed to external vibrations, the uppermost and lowermost first members 510 (i.e., "masses") will begin to oscillate predominantly at the natural frequency associated with the springs linked to the housing, and a lesser extent to the central mass. The central first member 510 (or "central mass") however responds to the forces imparted by the internal springs connected to the other masses and as such derives it's natural frequency from that internal spring system. The net affect of this arrangement is that by selection the masses and springs, the system can be made to respond to a multitude of input vibrations, thus widened the response bandwidth. All masses may or may not exhibit large amplitude motions however throughout the frequency range (e.g., one or more masses may be moving violently at one frequency, while the other(s) may seem to be relatively stationary, and the reverse situation could be evident at other frequencies). For the generator 500, electromagnetic elements are the masses and this type of system could be designed such a way to ensure that at least one of the elements would be generating power over a large range of input frequencies.

[00094] FIGS. 16A-D are various exploded and cross-sectional views of a buoy 600 within which is disposed, for purposes of illustration only, the power generator unit 500 of FIGS. 15A-C.. The power generator unit 500 is connected to the ceiling of an interior compartment 602 of the buoy 600 by a gimbal 604. The gimbal 604 allows the power generator unit 500 to freely hang, swing and otherwise move inside the compartment 602 (FIG. 1C illustrates that the gimbal 604 allows the unit 500 to maintain a generally vertical position even as the buoy 600 itself is tilted at an angle due to wave motion or the like). The linear generator unit 500 installed in the floating body (i.e., the buoy 600) where the uppermost portion of the housing 502 is attached through a flexible element 604 (i.e., gimbaled). This is done so as to allow the housing 502 to swing freely as the floating shell of the buoy 600 (i.e., the hull) is tossed and tilted by the action of the waves. The advantage of this gimbaled addition over the rigid fixing of the generator housing is to better allow the heaving (up – down) action of the buoy 600 to be transmitted to the internal masses (i.e., the first members 510) in the generator 500. As

the floating shell of the buoy 600 tilts as the wave builds and recedes, under it, the generator 500 stays roughly vertical. The generator 500 thus "sees" the vertical heave of the wave with little sideward pull to the internal masses. If, on the other hand, the generator 500 is affixed to the shell of the buoy 600 rigidly, the tilting action of the shell forces the internal generator bearing system to resist the sideward swing, and even though the bearing system can be made to be very robust and smooth, elimination of this side movement is preferred. As for any bearing system, the lesser the normal forces, the lesser the frictional forces will be. Secondly, as the buoy 600 tilts, there exists a whipping action at the upper extremities of the buoy 600 (and generator 500), like swinging a baseball bat. If the suspended mass of the generator 500 experiences this whipping at the same time as an upward heave, it effectively reduces the benefit of the heave motion, thus reducing the available power output of the generator 500.

[00095] The tuning process for resonant coupling of external motion to a power generator unit for a predetermined frequency range starts with a basic geometry that define physical, electrical and magnetic parameters of one or more spring-mass systems. Some or all parameters of such systems that impact Faraday's law in terms of basic geometry, material, physical, mechanical, electrical and magnetic are selected and adjusted to optimize power generation for a given package size, etc. Once this process is exhausted, optimum power can be derived from the power generator unit when it is subjected to the predetermined frequency range of external motion. The optimum generated power varies for different styles of generators within a given volumetric package size, mainly due to their inherent geometric configurations. For any geometry, optimizing power by adjusting one property may cause non-optimized performance due to another property. One aspect of the present invention involves inputting into a computerized processing system a predetermined frequency range to which a power generator unit will be exposed, as well as the properties of each component of one or more spring-mass systems, including any physical, mechanical, material electrical, and/or magnetic properties of the components, to determine which components can be selected and adjusted to optimize power generation by resonant coupling relative to the predetermined frequency range of motion.

[00096] Using the current invention, a variety of electronic devices can be powered or charged by the captured energy of unintended or passive motion. For instance, small electronic devices, such as mobile phones, personal data assistants, and portable music

players, can be powered or charged by the motion of the user if the devices are coupled to the present invention. In addition, the device may be coupled to other moving objects, such as handbags, brief cases, and cars, thereby resulting in movement of the generator. Moreover, a user may shake the device, intended motion, to quickly generate electricity.

[00097] The current invention may also be used to generate power for electronics which are known to undergo repetitive motion, for example the sensors or transducers of ocean buoys. Because of the remote location of ocean buoys, it is desirable that they have an independent power supply that can be maintained for long periods of time. The present invention would allow an ocean buoy to charge its battery or power its electronics through electricity captured from short and long period ocean swells.

[00098] The following claims are thus to be understood to include what is specifically illustrated and described above, what is conceptually equivalent, what can be obviously substituted and also what essentially incorporates the essential idea of the invention. Those skilled in the art will appreciate that various adaptations and modifications of the just-described preferred embodiment can be configured without departing from the scope of the invention. The illustrated embodiment has been set forth only for the purposes of example and that should not be taken as limiting the invention. Therefore, it is to be understood that, within the scope of the appended claims, the invention may be practiced other than as specifically described herein..

WHAT IS CLAIMED IS:

1. A power generator unit configured to be subjected to an external motion having a predetermined frequency range, comprising:

a first member comprising an magnetic component;

a second member comprising an electrical component movable relative to the magnetic component, whereby an electromagnetic interaction between the electrical and magnetic components generates an electrical current in the electrical component; and

a spring element coupled to at least one of the first and second members to define a spring-mass system configured to reciprocatively move the electrical and magnetic components relative to each other in response to the external motion, wherein one or more properties of the first member, the second member, and the spring element is selected and adjusted based on the predetermined frequency range of the motion to maximize the relative movement between the electrical component and the magnetic component.

2. The power generator unit of claim 1, further comprising a fluid bearing containing ferromagnetic particles, the fluid bearing being arranged to facilitate the movement of the electric and magnetic components relative to each other.

3. The power generator unit of claim 1, wherein the external motion comprises a plurality of external motions each having a predetermined frequency range, and wherein the spring element comprises a plurality of spring elements that define a plurality of spring-mass systems configured to reciprocatively move the electrical and magnetic components relative to each other.

4. The power generator unit of claim 1, wherein the first member comprises a first surface and a second surface, the first surface being spaced apart from and opposed to the second surface to define a gap.

5. The power generator unit of claim 4, wherein said magnetic component comprises a first array of magnets disposed on the first surface and a second array of

magnets disposed on the second surface.

6. The power generator unit of claim 5, wherein each magnet in each of the first and second arrays of magnets has a magnetic polarity opposite to that of an immediately adjacent magnet in the same array.

7. The power generator unit of claim 6, wherein each magnet in the first array of magnets is opposed to a corresponding magnet in the second array of magnets, said correspondingly opposing magnets having opposite polarities facing each other through the gap, whereby the magnetic flux generated by the magnetic component is substantially perpendicular to the movement axis.

8. The power generator unit of claim 5, further comprising:

a first magnetic yoke comprising material with high magnetic permeability and disposed to cover and magnetically link the first array of magnets; and

a second magnetic yoke comprising material with high magnetic permeability and disposed to cover and magnetically link the second array of magnets.

9. The power generator unit of claim 8, wherein the first and second magnetic yokes comprise mu metal.

10. The power generator unit of claim 5, wherein the second member is disposed in the gap in proximity to an end of each magnet in the first and second arrays, and wherein the electrical component comprises a coil.

11. The power generator unit of claim 10, wherein the coil comprises a plurality of coils.

12. The power generator unit of claim 10, wherein the coil comprises a plurality of nano-ferrite particles arranged in a desired orientation.

13. The power generator unit of claim 1, wherein the spring element comprises a coiled wire.

14. The power generator unit of claim 1, wherein the spring element comprises a rebound magnet.

15. The power generator unit of claim 1, wherein one of the first and second members defines a longitudinal axis, and wherein the reciprocative movement of the electrical and magnetic components relative to each other is along the longitudinal axis.

16. The power generator unit of claim 1, wherein one of the first and second members defines a central axis, and wherein the reciprocative movement of the electrical and magnetic components relative to each other is about the axis.

17. The power generator unit of claim 1, wherein the electrical current comprises a charge current for charging one or more batteries.

18. The power generator unit of claim 1, wherein the spring element comprises a linear or non-linear spring element.

19. A method for generating power with a power generator unit, the power generator unit comprising a first member comprising a magnetic component, a second member comprising an electrical component coupled to the magnetic component, and a spring element coupled to at least one of the first and second members to define a spring-mass system, the method comprising:

subjecting the power generator unit to an external motion having a predetermined frequency range;

reciprocatively moving the electrical and magnetic components relative to each other in response to the external motion;

generating an electrical current in the electrical component;

selecting one or more properties of the first member, the second member, and the spring element based on the predetermined frequency range of the motion; and

adjusting the one or more selected properties to maximize the relative movement between the electrical component and the magnetic component.

