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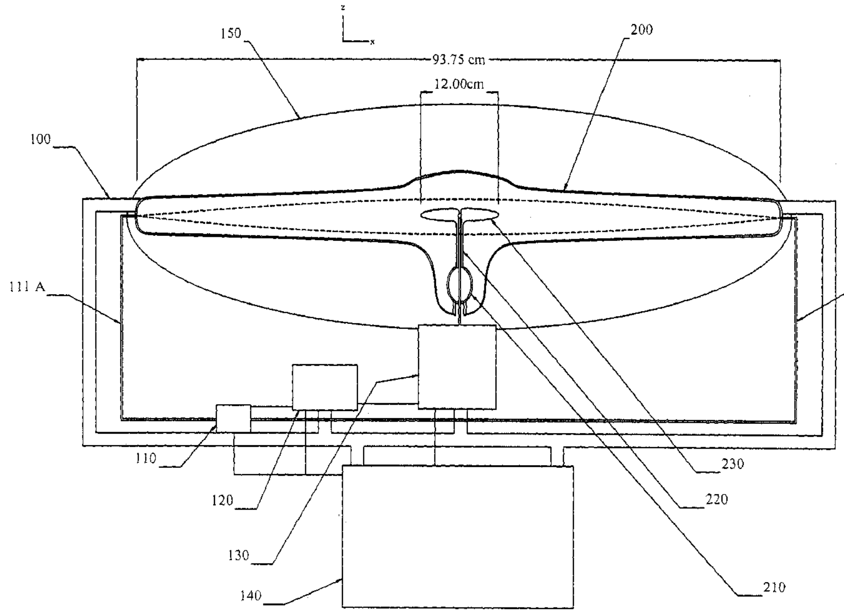

(57) Abstract: A propulsion system for producing a linear and/or a rotational force used to propel a vehicle or other body or to serve in other applications requiring such a force. The system generates thrust by creating specific interactions between resonating electromagnetic waves and devices carrying a surplus of electric charges, and/or devices carrying electric currents. This system allows for propellant-free propulsion in spaced-based and other applications.

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RESONATING CAVITY PROPULSION SYSTEM

RELATED APPLICATION

[0001] This application claims the benefit of priority to U.S. Provisional Application Serial Number 60/715,419, filed September 12, 2005, the contents of which are incorporated by reference herein.

FIELD OF THE INVENTION

[0002] The present invention concerns space-based propulsion systems and methods. In particular, these systems and methods use interactions between a thruster and the standing electromagnetic wave of a resonating cavity to achieve thrust.

BACKGROUND OF THE INVENTION

[0003] One issue facing space exploration programs is the development of an efficient, low mass propulsion system. The necessity of including reaction mass, as well as the mass on the engine itself, in traditional propulsion systems imposes practical limits to the range and lifetime of these propulsion systems. A number of approaches to this problem have been explored. One example of such a system is the Emdrive system.

[0004] The Emdrive system is a space propulsion system that uses the differences in radiation pressure exerted on two ends of a resonating cavity to generate thrust and, thus avoids the issue of reaction mass. The Emdrive is a resonating bottle full of microwaves. In the case of the prototype Emdrive, the closed resonating cavity is wider at one end than the other. Mathematical analysis by the designers of the Emdrive indicates that the group velocity of the resonating microwave may be higher at the wide end than the narrow end and that consequently, there may be a net excess force exerted on the wide end. Furthermore, the net excess force exerted is proportional to the Q of the Emdrive resonator, or the effectiveness that the cavity shows as a resonator. Thus, the Emdrive appears capable of developing thrust without the use of reaction mass.

[0005] Exemplary embodiments of the present invention may also be used to generate thrust without the use of reaction mass or ejected EM energy to create thrust, but does so in a manner distinct from the method of the Emdrive.

SUMMARY OF THE INVENTION

[0006] An exemplary embodiment of the present invention is a resonant cavity propulsion system, including: a resonant cavity including a conductive inner surface; a thruster including a first conductive end and a second conductive end coupled by an electrically conductive coupling member; an electrically insulating coupling member to mechanically couple the second conductive end of the thruster to the conductive inner surface of the resonant cavity; and a frequency generator electrically coupled to the resonant cavity. The resonant cavity is adapted to support a standing electromagnetic (EM) wave with an oscillating electric field vector pointing in a direction substantially normal to a transverse plane of the cavity. The frequency generator is used to generate the standing EM wave in the resonant cavity. The electrically insulating coupling member mechanically couples the second conductive end of the thruster to the conductive inner surface of the resonant cavity such that: the first conductive end of the thruster is substantially centered at an antinode of the lowest energy mode of the standing EM wave in the transverse plane; and the second conductive end of the thruster is substantially outside of the standing EM wave. EM interactions between the standing EM wave and the thruster produce a force in the direction substantially normal to the transverse plane.

[0007] Another exemplary embodiment of the present invention is a resonant cavity propulsion system, including: a resonant cavity including a conductive inner surface; a thruster including a conductive end and an electrically conductive coupling member; and a frequency generator electrically coupled to the resonant cavity. The resonant cavity is adapted to support a standing EM wave with an oscillating electric field vector pointing in a direction substantially normal to a transverse plane of the cavity. The frequency generator is used to generate the standing EM wave in the resonant cavity. The electrically conductive coupling member of the thruster is coupled between the conductive inner surface of the resonant cavity and the conductive end of the thruster such that the conductive end of the thruster is substantially centered at an antinode of the lowest energy mode of the standing EM wave in the transverse plane. EM interactions between the standing EM wave and the thruster produce a force in the direction substantially normal to the transverse plane.

[0008] A further exemplary embodiment of the present invention is a method of generating a unidirectional force using a resonant cavity. A standing EM wave that has an oscillating electric field vector pointing in a direction substantially normal to a transverse plane is generated in the resonant cavity. A thruster is arranged within the resonant cavity such that: a first conductive end of the thruster is substantially centered at an antinode of the lowest energy mode of the standing EM wave in the transverse plane; and a second conductive end of the thruster is substantially outside of the standing EM wave. The standing EM wave interacts with conduction charges within the thruster to produce the unidirectional force in the direction substantially normal to the transverse plane.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The invention is best understood from the following detailed description when read in connection with the accompanying drawings. It is emphasized that, according to common practice, the various features of the drawings are not to scale. On the contrary, the dimensions of the various features are arbitrarily expanded or reduced for clarity. Included in the drawing are the following figures:

[0010] Fig. 1 is a cross-sectional side-view schematic drawing illustrating an exemplary propulsion system according to the present invention;

[0011] Fig. 2 is a cross-sectional top-view schematic drawing illustrating the resonating cavity section of the exemplary propulsion system of the Fig. 1;

[0012] Fig. 3 is a cross-sectional side-view schematic drawing illustrating the Thruster Device and Cooling Unit of an exemplary embodiment of the present invention;

[0013] Fig. 4 is a flow chart illustrating an exemplary method of operation of the present invention;

[0014] Fig. 5 is a graph illustrating a propagating electromagnetic wave interacting with an electron;

[0015] Fig. 6 is a graph illustrating the magnetic and electric fields of a resonating electromagnetic wave;

[0016] Figs. 7A and 7B are cross-sectional side-view schematic drawings illustrating the standing wave electric field in an exemplary resonating cavity section according to the present invention;

[0017] Fig. 8 is a cross-sectional top-view schematic drawing illustrating the exemplary resonating cavity of Figs. 7A and 7B;

[0018] Figs. 9A and 9B are top-view schematic drawings illustrating exemplary magnetic field lines inside the exemplary resonating cavity of Figs. 7A, 7B, and 8;

[0019] Fig. 10 is a side-view schematic drawing illustrating two exemplary configurations of a section of the Thruster Device of the exemplary embodiment of Figs. 7A, 7B, and 8;

[0020] Fig. 11 is a side-view schematic drawing illustrating an alternate exemplary configuration for the Thruster Device of the exemplary embodiment of Figs. 7A, 7B, and 8;

[0021] Fig. 12A is a top-view schematic drawing illustrating the magnetic field vectors of exemplary electromagnetic waves near a section of the resonating cavity wall of the embodiment of Figs. 7A, 7B, and 8;

[0022] Fig. 12B is a side-view schematic drawing illustrating a section of the resonating cavity wall and exemplary electric current flow directions on the illustrated wall section of the exemplary embodiment of Figs. 7A, 7B, and 8;

[0023] Figs. 13A, 13B, 13C, and 13D are side-view schematic drawings illustrating for exemplary positions of an electron on an exemplary Thruster Device of Figs. 7A, 7B, and 8;

[0024] Fig. 14 is a schematic drawing illustrating an exemplary Thruster Device and extracavity source of power;

[0025] Figs. 15A and 15B are side-view schematic drawings illustrating alternative exemplary Thruster Devices that may be reconfigured;

[0026] Fig. 16 is a side-view schematic drawing illustrating an alternative exemplary Thruster Device configuration that may be moved with respect to a standing EM wave inside an exemplary resonating cavity;

[0027] Fig. 17 is a side-view schematic drawing illustrating an alternative exemplary Thruster Device configuration that uses the resonating cavity as the second conductive end of the Thruster Device;

[0028] Fig. 18 is a side-view schematic drawing illustrating an exemplary resonating cavity mounted in a three-axis gimbal;

[0029] Fig. 19 is a top-view schematic drawing illustrating an exemplary propulsion system according to the present invention including three resonating cavities mounted on a housing;

[0030] Fig. 20 is a cross-sectional top-view schematic drawing illustrating an exemplary resonating cavity that may operate in a third harmonic mode;

[0031] Fig. 21 is a sectional side-view schematic drawing illustrating the exemplary resonating cavity of Fig. 20.

Reference Numerals in Drawings

100	Housing
110	EM Wave Generator
111a	Coax Cable A
111b	Coax Cable B
120	Control Unit
130	Cooling Unit
131	Lance
140	Power Source
150	Cooling Shroud
200	Resonating Cavity
201	Non-Conducting Support
210	Capacitor B
220	Connecting Wire
230	Capacitor Disk A
231	Plug A
400	Configuration Of Resonating Cavity
401	Configuration Of Thruster Device
402	Powering Of EM Wave And Thruster Device
403	Powering Of EM Wave
404	Powering Of Thruster Device
405	Unidirectional Thrust Generated
406	Unidirectional Thrust Modulated

501	Electric Field
502	Magnetic Field
503	Electron
601	Electric Field
602	Magnetic Field
603	Point A
604	Point B
700	Resonating Cavity
701	Capacitor Sphere A
702	Capacitor Sphere B
703	Connecting Wire
704	Non-Conducting Support
705	EM Wave Generator
706	EM Wave Generator
707	Electric Field
708	Magnetic Field
709	Alternate Capacitor Disk
710	AC Current Path
711	AC Current Direction
712	Point C
713	AC Current Path
714	Spring A
715	Spring B
716	Electron
810	Resonating Cavity
811	Thruster Device
812	Piston
820	Resonating Cavity
821	Thruster Device
822	Outside Power Source
823	Opening
850	Resonating Cavity
851	Capacitor Disk
852	Connecting Wire
860	Capacitor Disk
861	Connecting Wire
862	Capacitor B
863	Connector
864	Control Unit
871	Resonating Cavity
872	Resonating Cavity
873	Resonating Cavity
874	Housing
880	Resonating Cavity
881	Gimbal
900	Resonating Cavity
901	Thruster Device A
902	Thruster Device B
903	Thruster Device C
904	Thruster Device D
905	Thruster Device E
906	Non-Conducting Support A
907	Non-Conducting Support C
908	Non-Conducting Support E

DETAILED DESCRIPTION OF THE INVENTION

I Overview of system operation

[0032] Figs. 7A, 7Bb, and 8 represent one exemplary embodiment of the present invention. A basic overview of system operation is described below.

[0033] Exemplary Resonating Cavity 700 is depicted in Figs. 7A, 7B, and 8.

[0034] A fundamental, or first harmonic, resonating electromagnetic (EM) wave (i.e. a standing EM wave) may be generated within Resonating Cavity 700. Dashed lines 707 of Figs. 7A and 7B represent the electric field maxima for the electric field of the standing EM wave.

[0035] Capacitor Sphere A 701, Capacitor Sphere B 702, and Connecting Wire 703 form a Thruster Device. The Thruster Device is composed of electrically conductive materials. The Thruster Device is desirably mounted on electrically Non-Conducting Support 704. Non-Conducting Support 704 is connected to Resonating Cavity 700.

[0036] As the electric field of the EM wave, Electric Field Vector 707, moves from a zero value to a maximum value (as depicted in Fig. 7A), free electrons (and/or Cooper pairs) are driven off of Capacitor Sphere A 701, through Conducting Wire 703 and onto Capacitor Sphere B 702. Desirably, during the majority of the half cycle when Electric Field Vector 707 of the EM wave points in the positive z-direction, Capacitor Sphere A 701 has a net positive electric charge and, thus, experiences a force in the positive z-direction as a result of being immersed in Electric Field Vector 707 of the standing EM wave.

[0037] As the amplitude of Electric Field Vector 707 of the EM waves passes again through a zero value and moves to a maximum value in the negative z-direction (as depicted in Fig. 7B), free electrons are driven off of Capacitor Sphere B 702, through Connecting Wire 703 and onto Capacitor Sphere A 701. Capacitor Sphere A 701 now has a net negative electric charge and is immersed in Electric Field Vector 707 of the EM wave which again results in a force on Capacitor Sphere A 701 in the positive z-direction.

[0038] The forces on Capacitor Sphere A 701 in the positive z direction are not balanced by an equal and opposite force on any or all of the other components of the propulsion system. Because Capacitor Sphere B 702 is located substantially outside of the area of the standing EM wave, it experiences little or no force from Electric Field Vector 707 of the standing EM wave. Capacitor Sphere A 701 experiences an unbalanced force that is transferred through the entire Thruster Device, then through Non-Conducting Support 704 and to Resonating Cavity 700 and any body attached to Resonating Cavity 700. Therefore, this system generates unidirectional thrust. This unidirectional thrust is a thrust that is generated without the use of reaction mass or ejected EM energy to balance momentum increase in the exemplary propulsion system.

The inventor is uncertain how the unidirectional thrust generated by exemplary embodiments of the present invention comports with conservation of momentum.

II Definitions used throughout the application:

[0039] Resonating Cavity: Any body capable of reflecting an electromagnetic wave for one or more reflections of the electromagnetic wave.

[0040] Unidirectional thrust: Thrust that is generated without the use of reaction mass or ejected EM energy to balance momentum increases in the propulsion system.

[0041] Thruster Device: A device that includes in some part of electrically conductive components with some part of said device being located within an area immersed within the electric and/or magnetic fields of a resonating electromagnetic wave of a resonating cavity. The Thruster Device may be partially or totally enclosed within the resonating cavity that contains the standing EM wave. In Figs. 7A, 7B, and 8, Capacitor Sphere A 701, Capacitor Sphere B 702, and Connecting Wire 703 form the Thruster Device.

[0042] First conductive end of the Thruster Device: The section of a Thruster Device that is immersed in the electric and/or magnetic fields of the standing EM wave. Capacitor Sphere A 701 of Figs. 7A, 7B, and 8 is the first conductive end of the Thruster Device.

[0043] Second conductive end of the Thruster Device: The section of a Thruster Device that is substantially outside of the electric and/or magnetic fields of the standing EM wave. Capacitor Sphere B 702 of Figs. 7A, 7B, and 8 is the second conductive end of the Thruster Device.

[0044] Substantially in phase: The phase angle between two oscillating entities is less than 45 degrees.

[0045] Substantially out of phase: The phase angle between two oscillating entities is more than 45 degrees and equal to or less than 90 degrees.

III Standard Electromagnetic Wave Momentum Transfer

[0046] Momentum transfer in standard electromagnetic interactions with charged particles is well known in the art. Electromagnetic (EM) energy interacts with electric charges and imparts momentum to those electrically charged particles. The momentum of an EM wave may be expressed as:

$$\rho = \frac{E}{c}, \qquad \text{Equation (1)}$$

where: ρ = wave momentum in kgm/s, E = wave energy in J, c = speed of light in m/s.

[0047] When a propagating EM wave reflects off of, passes through, or is absorbed by matter, it imparts momentum to the matter according to standard conservation of momentum equations. Radiation pressure exerted upon a reflective surface illustrates this principal.

[0048] A solar sail exploits radiation pressure by reflecting solar EM energy to create thrust. A laser engine is a conceptual engine that uses laser energy emitted from a propulsion system to drive the propulsion system in a direction opposite to the emitted laser energy.

[0049] Fig. 5 depicts a propagating EM wave interacting with a free electron.

[0050] In Fig. 5, the EM wave is propagating in the positive x direction. As the portion of Electric Field 501 of the EM wave that points in the minus z direction passes over Electron 503, the electron is forced in the positive z direction. The motion of Electron 503 caused by the interaction of the electron with Electric Field 501 of the EM wave creates a small electric current in the negative z direction that interacts with Magnetic Field 502 of the propagating EM wave. As Electron 503 is forced in the positive z direction creating an electric current in the negative z direction, the portion of Magnetic Field 502 of the EM wave that points in the positive y direction creates a force on Electron 502 in the positive x direction.

[0051] When the portion of the EM wave that has an electric field pointing in the positive z direction passes over Electron 503, the electron is forced in the negative z direction, creating an electric current in the positive z direction. The magnetic field of the EM wave pointing in the negative y direction interacts with this electric current and again forces the electron in the positive x direction.

[0052] Momentum is conserved in the interactions described above. The EM wave decreases in energy because of the work performed on the electron. The energy decrease of the EM wave also corresponds to a decrease in the momentum of the EM wave according to Equation (1). The momentum decrease in the EM wave is balanced by a momentum increase in the electron. The momentum of an EM wave is always imparted to electrically charged particles along an axis parallel to the axis of propagation and in the same direction as the direction of propagation of the EM wave.