20. The method for generating power of claim 18, wherein the external motion comprises a plurality of external motions each having a predetermined frequency range, and wherein the spring element comprises a plurality of spring elements that define a plurality of spring-mass systems configured to reciprocatively move the electrical and magnetic components relative to each other, the method further comprising.

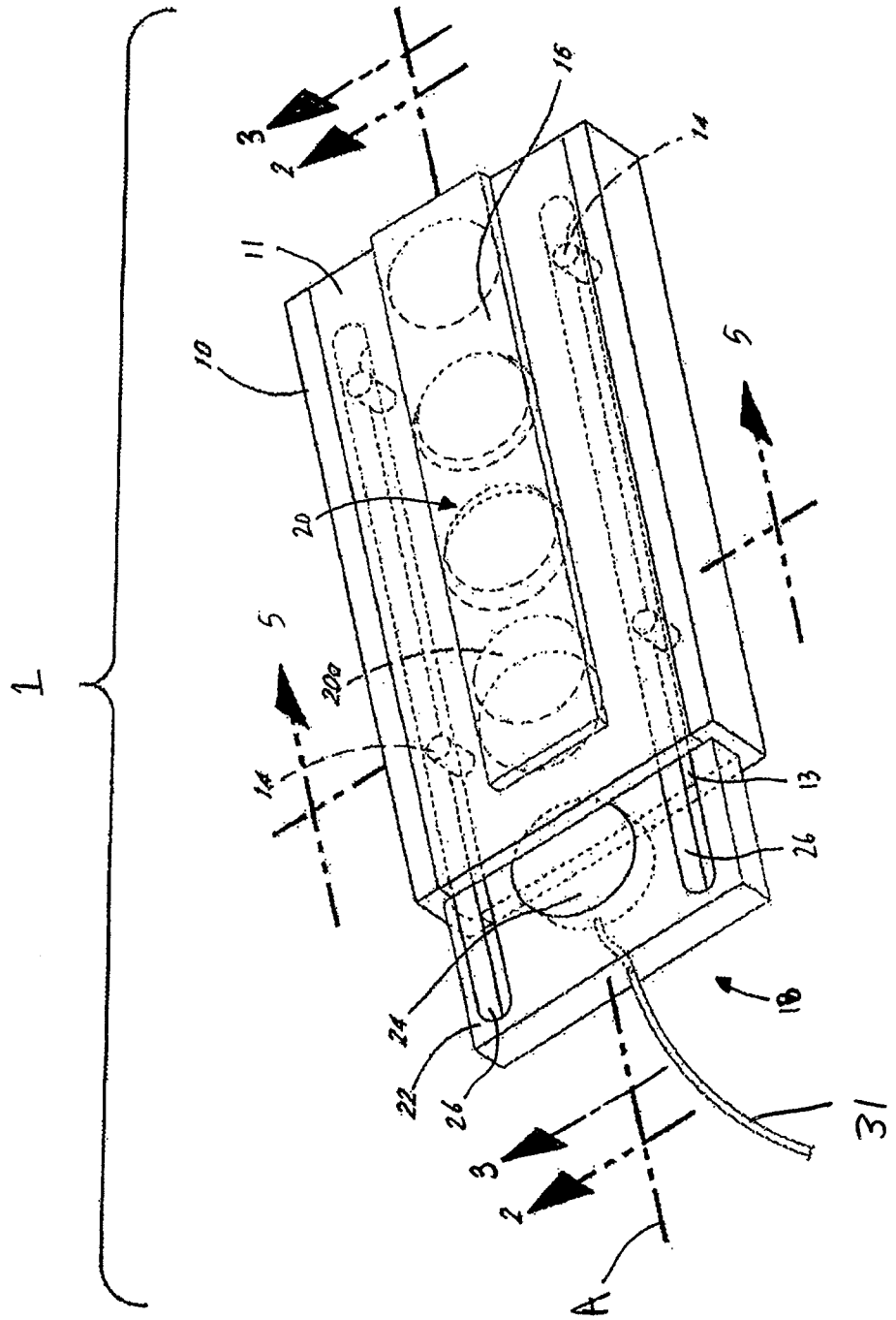


FIG. 1

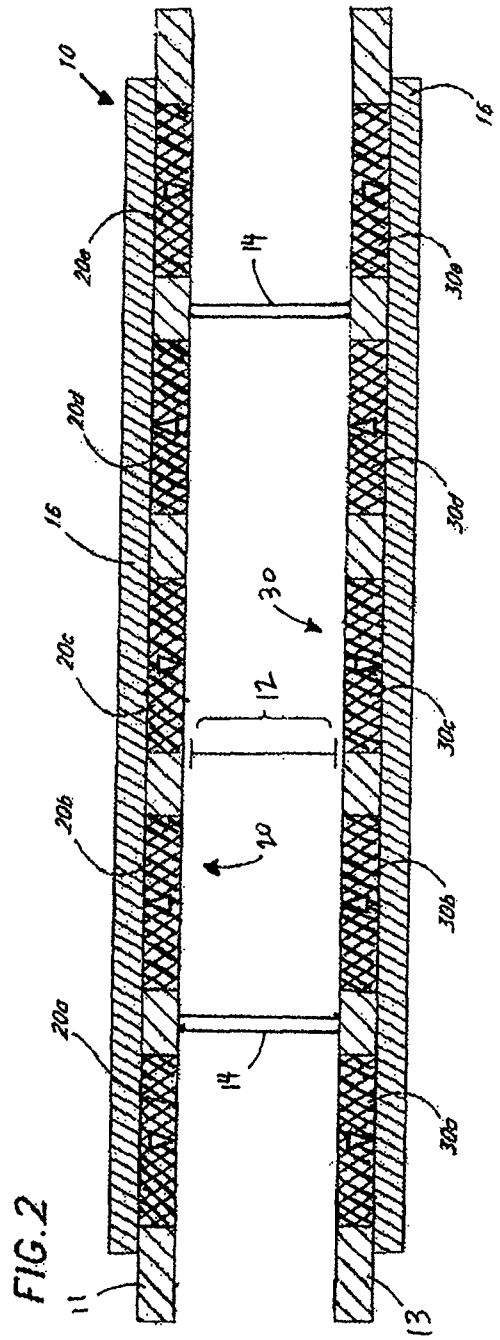

10
16
20a
14
30a
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16
30
20c
12
30c
20b
40
30b
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30a
11
13

FIG. 2

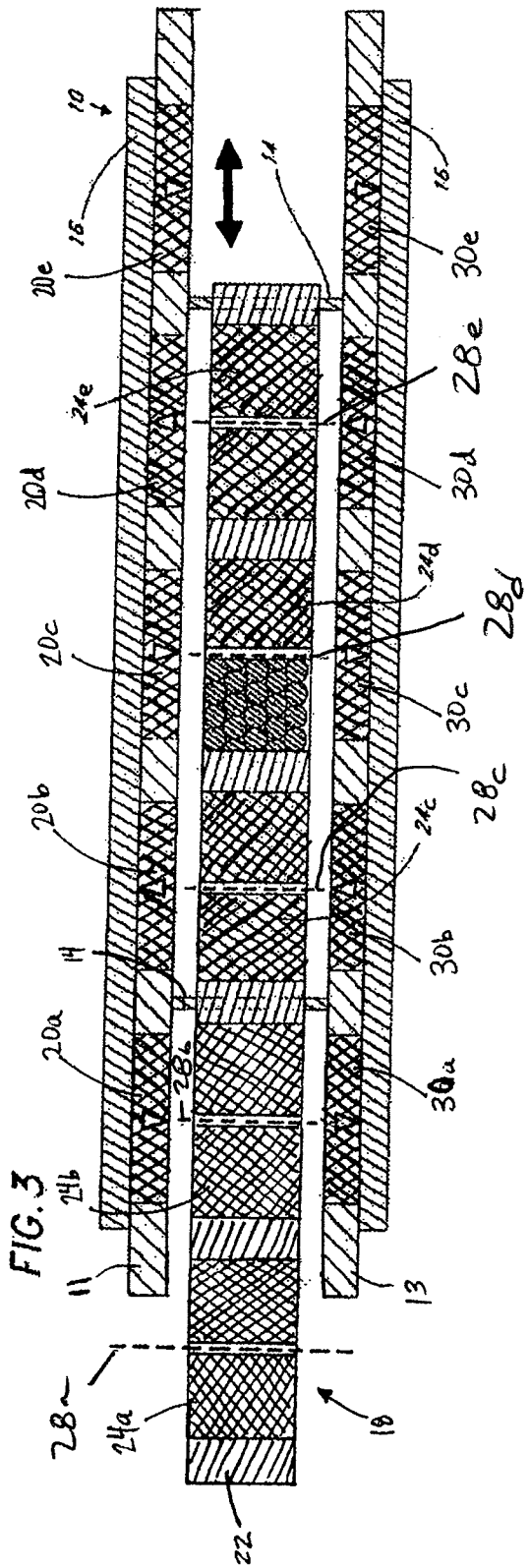

10
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20e
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24d
28d
20c
30c
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28a
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13
28
24a
18
22