[0053] To perform work on the electron, photons of the propagating EM wave is:

a) absorbed by the electron (corresponding to a higher kinetic energy of the electron, a heating in anything attached to the electron, or some other manifestation of the photon energy in the electron or any matter attached to the electron); and

b) reemitted from the oscillating electron with a slightly longer wavelength (corresponding to a decrease in photon energy).

[0054] Propagating EM wave momentum transfer involves two mechanisms:

a) an EM wave electric field to create movement of an electrically charged particle located within the area of the EM wave electric field.

b) An EM wave magnetic field to interact with the electric current created by the interaction of the electric field and the electrically charged particle.

IV Thrust generation and momentum in the present invention

[0055] The present propulsion system generates thrust using EM wave energy to generate propulsion. The exemplary system requires no propellant and no emitted EM energy to generate an unbalanced momentum increase of the propulsion system. The present propulsion system generates Unidirectional Thrust.

[0056] The present propulsion system uses the electric and magnetic field energy of standing EM waves to create an unbalanced force. Resonating EM waves are standing EM waves that exhibit a number of differences from propagating EM waves. These differences may be used to create Unidirectional Thrust.

[0057] Exemplary embodiments of the present invention utilize at least three different mechanisms to generate unidirectional thrust in an exemplary propulsion system. These exemplary propulsion systems may use one, two, or all of these three mechanisms to produce unidirectional thrusting.

a) Electric Charge Propulsion: This propulsion mechanism uses the electric field of the standing EM wave to exert a force on surplus of electric charges located on the end of a Thruster Device that is located within a portion of the resonant cavity with a high amplitude of the electric field of the standing EM wave.

b) Electric Current Propulsion: This propulsion mechanism uses the magnetic field of the standing EM wave to exert a force on an electric current located in a Thruster Device that is located within a portion of the resonant cavity with a high amplitude of the magnetic field of the standing EM wave.

c) Lorentz Force Propulsion: This propulsion mechanism creates unidirectional thrust by generating an imbalance in the Lorentz forces exerted on two ends of a Thruster Device that has one end located within an area with high electric and/or magnetic field amplitudes of a standing EM wave and one end substantially outside of the standing EM wave.

<u>Electric Charge Propulsion</u>:

[0058] Fig. 6 illustrates the magnetic field 602 and electric field 601 of a standing EM wave. Unlike a propagating EM wave, the electric field and magnetic field of a standing EM wave are 90° out of phase in location and in time. Thus, when the electric field of a standing EM wave are at a maximum amplitude, the magnetic field of the standing EM wave has zero amplitude at all points along the wave; and when the magnetic field of a standing EM wave is at a maximum amplitude, the electric field of the resonating wave has zero amplitude at all points on the wave. (It is noted that Fig.

6 shows both the electric and magnetic fields of the resonating wave at their maximum amplitudes for illustration purposes only. These fields are never at their maximum amplitudes simultaneously.) Standing EM waves also have fixed nodes and antinodes for both the electric and magnetic fields. These nodes and antinodes do not change position. Propagating EM waves do not have fixed nodes or fixed antinodes.

[0059] Assume a small point charge is placed at Point A 603 in Fig. 6. Point A 603 is an antinode of Electric Field 601 of the standing EM wave. The charged particle is forced in the positive and negative z directions by the electric potential of the oscillating Electric Field 601 surrounding Point A 603. There is no imparting of momentum to the particle along the axis of propagation of the standing EM wave (There is no actual propagation of the standing EM wave since it is a standing wave. The two or more component waves that interfere to create the standing wave propagate along the x axis). There is no magnetic field present at Point A 603 since Point A 603 is also a node of the magnetic field of the EM wave, Magnetic Field 602. There may be no momentum transfer in the x direction to a charged particle at Point A 603 due to oscillations of the charged particle in the positive and negative z directions. Magnetic Field 602 is always zero at Point A 603 and the magnetic field effects on either side of Point A 603 (in the x direction) cancel out because the magnetic field vector on either side of Point A point in opposite directions and have equal amplitudes. Thus, there is no momentum imparted to the charged particle along the longitudinal axis (the x-axis in Fig. 6) of the standing EM wave.

[0060] The charged particle, on average over many wave periods of the standing EM wave, gains no momentum in any direction, but continues to oscillate through Point A 603 along a path parallel to the z axis.

[0061] The Electric Charge Propulsion mechanism of the present invention consists in placing electric charges in the electric field of a standing EM wave centered on an antinode of the electric field. The electric charges are on a Thruster Device so that the force that the electric field exerts on these electric charges is transferred to the Thruster Device containing the electric charges (and any body attached to the Thruster Device). The electric charges are switched in polarity at the same rate as the electric field vector of the standing EM wave switches direction. Because the electric charges are switching polarity at the same frequency as the electric field vector of the standing EM wave is switching direction, there is a unidirectional force exerted on the electric charges. This unidirectional force creates an increase in momentum (creating Unidirectional Thrust) in any body containing or attached to the electric charges.

[0062] There is no significant net momentum transfer in the x direction from the standing EM wave because of the magnetic field considerations described above. There is also no significant counterbalancing force in the z direction to balance the force exerted on the electric charges on the Thruster Device by the electric field of the standing EM wave. Typically, it is interactions with the magnetic field that imparts momentum to charged particles being acted on by the electric fields of an EM wave. However, the magnetic fields present in the exemplary standing EM wave used in exemplary embodiments of the present invention do not impart significant net momentum in the z direction to electrically charged particles moving in the z direction near the antinode of the electric field.

[0063] Figs. 7A and 7B depict a cross-sectional view of an exemplary embodiment of the present invention. This exemplary embodiment consists of a resonating cavity and a number of coupled components. Resonating Cavity 700 is electrically coupled to two EM wave generators, EM Wave Generator 705 and EM Wave Generator 706. Resonating Cavity 700 is also coupled to a Non-Conducting Support 704, which in turn is coupled to Capacitor Sphere B 702. Capacitor Sphere B 702 is an electrically conductive sphere and is electrically coupled to Capacitor Sphere A 701 by Connecting Wire 703. Capacitor Sphere A 701 is also an electrically conductive sphere. Resonating Cavity 700 is desirably symmetrical around an axis that is parallel to the z-axis, and said axis runs through the center of Capacitor Sphere A 701.

[0064] EM Wave Generators 705 and 706 generate a first harmonic standing EM wave inside Resonating Cavity 700. It is noted that EM Wave Generators 705 and 706 may represent two separate EM wave generators units or may be a single EM wave generator coupled around the circumference of Resonating Cavity 700.

[0065] The dashed lines in Figs. 7A and 7B represents the electric field maxima of Electric Field Vector 707 of the first harmonic standing EM wave created by EM Wave Generators 705 and 706 inside Resonating Cavity 700. Electric Field Vector 707 of the standing EM wave oscillates between pointing in the positive z direction as in Fig. 7A to pointing in the negative z direction as depicted in Fig. 7B. Capacitor Sphere A 701 is located approximately at the center of Resonating Cavity 700 such that Capacitor Sphere A 701 is approximately centered at the antinode of the oscillating electric field of the standing EM wave. The electric field fluctuations of Electric Field Vector 707 of the standing EM wave cause electrons (and/or Cooper pairs) to be forced off of Capacitor Sphere A 701 (as in Fig. 7A) and drawn onto Capacitor Sphere A 701 (as in Fig. 7B). These conduction electrons oscillate between Capacitor Sphere A 701 and Capacitor Sphere B 702 based on the direction of Electric Field Vector 707 of the standing EM wave. Capacitor Sphere B 702 is located substantially outside of the standing EM wave, so that the amplitude of Electric Field Vector 707 on Capacitor Sphere B 702 is significantly less than it is on Capacitor Sphere A 701. Therefore, electrons move onto and off of Capacitor Sphere B 702 primarily based on the potential caused by the standing EM wave acting through Capacitor Sphere A 701 and Connecting Wire 703.

[0066] In Fig. 7A, Electric Field Vector 707 of the standing EM wave has driven free electrons off of Capacitor Sphere A 701 and onto Capacitor Sphere B 702, leaving Capacitor Sphere A 701 with a net positive electric charge. Electric Field Vector 707 of the standing EM wave exerts a net force on this excess positive electric charge of Capacitor Sphere A 701 and Capacitor Sphere A 701 experiences a net force in the positive z direction during periods when Electric Field Vector 707 of the standing EM wave is pointing in the positive z direction.

[0067] In Fig. 7B, Electric Field Vector 707 of the standing EM wave has drawn free electrons off of Capacitor Sphere B 702 and onto Capacitor Sphere A 701 so that Capacitor Sphere A 701 has a net negative electric charge. Electric Field Vector 707 of the standing EM wave exerts a net force on the excess of negative electric charges located on Capacitor Sphere A 701 and Capacitor Sphere A 701 experiences a net force in the positive z direction during periods when Electric Field Vector 707 of the standing EM wave is pointing in the negative z direction.

[0068] The cycle of electron buildup and discharge on Capacitor A 701 and Capacitor B 702 as Electric Field Vector 707 of the standing EM wave fluctuates between a positive z and negative z direction repeats continuously. If the resistance of the Thruster Device is low, this charge oscillation may be substantially in phase with the standing EM wave. Thus, Capacitor Sphere A 701 has an electric charge that has a force in the positive z direction exerted on it from Electric Field Vector 707 of the resonating wave throughout most, or all, of each cycle. This leads to a nearly continuous upward force being exerted on the Capacitor A 701 (except during brief periods of the cycle near when Electric Field Vector 707 passes through zero amplitude due to a slight phase shift of the oscillating charge). Capacitor Sphere B 702 experiences only minimal direct force from Electric Field Vector 707 of the standing EM wave due to the low amplitude of Electric Field Vector 707 of the standing EM wave on its vicinity. This imbalance of forces exerted upon Capacitor Sphere A 701 and Capacitor Sphere B 702 is transferred to Resonating Cavity 700 through Non-Conducting Support 704. The unidirectional force exerted on Capacitor Sphere A 701 may then be converted to thrust of any vehicle or body attached to Resonating Cavity 700.

Equations governing thrust:

[0069] The force on Capacitor A 701 is:

$$F = QE \, , \qquad \text{Equation (2)}$$

where $Q =$ the electric charge in Coulombs on Capacitor Sphere A 701, $E =$ the electric field operating on the capacitor in V/m, and $F =$ the force on the capacitor in Newtons.

[0070] The electric charge on the capacitor is:

$$Q = CE\text{,} \qquad \text{Equation (3)}$$

where $E =$ the electric field operating on the capacitor in V/m, and $C =$ the capacitance of Capacitor Sphere A 701 in Farads.

[0071] For calculation purposes, the charged Capacitor Spheres A and B may be considered as operating as an isolated spherical capacitor. The capacitance of an isolated sphere is:

$$C = 4\pi\varepsilon_0 r\text{,} \qquad \text{Equation (4)}$$

where ε_0 is the permittivity constant = 8.85 x 10^{-12} F/m, and $r =$ is the sphere radius in meters.

[0072] In an exemplary embodiment, the capacitor spheres and the wire connecting the capacitors are desirably operated in the superconducting temperature range of the materials of construction of those components. This may reduce the thermal heating of the spheres and the wire connecting the spheres. In addition, the extremely low resistance resulting from operating an AC current in a superconductor may reduce the time constant of the capacitors to approximately zero, and allow instantaneous charging of the capacitor, i.e. zero phase shift (approximately, for calculation purposes). Note: *The present invention may also be operated with the components of the Thruster Device and resonating cavity made of materials that do not operate at or below the material's superconducting critical temperature. However, when the present invention is not operated in the superconducting mode, additional heat removal (over levels required for superconducting operating modes) may be required for system operation.*

[0073] The time constant, τ, for a capacitor is:

$$\tau = RC\text{,} \qquad \text{Equation (5)}$$

and the resistance in the superconductor is 1 x 10^{-7} ohms or less and the charge on a capacitor is:

$$Q = CV\left[1 - e^{\frac{-t}{RC}}\right]\text{,} \qquad \text{Equation (6)}$$

which reduces to approximately Q=CV in the case of an exemplary superconducting configuration of the resonant cavity propulsion system of the present invention.

[0074] In addition, the actual capacitance of the two spheres is increased due to the presence of the oppositely charged capacitor sphere in close proximity. The increased capacitance of the spheres increases the thrust levels possible for this configuration. For calculation of basic system performance, the capacitors are treated as isolated spheres.

[0075] Therefore the instantaneous force on Sphere A 701 is:

$$F = QV = CV^2 = 4\pi\varepsilon_0 rV^2, \qquad \text{Equation (7)}$$

[0076] The voltage of the electric field of the standing wave is a sine function; therefore, over ½ cycle of the average value of $V=1/2\ V_{max}$, so the time averaged force exerted on Sphere A is:

$$\overline{F} = 2\pi\varepsilon_0 rV_{max}^{\ 2}, \qquad \text{Equation (8)}$$

$$\overline{F} = \frac{1}{4}CV_{max}^2 = \pi\varepsilon_0 rV_{max}^2$$

$\overline{F}$ = the time-averaged unbalanced force on Capacitor Sphere A in Newtons.

[0077] This time-averaged force creates thrust in any vehicle attached to the resonating cavity. This unbalanced force is not balanced by an equal and opposite force on Capacitor Sphere B 702 since Capacitor Sphere B 702 is located substantially outside the area of operation of the electric field of the standing EM wave. Photons of the standing EM wave cannot oscillate efficiently in the area surrounding Capacitor Sphere B 702, hence there is no significant EM wave electric field to create a force on the surplus of electric charges on Capacitor Sphere B 702. Thus, Capacitor Sphere B 702 is not significantly affected by the electric field of the standing EM wave, except as the electric field of the resonating wave creates a voltage that is transferred to Capacitor Sphere B 702 through Capacitor Sphere A 701 and Connecting Wire 703 by electric currents created by the motion of free electrons.

[0078] It is noted that there are many additional configurations of Thruster Devices that may exploit this Electric Charge propulsion mechanism. The electric currents on the central capacitors of the examples depicted in Figs. 7A, 7B, are driven by the electric field oscillations of the standing EM wave moving free electrons onto and off of Capacitor Sphere A 701. Power sources other than the standing EM wave may also be used to drive electric charges onto and off of Capacitor Sphere A 701. These power sources are not depicted in Figs. 7A, 7B, and 8.

Electric Current Propulsion

[0079] The exemplary Electric Current Propulsion mechanism of the present invention uses the magnetic field potential of a standing EM wave to create an unbalanced force on a device carrying an electric current within an area affected by the magnetic field of said standing EM wave.

[0080] Figs. 9A and 9B represent a cross-sectional top view of the magnetic fields of the propulsion system depicted in Figs. 7A, 7B, and 8 from the perspective of the z axis.

[0081] Figs. 9A and 9B each have an exploded view of Capacitor Sphere A 701 interacting with Magnetic Field 708 of the standing EM wave. In Fig. 9A, Magnetic Field 708 of the standing EM wave points counterclockwise at all points around Capacitor Sphere A 701. In Fig. 9B, Magnetic Field 708 of the standing EM wave points clockwise at all points around Capacitor Sphere A 701.

[0082] Magnetic Field 708 of the standing EM wave oscillates from a maximum amplitude in the configuration of Fig. 9A, through a zero value to a maximum amplitude in the configuration of Fig. 9B, then again through a zero value and back to a maximum amplitude in the configuration of Fig. 9A.

[0083] In the exploded view of Capacitor Sphere A 701 in Fig. 9A, arrows depict the current flow on Capacitor Sphere A 701 that is parallel to the xy plane. The current flow onto and off of Capacitor Sphere A 701 is in phase with the magnetic field oscillations of the standing EM wave. At substantially all times that Magnetic Field 708 of the standing EM wave has a clockwise orientation as depicted in Fig. 9A, current is flowing onto Capacitor Sphere A 701. At substantially all times that Magnetic Field 708 of the standing EM wave has a clockwise configuration as depicted in Fig. 9B, current is flowing off of Capacitor Sphere A 701. Current flow onto Capacitor A 701 is driven by the oscillating electric field potential of the standing EM wave in Resonating Cavity 700. Current flow onto and off of Capacitor Sphere A 701 is balanced by current flow onto and off of Capacitor Sphere B 702 of Figs. 7A, and 7B.

[0084] Unidirectional thrust is generated by the effect of the interaction of Magnetic Field 708 of the standing EM wave with the current moving onto and off of Capacitor Sphere A 701. Using the right hand rule, Magnetic Field 708 of the standing EM wave exerts a force in the positive z direction on the electric current on Capacitor Sphere A 701 that is parallel to the xy plane (the positive z direction is depicted in Figs. 7A, and 7B and is out of the page and towards the reader in Figs. 9A, and 9B).

[0085] Magnetic Field 708 of the standing EM wave is much smaller at points near Capacitor Sphere A 701 than at points near the wall of Resonating Cavity 700 since Capacitor Sphere A 701 is centered at the node of Magnetic Field 708. Alternative configurations of Capacitor Sphere A 701 may increase the unidirectional thrust generated by the Electric Charge Propulsion Mechanism. Fig. 10 represents one exemplary reconfiguration of Capacitor Sphere A 701 to increase the propulsion provided by the Electric Charge Propulsion mechanism of the present invention. The Alternative Capacitor Disk 709 of Fig. 10, which may desirably have an oblate spheroidal shape, may desirably have a higher level of thrust due to the Electric

Current Propulsion mechanism than Capacitor Sphere A 701. Assuming equal capacitance for Capacitor Sphere A 701 and Alternative Capacitor Disk 709, Alternative Capacitor Disk 709 may have a higher level of current flow parallel to the xy plane, and experience a higher average magnetic field force on that electric current because Alternative Capacitor Disk 709 extends into regions of higher standing EM wave magnetic field strength.