FIG. 3

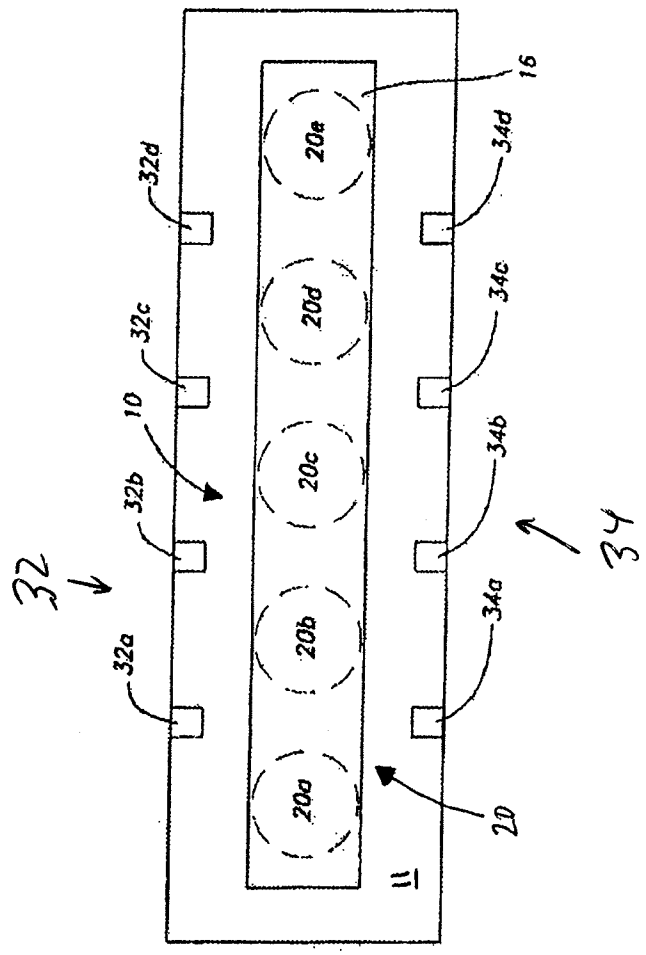


FIG.4

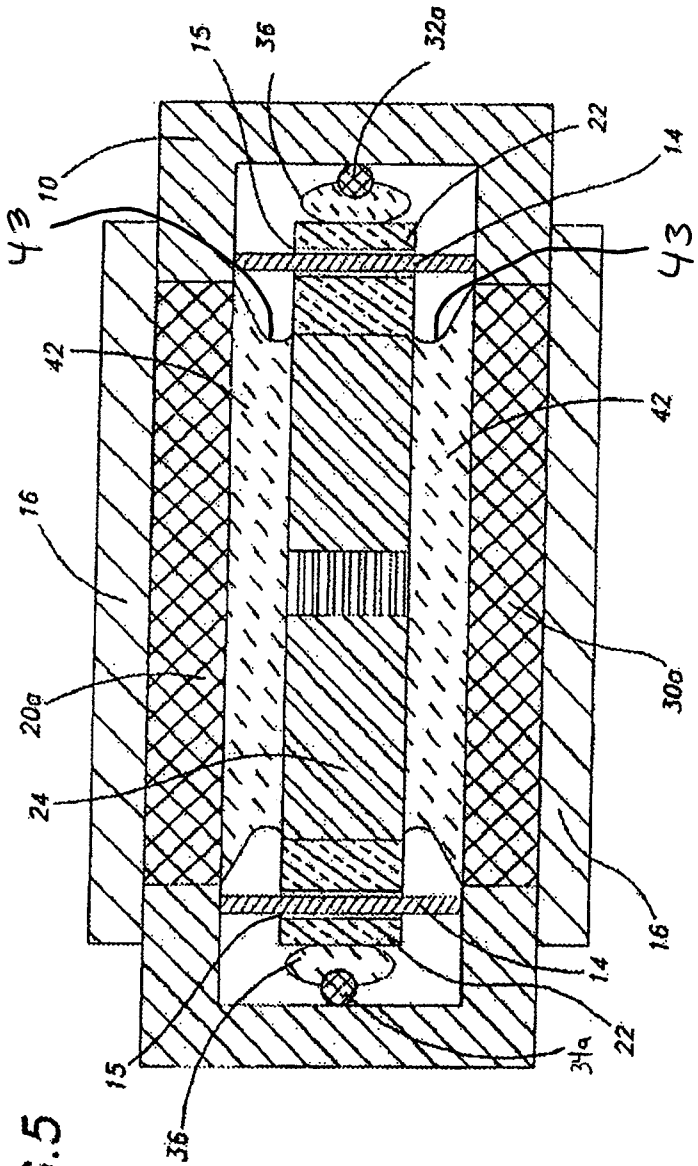


FIG.5

FIG. 6

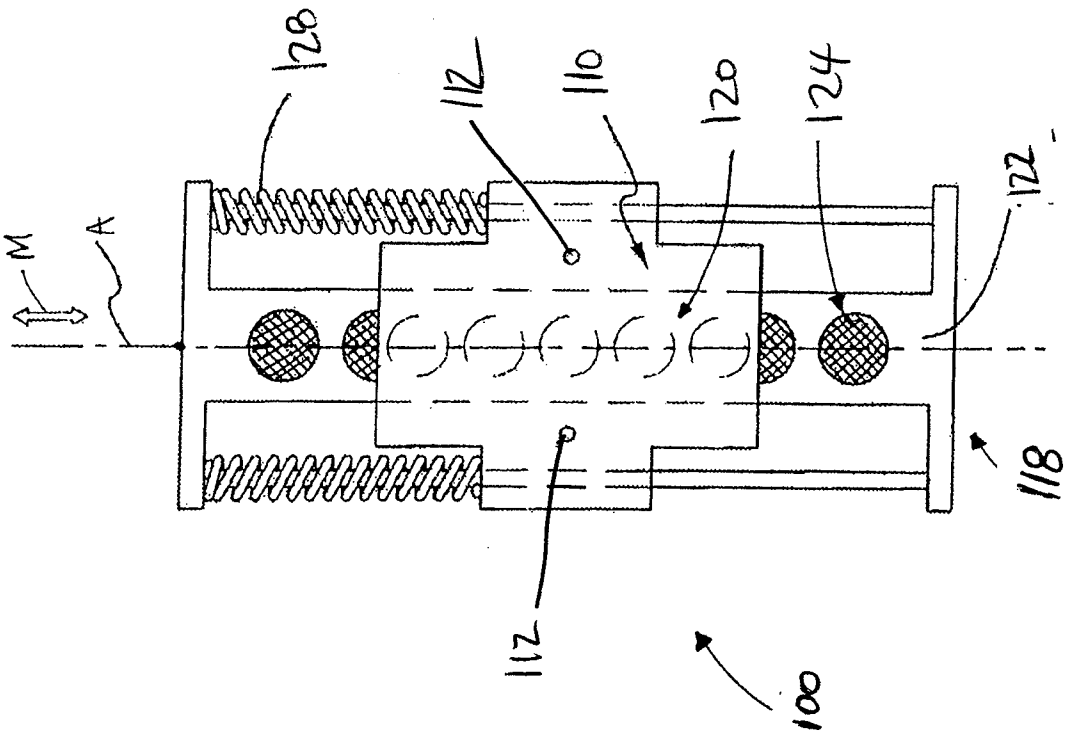
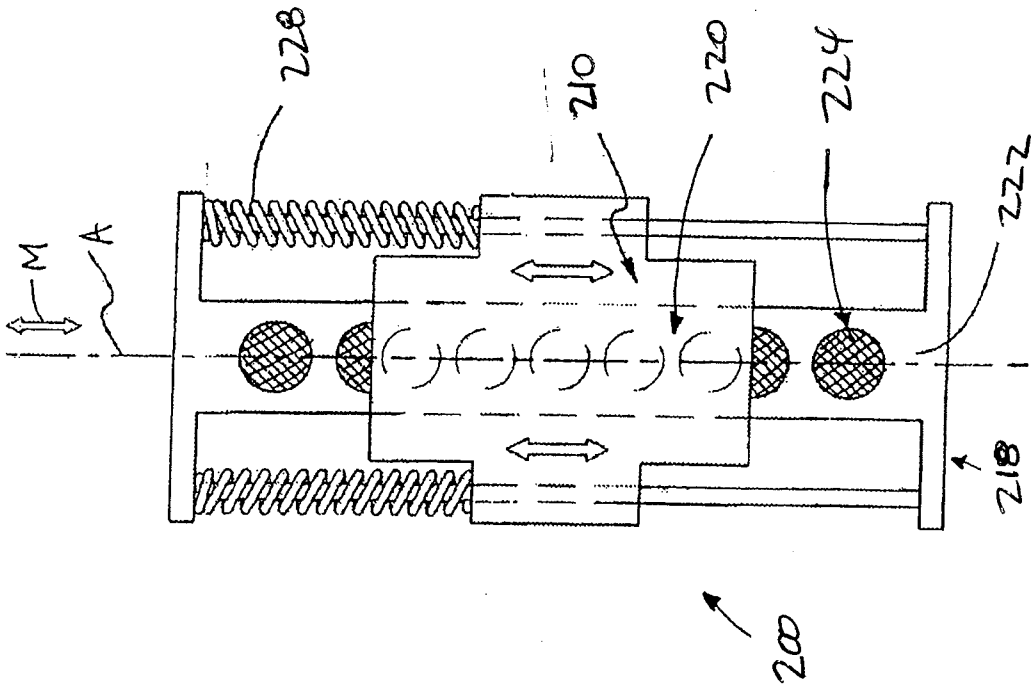


FIG. 7



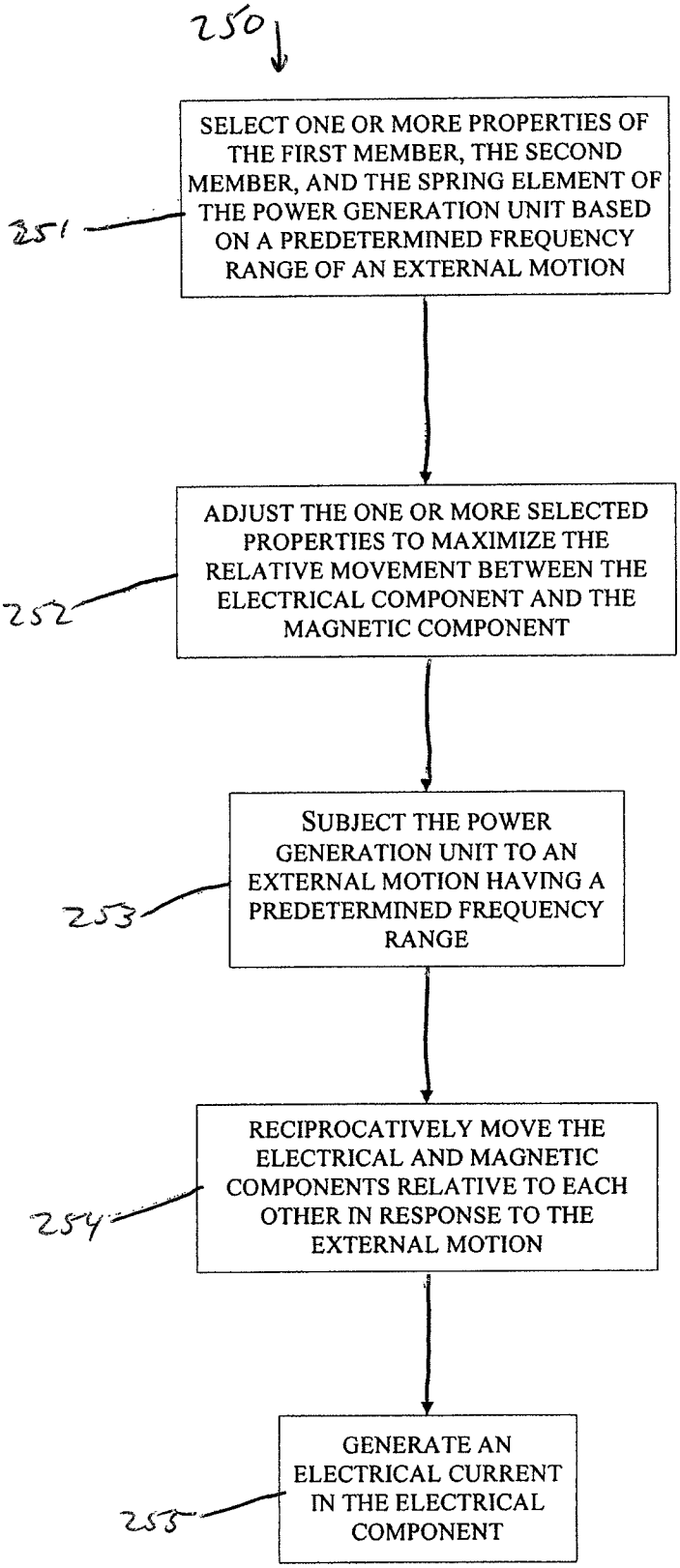

250
SELECT ONE OR MORE PROPERTIES OF THE FIRST MEMBER, THE SECOND MEMBER, AND THE SPRING ELEMENT OF THE POWER GENERATION UNIT BASED ON A PREDETERMINED FREQUENCY RANGE OF AN EXTERNAL MOTION
251
ADJUST THE ONE OR MORE SELECTED PROPERTIES TO MAXIMIZE THE RELATIVE MOVEMENT BETWEEN THE ELECTRICAL COMPONENT AND THE MAGNETIC COMPONENT
252
SUBJECT THE POWER GENERATION UNIT TO AN EXTERNAL MOTION HAVING A PREDETERMINED FREQUENCY RANGE
253
RECIPROCATIVELY MOVE THE ELECTRICAL AND MAGNETIC COMPONENTS RELATIVE TO EACH OTHER IN RESPONSE TO THE EXTERNAL MOTION
254
GENERATE AN ELECTRICAL CURRENT IN THE ELECTRICAL COMPONENT
255