[0086] There are many additional configurations of current carrying devices that may exploit the Electric Current propulsion mechanism. The electric currents on the central capacitors of the examples depicted in Figs. 7A, 7B, 8, 9A, 9B, and 10 are driven by the electric field oscillations of the standing EM wave moving free electrons onto and off of Capacitor Sphere A 701 and Alternative Capacitor Disk 709 of Fig. 10. Power sources other than the standing EM wave may be used to drive electric currents located on devices that are within the area affected by the magnetic field of the Standing EM wave.

[0087] A fundamental principal of the Electric Current Propulsion mechanism is that, for the purpose of generating unidirectional thrust, an alternating electric current is located on a Thruster Device that may be acted on by the magnetic field of a standing EM wave and, on some portion of said Thruster Device, some part of said current flows perpendicularly to the magnetic field direction of the standing EM wave. In addition, the oscillations of the alternating current are substantially in phase with the oscillations of the magnetic field of the standing EM wave.

Lorentz Force Propulsion

[0088] The Lorentz Force Propulsion mechanism of the present invention utilizes an imbalance in the Lorentz forces exerted on two or more sections of a Thruster Device some section of said Thruster Device located within the electric and/or magnetic field of a standing EM wave) to generate unidirectional thrust. The magnetic fields that create the Lorentz forces are generated by electric currents located on said Thruster Device.

[0089] The Lorentz Force Propulsion mechanism as it relates to the *present invention* refers to forces exerted on sections of a Thruster Device resulting from the interaction of electric currents in sections of said thrusting device with magnetic fields generated by electric currents in other sections of said thrusting device.

[0090] The Lorentz Force law is:

$$F = q(E + v \times B), \qquad \text{Equation (9)}$$

where F = Force in Newtons, E = Electric field in Volts/meter, B = magnetic field in Teslas, q = electric charge in coulombs, v = velocity of the charge in meters/second, x = cross product.

[0091] The qE portion of the Force in Equation 9 is considered under the Electric Charge Propulsion mechanism and does not contribute to the Lorentz Force Propulsion mechanism of the present invention.

[0092] The magnetic field of the EM wave that exerts a force on electric currents that are on a Thruster Device located within the magnetic field of the EM wave is considered under the Electric Current Propulsion mechanism and does not contribute to the Lorentz Force Propulsion mechanism of the present invention.

[0093] Consider the exemplary embodiments of the present invention that is depicted in Fig. 10. For example, Alternative Capacitor Disk 709 of Fig. 10, Connecting Wire 703, and Capacitor Sphere B 702 are electrically coupled and, during normal system operation, have an AC current oscillating between the members of this circuit. Alternative Capacitor Disk 709, Connecting Wire 703, and Capacitor Sphere B 702 form a Thrusting Device. The AC current on this Thruster device is driven by the electric field oscillations of the standing EM wave. Fig. 11 depicts the circuit created by Alternative Capacitor Disk 709, Connecting Wire 703, and Capacitor Sphere B 702. This is not a standard AC circuit. There is no circuit loop. The alternating electric current results from free electrons oscillating in location between Alternative Capacitor Disk 709, Connecting Wire 703, and Capacitor Sphere B 702. On the right side of Fig. 11, there is a representation of the electric current path (AC Current Path 710) traveled by the free electrons on ½ of Alternative Capacitor Disk 709, Connecting Wire 703, and ½ of Capacitor Sphere B 702 in the present embodiment. Whenever electrons are moving along Connecting Wire 703, the electric current in Connecting Wire 703 generates a magnetic field. The magnetic field generated by currents in the connecting wire may exert a force in the positive z direction on electrons traveling along Alternative Capacitor Disk 709 in a direction parallel to the x-axis. The magnetic field generated by currents in Connecting Wire 703 may also exert a force in the negative z direction on electrons traveling along Capacitor Sphere B 702 in a direction parallel to the x-axis. The current path in the x direction on Alternative Capacitor Disk 709 is longer than the current path in the x direction on Capacitor Sphere B 702. Therefore, the magnetic fields generated by the AC current in Connecting Wire 703 may exert more force in the positive z direction on Alternate Capacitor Disk 709 than the force exerted in the negative z direction on Capacitor Sphere B 702. This may lead to a net force in the positive z direction on the Thruster Device and any body connected to the Thruster Device, creating additional Unidirectional Thrust.

[0094] The Lorentz Force Propulsion mechanism is similar to the Electric Current Propulsion mechanism of the present invention in that an unbalanced force is created by the interaction of magnetic fields with electric currents located on a Thruster Device. The magnetic fields that create the unbalanced forces of the Lorentz Force Propulsion mechanism, however, are generated by electric currents on the Thruster Device itself. The magnetic fields that create the unbalanced forces of the Electric Current Propulsion mechanism are the magnetic fields of the standing EM wave.

V Forces opposing the unidirectional thrust of the present invention.

[0095] There are other forces present in this exemplary propulsion system that have the potential to oppose the unidirectional force created by the present invention. However, as described below, the inventors have found that none of these forces appear to create sufficient force to completely oppose the unidirectional thrusting of exemplary embodiments of the present invention.

The forces include: wall forces on the walls of the resonating cavity; the magnetic field of the resonating wave acting on electric currents on the thruster device; the magnetic field created by electric currents on certain sections of the Thruster Device interacting with electric currents on other sections of the Thruster Device; forces acting on the sections of the thruster device that are outside the area of affect of the electric and magnetic fields of the standing EM wave; electrostatic forces; forces involved in charging Capacitor Sphere A 701 and Capacitor Sphere B 702; and electron motion on the Thruster device.

Wall forces on the walls of the resonating cavity

[0096] Fig. 12A depicts a top-down view of a section of the wall of Resonating Cavity 700 of the embodiment depicted in Figs. 7A, 7B, 8, 9A, and 9B. On Fig. 12A, the arrows represent the two directions that Magnetic Field 708 of the standing EM wave is oriented during system operation. Reflections of the standing EM wave from the wall of Resonating Cavity 700, and interactions of Magnetic Field 700 of the standing EM wave with the wall of Resonating Cavity 700 create vertical oscillations of electrons located on the cavity walls. The vertical oscillations of the electrons in the resonating cavity wall at points close to Point C 712 are substantially parallel to the z-axis (the z-axis is positive perpendicular to the xy plane of Fig. 12A). Magnetic Field 708 of the standing EM wave creates a force parallel to the x-axis on the oscillating electrons at point C 712 of Fig. 12A. However, the unbalanced force generated by the Electric Charge Propulsion mechanism, the Electric Current Propulsion Mechanism and the Lorentz Force Propulsion Mechanism on this embodiment of the present invention is in the positive z direction. Therefore, no wall forces oppose the unbalanced force exerted on capacitor Sphere A 701 (or on this configuration which uses Alternative Capacitor Disk 709 of Fig. 10). The wall forces exerted by the standing EM wave on the walls of the resonating cavity are directed substantially radially outward from the cavity center, and those forces have a direction parallel to the xy plane (for the embodiment depicted in Figs. 7A, and 7B). There are, thus, no significant forces exerted by the resonating wave on the resonating cavity walls in the z direction at Point C 712 to oppose the unbalanced force generated by the Thruster Device in exemplary embodiments of the present invention.

[0097] Fig. 12B depicts a side view cross-section of a section of the resonating cavity wall of the embodiment of the present invention depicted in Figs. 7A, 7B, 8, 9A, and 9B. The vertical oscillations of electrons on the resonating cavity wall above and below point C 712 have a component of the electric current flowing parallel to the xy plane. However, the interactions of Magnetic Field 708 of the standing EM wave with the electric current on the wall of the resonating cavity cancel out above and below Point C 712 and there is no significant net force on Resonating Cavity 700 due to standing EM wave magnetic field interactions with electric currents in the walls of the resonating cavity.

The magnetic field of the resonating wave acting on electric currents on the thruster device

[0098] As discussed above, the force generated by the interaction of the magnetic field of the standing EM wave with currents on Capacitor Sphere A 701 is in the positive Z direction. By appropriate design of a Thruster Device, the magnetic field of the standing EM wave may increase the unidirectional thrust of the present invention.

The magnetic field created by electric currents on certain sections of the Thruster Device interacting with electric currents on other sections of the Thruster Device

[0099] As discussed above, by appropriate design, the magnetic field generated by electric currents on certain sections of a Thruster Device may interact with electric currents on other sections of said Thruster Device in order to increase the unbalanced force exerted upon said Thruster Device, and increase the total thrust of the propulsion system. In the configuration depicted in Figs. 7A, 7B, 8, 9A, and 9B, using Alternative Capacitor Disk 709 of Fig. 10, the unbalanced Lorentz forces exerted on the two ends of the Thruster Device (Alternative Capacitor Disk 709 and Capacitor Sphere B 702) may increase the unidirectional thrust in the positive z direction generated by this embodiment.