FIG. 8

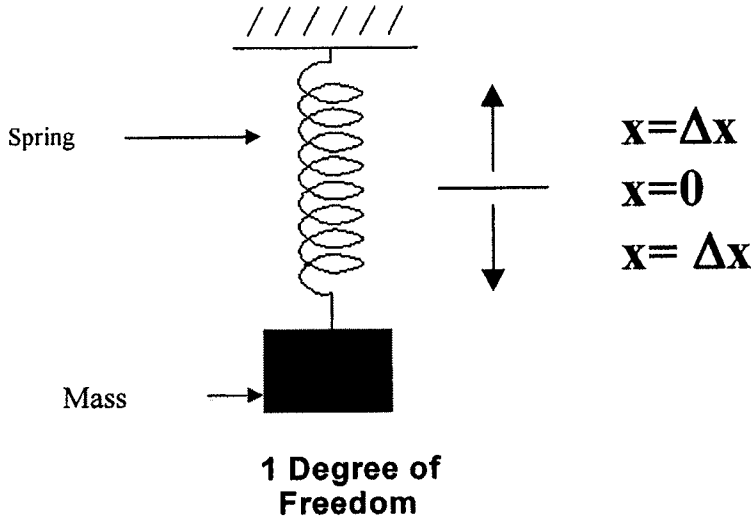

Spring
Mass
x=Δx
x=0
x= Δx
1 Degree of Freedom

FIG. 9

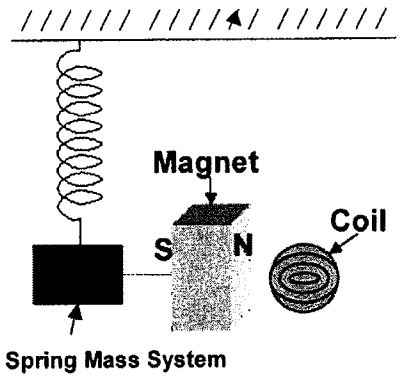

Magnet
S
N
Coil
Spring Mass System

FIG. 10

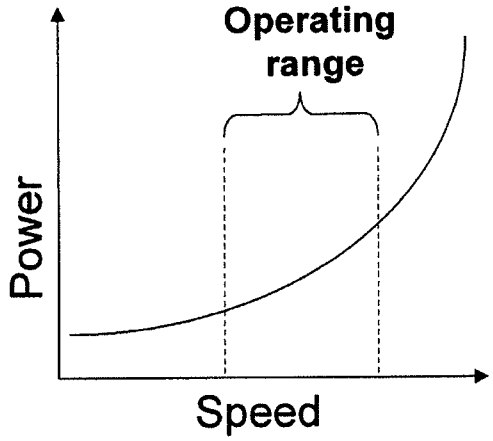

Operating range
Power
Speed

FIG. 11

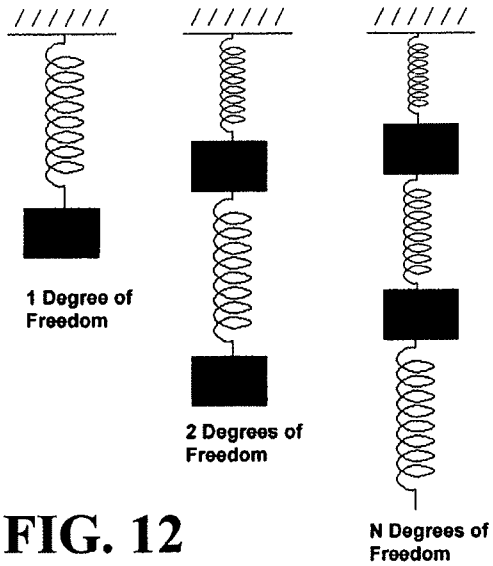

1 Degree of Freedom
2 Degrees of Freedom
N Degrees of Freedom

FIG. 12

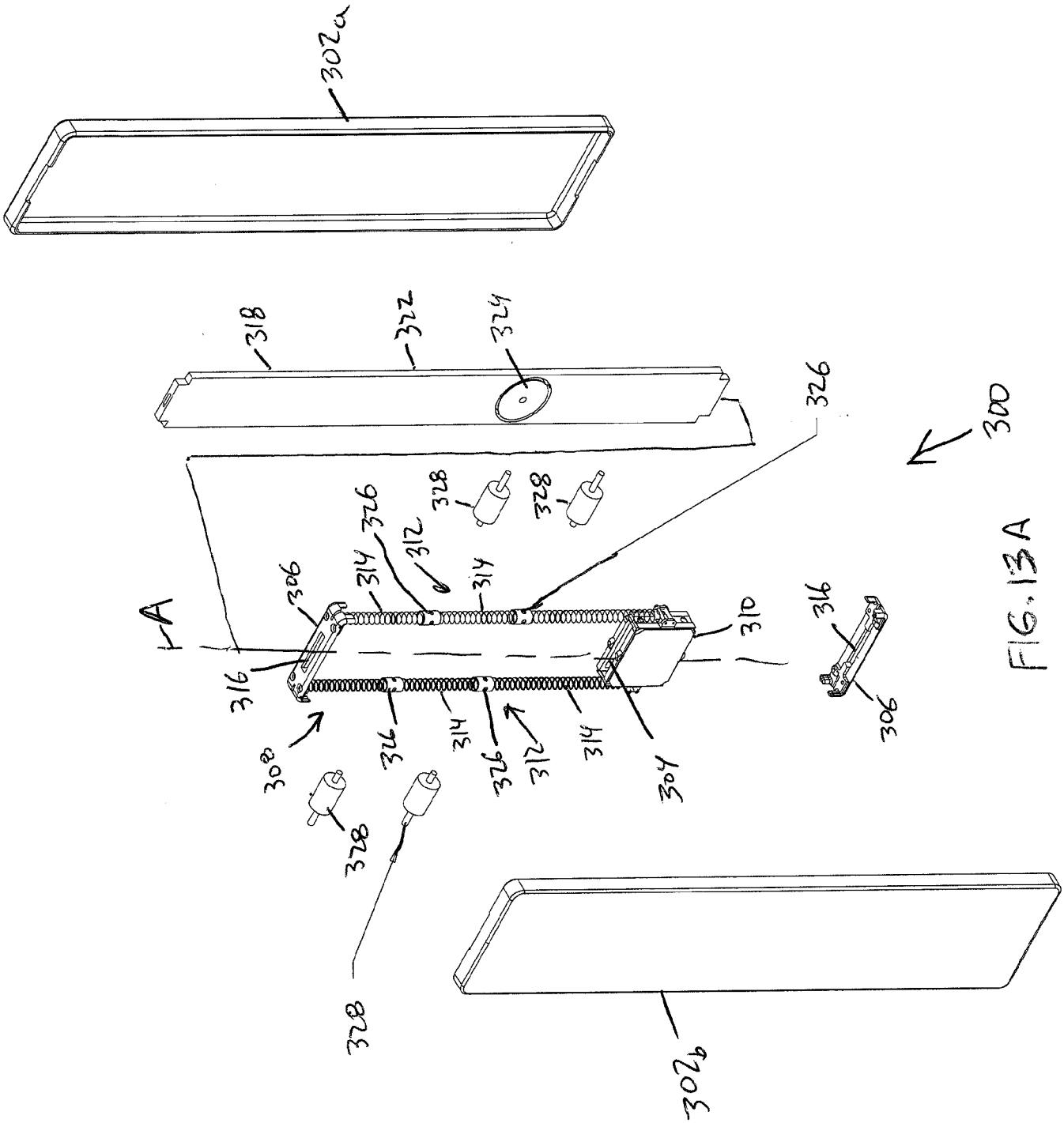

302a
318
322
324
326
300
328
328
326
312
314
314
306
316
310
316
306
A
308
326
314
326
312
314
304
328
328
302b