Forces acting on the sections of the thruster device that are outside the area of effect of the electric and magnetic fields of the standing EM wave

[00100] In the embodiment of the present invention depicted in Figs. 7A, 7B, 8, 9A, and 9B, the Thruster Device includes Capacitor Sphere A 701, Connecting Wire 703, and Capacitor Sphere B 702. During normal system operation, there is an unbalanced force exerted on Capacitor Sphere A 701. As discussed, the force on Capacitor Sphere A 701 due to the Electric Charge Propulsion mechanism, and due to the Electric Current Propulsion Mechanism is desirably directed in the positive z direction (and in the case of the Alternative Capacitor Disk 709 configuration of Fig. 10, the Lorentz Force Propulsion mechanism also contributes to the net unbalanced force in the positive z direction). An equal and oppositely directed force on Capacitor Sphere B 702 due to standing EM wave interactions does not exist. Capacitor Sphere B 702 is not substantially within an area of Resonating Cavity 700 that is traversed by the component waves of the standing EM wave. The electric and magnetic fields of the Standing EM wave do not significantly pass over Capacitor Sphere B 702, therefore the electric and magnetic fields of the Standing EM wave do not create sufficient forces on Capacitor Sphere B 702 to oppose the force which the standing EM wave exerts on Capacitor Sphere A 701.

Electrostatic forces

[00101] The Thruster Device of exemplary embodiment of the present invention includes Capacitor Sphere A 701, Connecting Wire 703, and Capacitor Sphere B 702. Capacitor Sphere A 701 and Capacitor Sphere B 702 may have a surplus of electric charges located on the spheres during normal system operation. There may be no significant net force exerted on the Thruster Circuit due to internal electric charge distributions. Any downward pull on Capacitor Sphere A 701 is balanced by an upward pull on Capacitor Sphere B 702. In addition, sections of Resonating Cavity 700 surrounding the Thruster Circuit may build up an electric charge, creating electrostatic forces between the Thruster Circuit and Resonating Cavity 700. Over many resonating wave cycles, these forces balance out so that no significant unbalanced force in the negative z direction is generated.

Forces involved in charging Capacitor Sphere A 701 and Capacitor Sphere B 702

[00102] Figs. 13A-D represent a hypothetical configuration of Capacitor Sphere A 701, Capacitor Sphere B 702 and Connecting Wire 703 that form an exemplary Thruster Device. For demonstration purposes assume that in Connecting Wire 703 is a single electron, Electron 716. Electron 716 is attached to Spring A 714, and Spring B 715. Spring A 714 and Spring B 715 are an analog for the force of attraction and repulsion that exist between the free electron and the positive and negative charges that exist on Capacitor Sphere A 701 and Capacitor Sphere B 702 during system operation. During operation, the Thruster Device starts in position A as depicted in Fig. 13A, and then moves to the configurations depicted in Figs. 13B, 13C, and 13D in turn, and then the Thruster Device to the configuration of Fig. A. During system operation, this cycle of Capacitor charging continues. The electric field potential of the standing EM wave creates the force on Electron 716 to drive Electron 716 through the positions depicted in positions depicted in Figs. 13A-D.

[00103] To move Electron 716 from the configuration of Fig. 13A to the configuration of Fig. 13B, an unbalanced force in the negative z direction is exerted by the electric field of the standing EM wave on the Thruster Device. As discussed above, no counterbalancing force in the positive z (or negative z) direction may be transferred to the resonating cavity by the EM wave. There is an unbalanced force created on the Thruster Device (and the whole propulsion system) by the charging of Capacitor Sphere B 702 with Electron 716. If the electric field depicted in Fig. 13B were a static electric field, a counterbalancing force in the positive z direction would be exerted on the device creating the static electric field, and there would be no net unbalanced force exerted on the combination of the Thruster Device and the device sustaining the static electric field.

[00104] To move Electron 716 from the configuration of Fig. 13C to the configuration of Fig. 13D, an unbalanced force in the positive z direction is exerted by the electric field of the standing EM wave on the Thruster Device. Once again, no counterbalancing force in the negative z (or positive z) direction may be transferred to the resonating cavity by the EM wave. There is an unbalanced force created on the Thruster Device (and the whole propulsion system) by the charging of Capacitor Sphere A with Electron 716.

[00105] Over a complete wave period of the standing EM wave, the unbalanced forces on the Thruster Device created by moving and holding Electron 716 on Capacitor Sphere A 701 and Capacitor Sphere B 702 cancel out. There is no time-averaged unbalanced force on the Thruster Device from forces required to create electron movement on the Thruster Device. Over one wave period, the unbalanced force in the negative z direction resulting from moving electrons from the configuration of Fig. 13A to the configuration of Fig. 13B and is balanced by the unbalanced force in the positive z direction resulting from moving electrons from the configuration of Fig. 13C to the configuration of Fig. 13D.

[00106] In the same fashion, the unbalanced force on the Thruster Device required to hold Electron 716 on Capacitor Sphere B 702 during the transition from the configuration of Fig. 13B to the configuration of Fig. 13C is balanced over one wave period by the unbalanced force on the Thruster Device required to hold Electron 716 on Capacitor Sphere A 701 during the transition from the configuration of Fig. 13D to the configuration of Fig. 13A.

[00107] The forced oscillations of electrons on the Thruster Device creates no significant time-averaged net force on the Thruster Device and does not oppose the thrusting of the present invention.

<u>Electron motion on the Thruster device</u>

[00108] Electrons move back and forth between Capacitor Sphere A 701 and Capacitor Sphere B 702 during system operation. Over many cycles, the center of mass for the oscillating electrons does not change, and no net force is exerted on the system in this manner.

Conclusion on forces:

[00109] There are no forces available in the system to counter the unbalanced force in the positive z direction exerted upon the Thruster Device by the Electric Charge Propulsion mechanism, the Electric Current Propulsion mechanism, and/or the Lorentz Force Propulsion mechanism.

- The Standing EM wave cannot transfer forces to the cavity wall to create a net, z-directed force.
- The magnetic fields generated by electric currents on the Thruster Device and the magnetic fields of the standing EM wave acting on the electric currents on the Thruster Device may actually enhance the unbalanced force in the positive z direction created by the propulsion system.
- The charging and discharging of the capacitors of the Thrusting Device and electron motion on the Thruster Device do not create any significant time-averaged net force on the Thruster Device.
- Capacitor B remains substantially outside of the area of the component waves of the standing EM wave, and therefore, no significant forces in the negative z-direction may be exerted upon Capacitor Sphere B by the standing EM wave.
- There is no force generated anywhere in the system sufficient to counter the unbalanced force in the positive z-direction created by the system.

VI Conservation of Energy

[00110] Exemplary embodiments of the present invention obey conservation of energy. Kinetic energy increases created by the propulsion system are offset by a decrease in EM resonating energy within the resonating cavity of the propulsion system.

[00111] For example, if a 1000 kg vehicle equipped with the present invention is accelerated from an initial velocity of 0 m/s to a final velocity of 10 m/s, the kinetic energy increase of the vehicle is given by:

$$\Delta E_k = \frac{1}{2} m (v_f^2 - v_i^2), \qquad \text{Equation (10)}$$

where m = mass in kg, v_i = initial velocity in m/s, v_f = final velocity in m/s, E_k = kinetic energy in joules.

[00112] In the present example, the vehicle increases 50,000 joules in kinetic energy. The propulsion system must use at least 50,000 joules of EM energy to achieve this increase in vehicle kinetic energy. In actual operation, exemplary embodiments of the present invention expend more than 50,000 joules of EM wave energy to achieve an increase of 50,000 joules in vehicle kinetic energy. In addition to the 50,000 joules of EM energy consumed to generate 50,000 joules of kinetic energy, the standing EM wave also loses significant amounts of energy because of heating losses in the walls of the resonating cavity and Thruster Device.

[00113] Exemplary embodiments of the present invention may only impart kinetic energy to a vehicle by consuming an amount of EM wave energy equal to, or greater than the amount kinetic energy imparted. Amounts of EM wave energy consumed in excess of imparted kinetic energy shows up as heat energy in the walls of the resonating cavity and Thruster Device of the present invention.

[00114] To generate this kinetic energy, work is done on the vehicle at a minimum rate of:

$$\frac{\Delta E_k}{dt} = \frac{1}{2}\frac{\overline{F}^2}{m}, \qquad \text{Equation (11)}$$

where m = mass in kg, $\overline{F}$ = time-averaged force created by system in Newtons.

[00115] For example, if a 3000 kg vehicle experiences a 2 Newton continuous time-averaged force from a resonating cavity propulsion system unit, the time-averaged kinetic energy input into the vehicle is 6.7 x 10^{-4} watts. The standing EM wave must be depleted of energy by at least 6.7 x 10^{-4} joules per second to sustain the 2 Newton force.