FIG. 13A

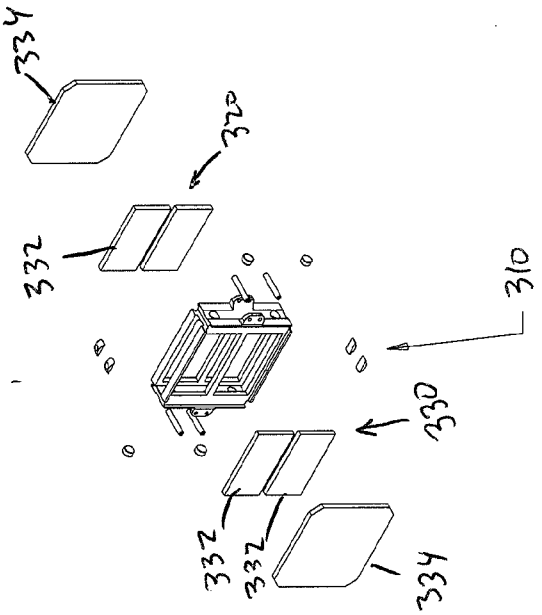


FIG. 13C

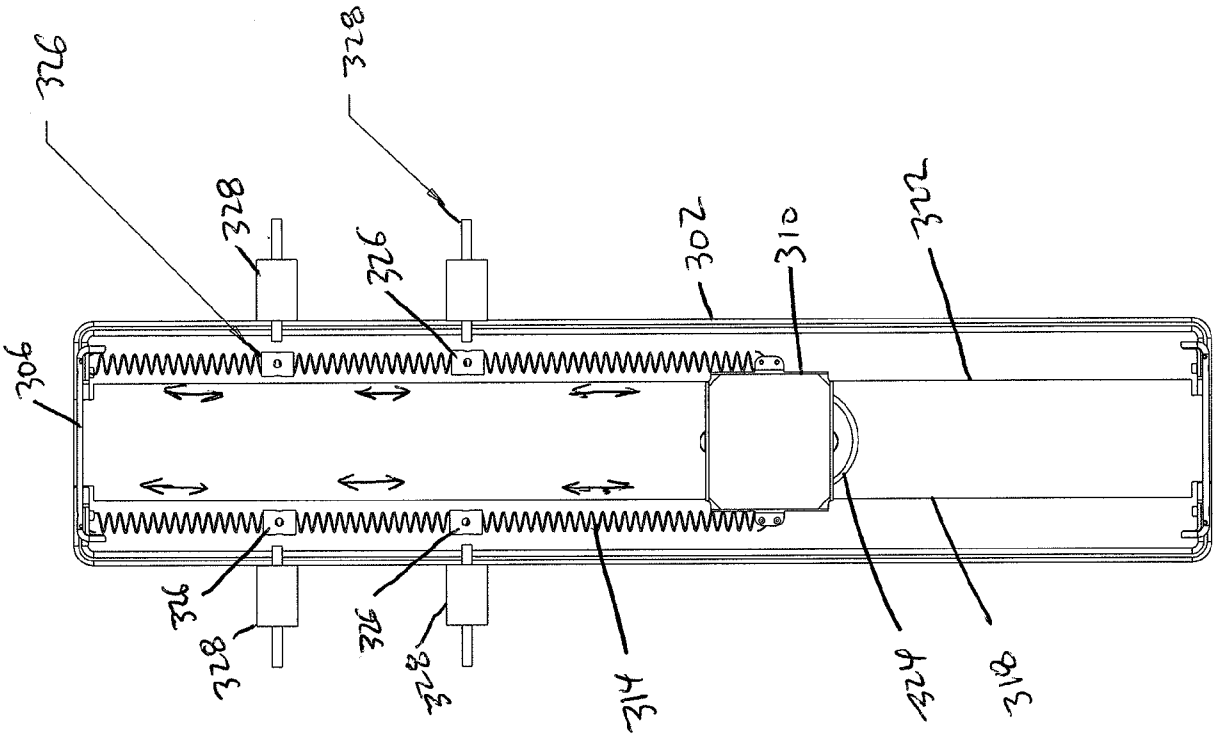


FIG. 13B

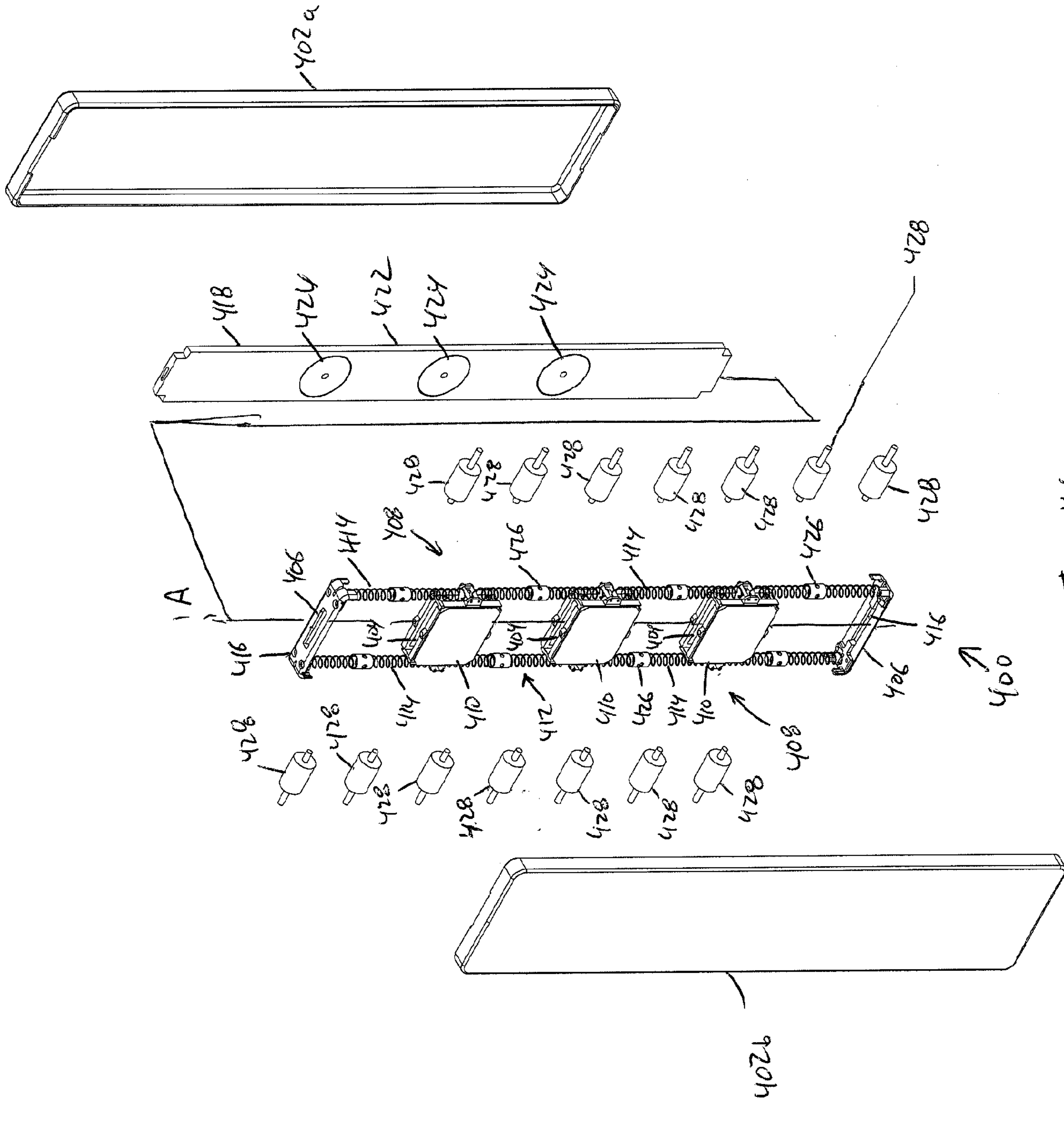

402a
418
424
422
424
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428
A
406
414
408
426
414
426
416
404
410
412
400
402b

FIG. 14A

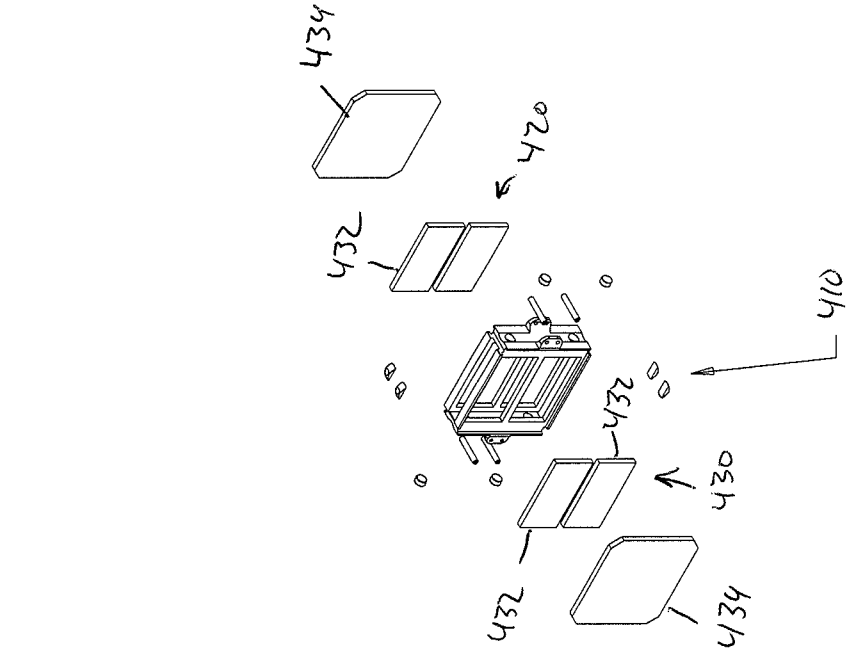


FIG. 14C

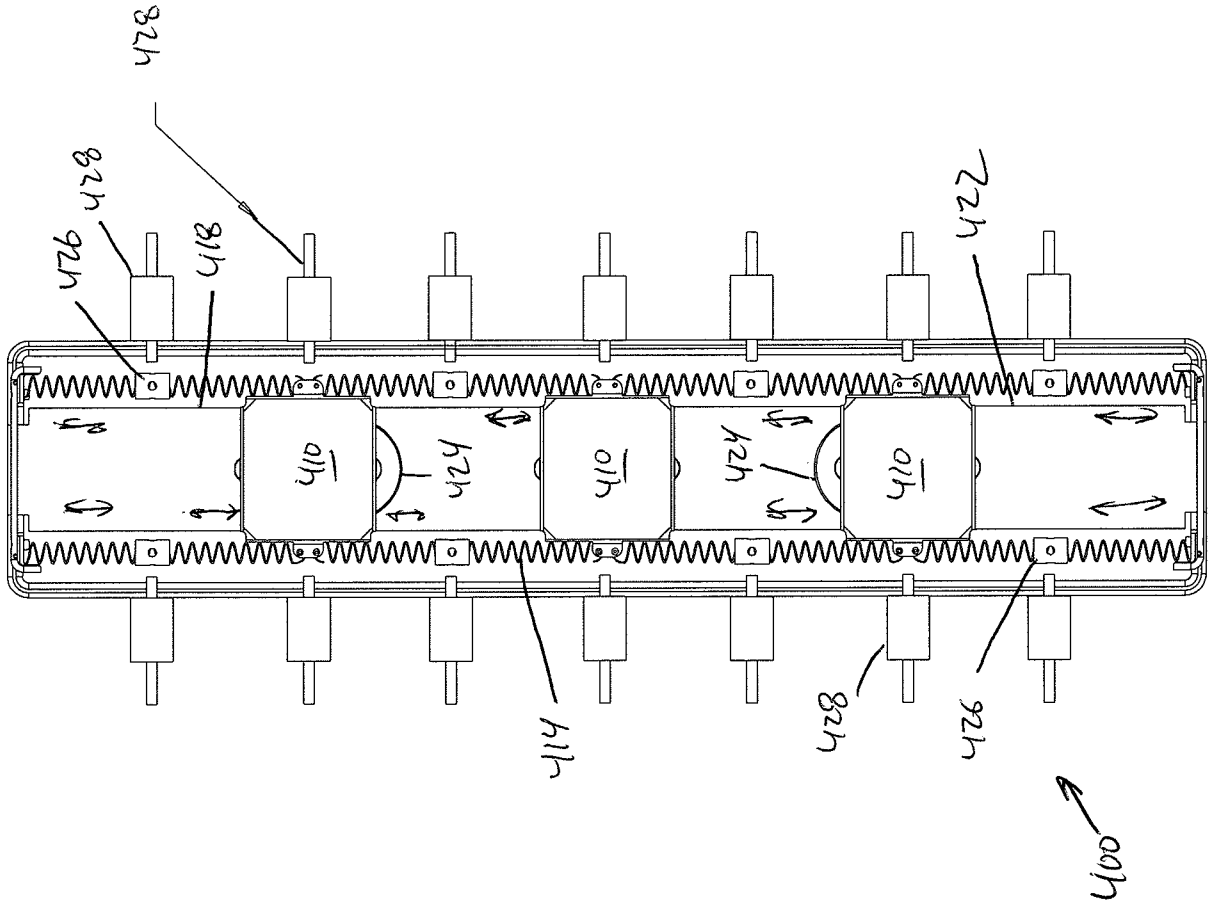


FIG. 14B

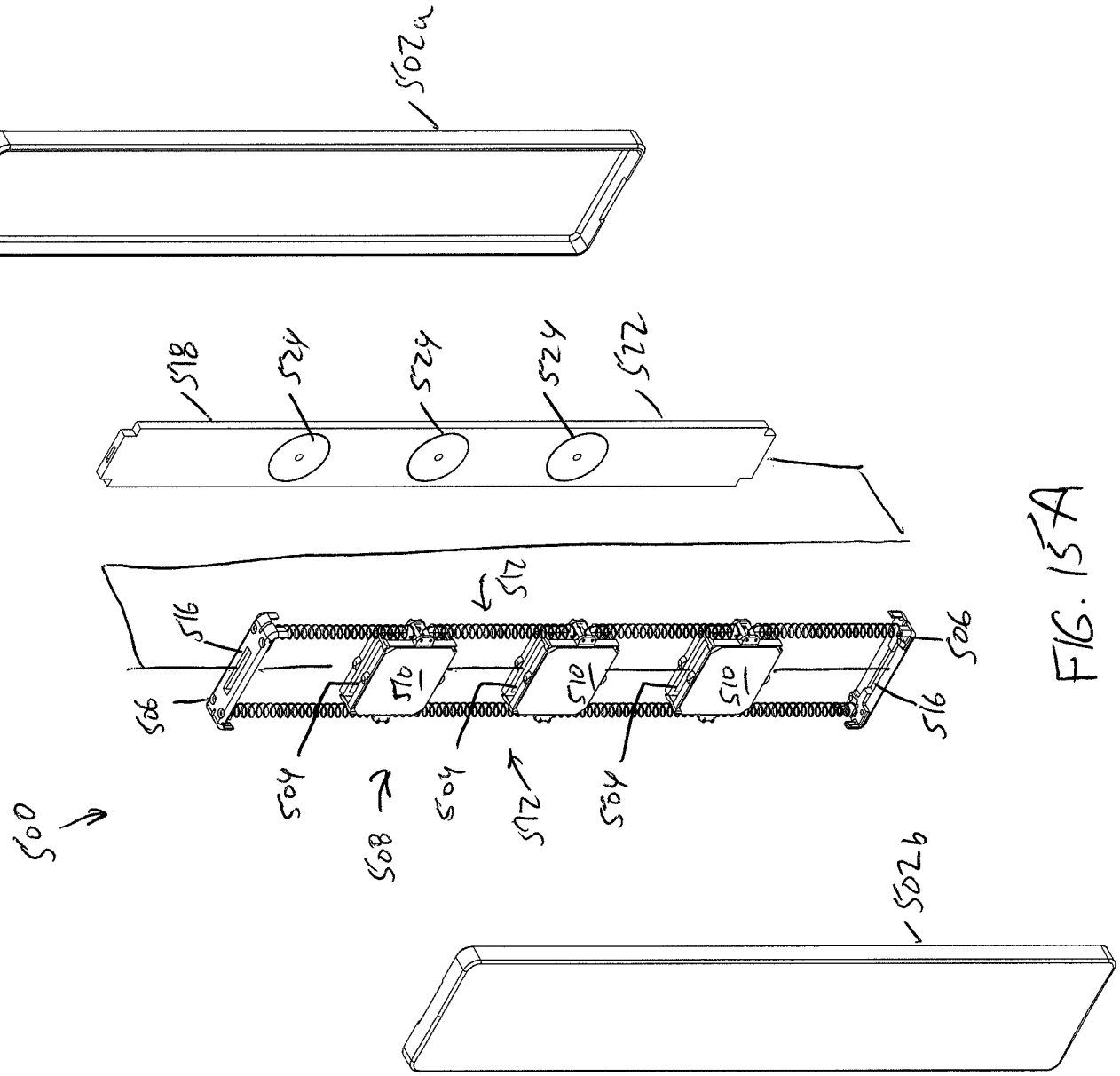


FIG. 15A

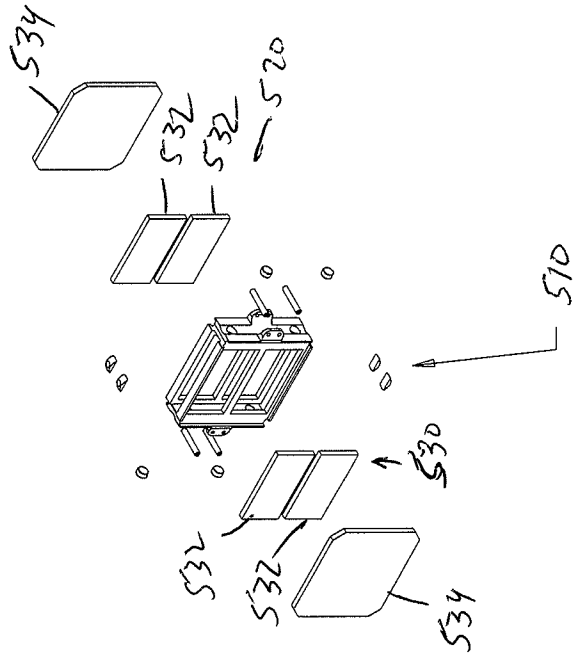


FIG. 15C