VII: Design Considerations

[00116] A variety of materials and configurations may be used for the components of exemplary embodiments of the present propulsion system. Some design considerations in the construction and operation of these various components are as follows:

Resonating Cavity:

- Low resistance materials: EM wave reflecting surfaces within the resonating cavity are desirably formed of a low resistance material that has a high reflectivity of the EM wavelength. Lower resistance materials used on the reflecting surfaces within the cavity may minimize cooling and power requirements for propulsion system operation. The ideal material for the reflecting surfaces is one that has zero AC electrical resistivity and that is able to withstand high magnetic fields while maintaining AC superconductivity. No such AC superconductor is presently known to the inventor. However, materials are known that have low AC resistivities and high critical magnetic field strengths.
- Larger cavity size: Large cavity size allows for lower EM wave frequency. Lower wave frequency may minimize heating in the walls of the resonating cavity and decrease the AC currents and heating in the Thruster Device.

Optimization of cavity size depends on the material parameters of the reflecting surface material and the Thruster Device material of construction.

Thruster Device:

- Low resistance materials: The conducting sections of the Thruster Device is desirably formed of materials with:
  - Low electrical resistivity
  - High critical current density
  - High critical magnetic field strength
- High heat transfer coefficient materials: The Thruster Device may be heated by the movement of charge on the Thruster Device. It is desirable to remove this heat during continued operation of the system. Thus, materials with sufficient heat transfer properties to maintain operable temperatures are desired. This consideration may be particularly important if superconducting materials are used in the construction of the Thruster Device.
- Surface Area/Capacitance: The surface area of the First Conductive End of the Thruster Device is desirably as large as possible to maximize the Thrust generated by the system. The capacitance of the First Conductive End is directly related to the surface area of the First Conductive End. However, the size of the First Conductive End is limited by the resonating cavity size, and by the potential to cause interference with the maintenance of the resonating EM wave in the cavity. If the First Conductive End is too large, the resonating EM wave may not be able to be sustained within the resonating cavity. In addition to surface area, dielectric materials may also be used in the construction of a Thruster Device to increase capacitance of the Thruster Device. The use of dielectric materials may increase the capacitance of the First Conductive End of the Thruster Device and thus increase total propulsion system thrust.

Cooling System:

The resonating cavity and Thruster Device of the present propulsion system is likely to generate heat during normal operation. It is desirable to remove this heat during continued operation of the system. A variety of techniques for heat removal are known to those skilled in the art. The critical design features for the cooling system are:

Maintaining operating temperatures:

- When superconducting materials are used in the operation of the present propulsion system, the cooling system desirably maintains all superconducting materials at or below the critical temperature of the superconducting materials.
- When non-superconducting propulsion systems are used, the cooling system desirably maintains system temperatures at a level that allows for continued operation. Mechanical failure or detrimental changes to the physical

parameters of system materials may occur if heat is not removed from the system.

Mechanical construction of component parts:

- A variety of materials may be used in the construction of system components. Any materials with sufficient physical performance characteristics to mechanically function in a subsystem of the present propulsion system are acceptable.

VIII Alternative Configurations

[00117] A variety of alternative configurations of components of the present invention may allow for versatile operation of the present invention including:

- Ability to modulate Unidirectional Thrust levels.
- Ability to control direction of Unidirectional Thrust.
- In addition to Unidirectionally Thrusting in 3 directions, alternative configurations may be used to control yaw, pitch, and roll of the propulsion system and bodies attached to the propulsion system.
- Ability to use a variety of power sources to generate Unidirectional Thrust.
- Ability to achieve higher thrust levels using higher EM wave resonating operating modes (2nd harmonic, 3rd harmonic, 4th harmonic, etc.)

Outside Power Sources

[00118] In an exemplary embodiment of the present invention, the Thruster Device may be powered by the energy of the standing EM wave that resonates around the first conductive end of the Thruster Device, generating Unidirectional Thrust. Configurations of a Thruster are possible using power sources other than the standing EM wave to power the electric current/charge oscillations on the Thruster Device.

[00119] Fig. 14 depicts a configuration of the present propulsion using an outside power source to power the Thruster Device. In Fig. 14, Outside Power Source 822 is connected to Thruster Device 821. Some or all of Thruster Device 821 may be located within Resonating Cavity 820.

[00120] The system is operated as follows:

Case 1) Outside Power Source 822 Powers Thruster Device 821

[00121] In this configuration, Outside Power Source 822 causes oscillating electric currents and/or oscillating electric charges on Thruster Device 821. Thruster Device 821 has a first conductive end located within an area of the electric and/or magnetic field of the standing EM wave resonating inside Resonating Cavity 820.

[00122] The Standing EM wave is established in Resonating Cavity 820 by a power source other than Outside Power Source 822.

[00123] The interaction of the standing EM wave inside of Resonating Cavity 820 with Thruster Device 821 may cause unidirectional thrust to be generated by any combination of the three exemplary propulsion mechanisms of the present invention described in detail above:

- The Electric Charge Propulsion Mechanism
- The Electric Current Propulsion Mechanism
- The Lorentz Force Propulsion Mechanism

Case 2) Outside Power Source 822 Powers Thruster Device 821 and the EM resonating wave within Resonating Cavity 820

[00124] In this configuration, Outside Power Source 822 causes oscillating electric currents and/or oscillating electric charges on Thruster Device 821. The oscillations of electric currents/charges on Thruster Device 821 cause a standing EM wave to be established inside Resonating Cavity 820. Thruster Device 821 has a first conductive end located within an area of the electric and/or magnetic field of the standing EM wave resonating inside Resonating Cavity 820.

[00125] The interaction of the standing EM wave inside of Resonating Cavity 820 with Thruster Device 821 may cause unidirectional thrust to be generated by any combination of the three exemplary propulsion mechanisms of the present invention described in detail above:

- The Electric Charge Propulsion Mechanism
- The Electric Current Propulsion Mechanism
- The Lorentz Force Propulsion Mechanism

Case 3) Outside Power Source 822 Powers Thruster Device 821 and partially powers the EM resonating wave resonating inside Resonating Cavity 820

[00126] In this configuration, Outside Power Source 822 causes oscillating electric currents and/or oscillating electric charges on Thruster Device 821. Thruster Device 821 has a first conductive end located within an area of the electric and/or magnetic field of the standing EM wave resonating inside Resonating Cavity 820.

[00127] The standing EM wave may be established and maintained in Resonating Cavity 820 by a power source other than Outside Power Source 822 and by oscillations of electric currents/charges on Thruster Device 821.

[00128] The interaction of the standing EM wave inside of Resonating Cavity 820 with Thruster Device 821 may cause unidirectional thrust to be generated by any combination of the three exemplary propulsion mechanisms of the present invention described in detail above:

- The Electric Charge Propulsion Mechanism
- The Electric Current Propulsion Mechanism
- The Lorentz Force Propulsion Mechanism

Reconfigurable Thruster Device

[00129] In an exemplary embodiment of the present invention, the Thruster Device may be fixed in position within the resonating cavity and may be fixed in shape and in mechanical properties. However, alternative configurations of a Thruster Device are possible that are movable, may change shape, and/or have non-constant mechanical properties. Such reconfiguration of a Thruster Device may be advantageous to:

- Modulate system thrust
- Modulate system power requirements
- Modulate system temperature and system cooling requirements

[00130] Figs. 15A and 15B depict an exemplary reconfigurable Thruster Device and a control unit. In Figs. 15A and 15B, Capacitor Disk 860 is electrically coupled to Connecting Wire 861. Connecting Wire 861 is electrically coupled to Capacitor B 862. Connecting Wire 861 is also electrically coupled to Connector 863. Connector 863 is electrically coupled to Control Unit 864.

[00131] The Thruster Device includes Capacitor Disk 860, Connecting Wire 861, and Capacitor B 862. Capacitor Disk 860 is the first conductive end of the Thruster Device. Capacitor B 862 is the second conductive end of the Thruster Device. Control Unit 864 modulates the shape and mechanical properties of the Thruster Device and may modulate the shape and mechanical properties of the Thruster Device based on propulsion system requirements.

[00132] In Fig. 15A, Capacitor Disk 860 has a smaller diameter than in Fig. 15B. The diameter of Capacitor Disk 860 may be modulated by Control Unit 864. For example, a telescoping device or a variety of techniques known to those skilled in the art may be used to accomplish shape changes of Capacitor Disk 860 or any part of the Thruster Device.

[00133] Increasing and decreasing the diameter of Capacitor Disk 860 may be used to increase/decrease thrusting of the system at certain times. The larger diameter Capacitor Disk 860 of Fig. 15B causes a higher capacitance and heating of capacitor Disk 860 and may create increased thrust, power and cooling requirements than Capacitor Disk 860 of Fig. 15A.