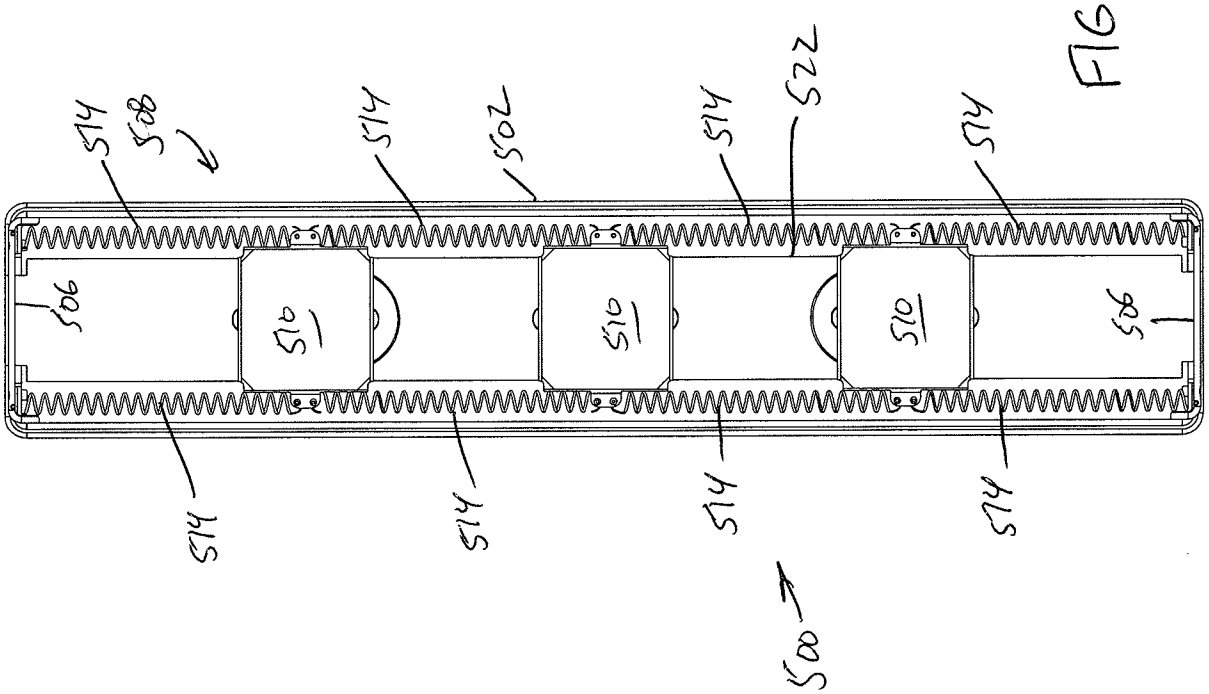


FIG. 15B

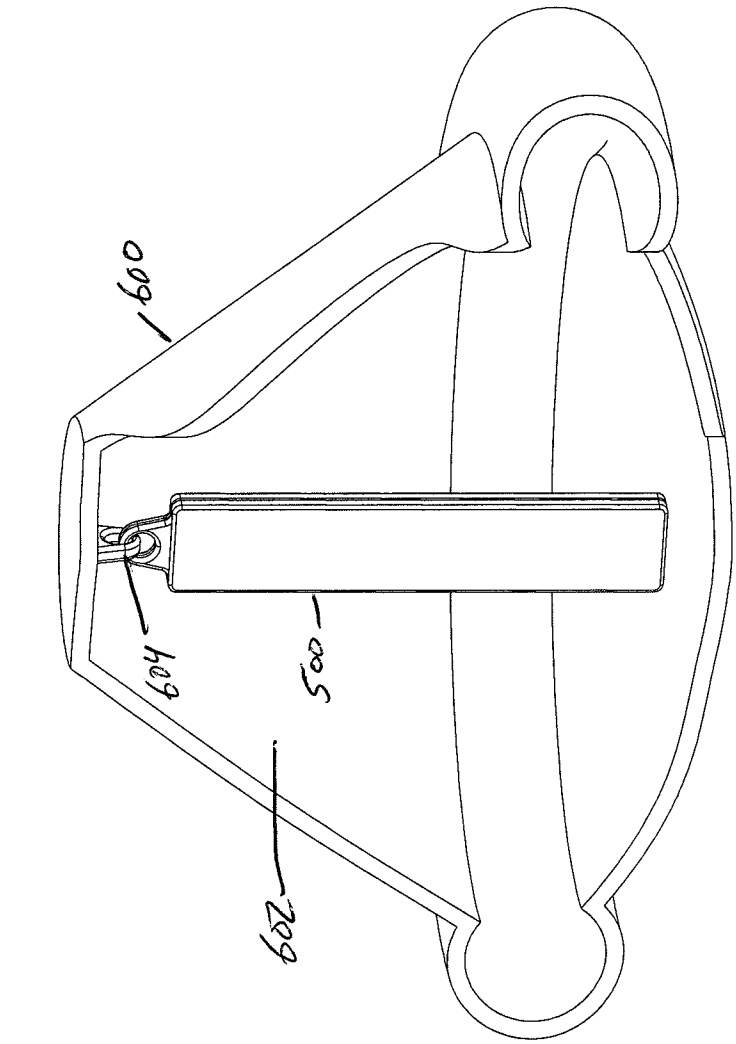


FIG. 16B

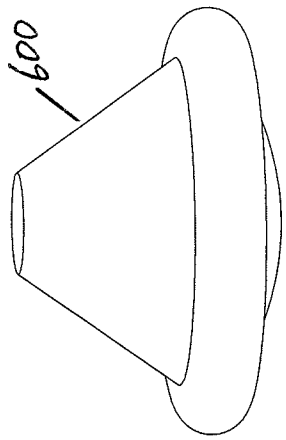


FIG. 16A

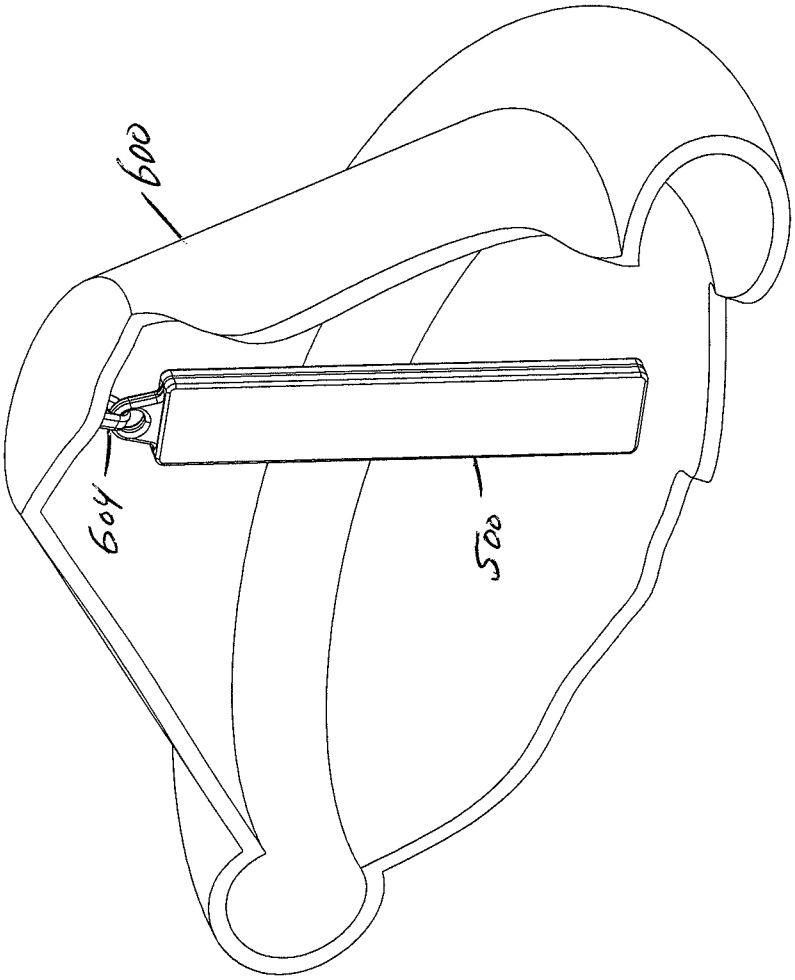


FIG. 16C

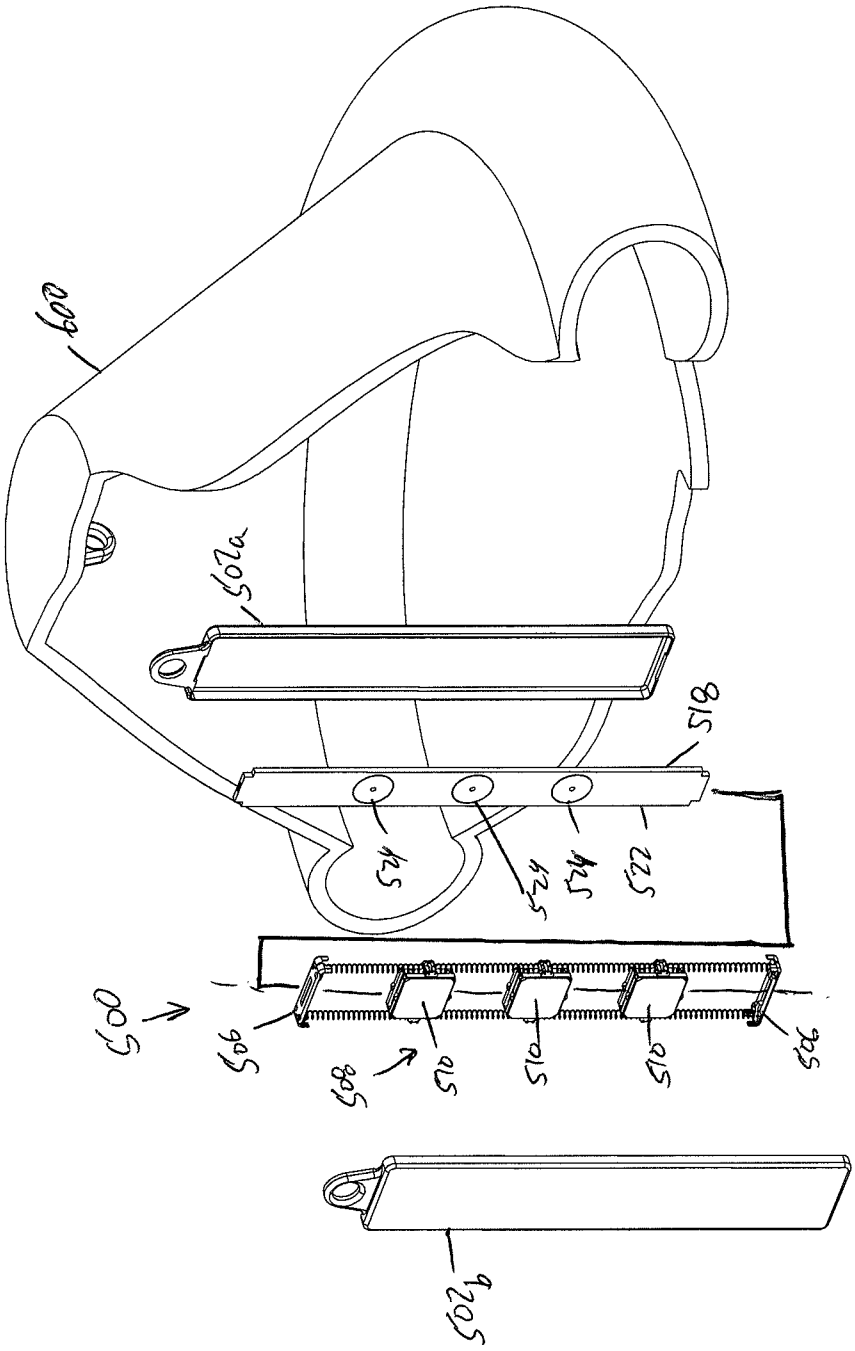


FIG. 16D