[00134] In addition to shape changes to any part of the Thruster Device of the present invention, the mechanical properties of the Thruster Device may be modulated to:

- Modulate system thrust
- Modulate system power requirements
- Modulate system temperature and system cooling requirements

[00135] Examples of mechanical properties of components of the Thruster Device that may be used to modulate system operation are:

- Opening/closing switches on any part of the Thruster Device to modulate electric currents
- Applying electric currents/ magnetic fields to move a material in and out of superconducting operation.
- Modulating voltage to a voltage-variable dielectric material incorporated into the Thruster Device.

Changing the position of the Thruster Device may also be used to modulate system operation.

[00136] Fig. 16 depicts a movable Thruster Device in a resonating cavity.

[00137] In Fig. 16, Thruster Device 811 is attached to Piston 812. Piston 812 may be partially located within Resonating Cavity 810. Piston 812 is capable of moving in the positive and negative z directions. Piston 812 may be used to move the first conductive end of Thruster Device 811 into and out of the electric and/or magnetic fields of the standing EM wave inside of Resonating Cavity 810. A variety of techniques known to those skilled in the art may be used to move a Thruster Device of the present invention.

Alternative Thruster Device Configuration

[00138] Fig. 17 represents an exemplary embodiment for the Thruster Device of the present invention.

[00139] In Fig. 17, Resonating Cavity 850 is electrically coupled to Connecting Wire 852. Connecting Wire 852 is electrically coupled to Capacitor Disk 851. The Thruster Device includes: Capacitor Disk 851 (First Conductive End); Connecting Wire 852; and Resonating Cavity 850 (Second Conductive End).

[00140] In this configuration, electrons may move onto and off of Capacitor Disk 850 through Connecting Wire 852 and onto and off of Resonating Cavity 850.

6-Axis Motion Control

[00141] In many of the exemplary embodiments of the present invention, thrust may be generated in the positive z direction only. However, it is also possible to use embodiments of the present invention to generate 6-axis motion. Control of 6-axis motion allows for thrusting of the propulsion system to control motion in the x, y, and z directions as well as controlling yaw, pitch and roll.

[00142] Fig. 18 represents an exemplary embodiment of the present invention mounted in a 3-axis gimbal. Through rotation of Resonating Cavity 880 within Gimbal 881, thrusting along any of the three linear axes may be achieved.

[00143] Fig. 19 represents an exemplary embodiment of the present invention that uses three resonating cavity thrusters mounted on a housing to achieve 6-axis motion control. In Fig. 19, Resonating Cavities 871, 872, and 873 are attached to Housing 874.

[00144] By modulation of the Unidirectional Thrust generated within Resonating Cavity 871, Resonating Cavity 872, and Resonating Cavity 873, 6-axis motion control may be achieved. In addition, Resonating Cavity 871, Resonating Cavity 872, and Resonating Cavity 873 are desirably movable on Housing 874, so that Resonating Cavity 871, Resonating Cavity 872, and Resonating Cavity 873 may achieve 6-axis motion control while maintaining constant levels of Unidirectional Thrust generated within each cavity.

Higher Resonance Mode operation

[00145] In the exemplary embodiments of Figs. 1, 2, and 3, the exemplary propulsion system operates with a first harmonic standing EM wave. Higher resonating operating modes for the standing EM wave are also possible.

[00146] Figs. 20 and 21 represent an exemplary embodiment of the present invention that uses a third harmonic standing EM wave during operation. Fig. 20 is a cross-sectional top-view of Resonating Cavity 900 and Thruster Devices A 901, B 902, C 903, D 904, and E 905. Fig. 21 is a cross-sectional side view of Resonating Cavity 900 and Thruster Devices A 901, C 903, and E 905, and Non-Conducting Supports A 906, C 907, and E 908.

[00147] The dashed line of Fig. 21 represents the electric field of the standing EM wave. As with a first harmonic embodiments of the present invention, the interactions of the EM wave with the Thruster Devices of the system depicted in Figs. 20, and 21 may generate Unidirectional Thrust by:

- The Electric Charge Propulsion Mechanism
- The Electric Current Propulsion Mechanism
- The Lorentz Force Propulsion Mechanism

[00148] By combination of the embodiment of Figs. 20 and 21 with the embodiment of Fig. 16 (a Thruster cable of being moved into and out of the area of the electric and/or magnetic fields of the standing EM wave), 6-axis motion control is possible. The other techniques for modulation of thrust on a single Thruster Device that are described above may be used on the embodiment of Figs. 20 and 21 to generate 6-axis motion control.

[00149] Any resonant mode of operation for the standing EM wave is possible for the present invention. Different application requirements for the present invention may require a variety of optimal standing EM wave harmonic modes.

An Exemplary Method Of Propulsion According To The Present Invention

[00150] Fig. 4 depicts the steps of an exemplary method by which the present invention may generate and modulate Unidirectional Thrust.

[00151] The exemplary method proceeds as follows:

Step 400: Configuration of a Resonating Cavity

[00152] A cavity capable of reflecting an electromagnetic wave for one or more reflections of the EM wave is established. The cavity may be designed for: superconducting operation; non-superconducting operation; or a combination of superconducting and non-superconducting operation.

Step 401: Configuration of the Thruster Device

[00153] A Thruster Device is positioned with at least one first conductive end of the Thruster Device within an area of the electric and/or magnetic fields of the standing EM wave that the Cavity of Step 400 is capable of reflecting. The thruster Device is oriented to the resonating cavity: fully within resonating cavity; partially within resonating cavity; or a reconfigurable position with respect to the cavity. The thruster may be designed for: superconducting operation; non-superconducting operation; or a combination of superconducting and non-superconducting operation.

Step 402: Powering of EM wave and Thruster Device

[00154] In this Step, power is provided to create a standing EM wave within the cavity of Step 400, and power may also be provided to create the oscillating electric currents/charges on the Thruster Device.

[00155] The EM wave and the Thruster Device may be powered by: (a) powering the standing EM wave (Step 403), and said EM wave creates the oscillating electric currents/charges on the Thruster Device (Step 404); (b) powering the Thruster Device (Step 404), and oscillations of electric currents on said Thruster Device power the creation of the standing EM wave (Step 403); or (c) the standing EM wave may be powered by one power source (Step 403) and the Thruster Device powered by a separate power source (Step 404). Any combination of options (a), (b), or (c) may be used to power the EM wave (403) and the Thruster Device (404).

[00156] The Standing EM wave may be operated: at the fundamental mode (i.e. the first harmonic); a higher harmonic resonance mode, or a combination of harmonic modes.

Step 405: Unidirectional Thrust is Generated:

[00157] Unidirectional Thrust is generated by the interaction of the standing EM wave with conduction charges in the Thruster Device. This thrust may be generated by: an electric Charge Propulsion mechanism; an electric Current Propulsion mechanism; a Lorentz Force propulsion mechanism; or a combination thereof.

Step 406: Unidirectional Thrust modulated

[00158] The amount and direction of Unidirectional Thrust in up to 6-axes of motion may be controlled: by controlling the orientation of the cavity and Thruster Device; by controlling the shape, position (in reference to the electric and/or magnetic fields of the standing EM wave) or mechanical properties of the Thruster Device; and/or by controlling the power to the Thruster Device and/or the power delivered to the standing EM wave.

An Exemplary Propulsion System According To The Present Invention

[00159] Figs. 1, 2, and 3 depict an exemplary embodiment of the present invention.

[00160] In Fig. 1: Housing 100 is connected to Wave Generator 110, Control Unit 120, Cooling Unit 130, Power Source 140, Cooling Shroud 150 and Resonating Cavity 200. Resonating Cavity 200 is connected to Non-Conducting Support 201, Coax Cable A 111A, and Coax Cable B 111B. Non-Conducting Support 201 is connected to Capacitor B 210. Capacitor B 210 is electrically coupled to Connecting Wire 220. Connecting Wire 220 is electrically coupled to Capacitor Disk A 230. In Fig. 3, Capacitor Disk A 230 is connected to Plug 231.

[00161] System Operation: Power source 140 provides power to EM wave generator 110. EM Wave Generator 110 creates a 160 MHz electromagnetic wave that is transferred through Coax Cable A 111A and Coax cable B 111B to Resonating Cavity 200. Within Resonating Cavity 200, the 160 MHz electromagnetic waves transferred by Coax Cables 111 A and 111 B create a resonating electromagnetic wave with a maximum and minimum electric field value depicted as the two dashed lines in Fig. 1.

[00162] The Thruster Device of this exemplary embodiment is depicted in Fig. 3 and includes four parts, Capacitor Disk A 230, Capacitor B 210, Connecting Wire 220 and Plug 231. As the electric field of the standing EM wave increases from a zero value to a maximum value as depicted by the upper dashed line in Fig. 1, electrons are driven off of Capacitor Disk A 230, through Connecting Wire 220 and onto Capacitor B 210. After electrons are removed from Capacitor Disk A 230, Capacitor Disk A 230 has a net positive electric charge and experiences a force in the positive z direction from the effect of being immersed in the positive electric field of the standing EM wave. As the electric field of the standing EM wave drops back to a zero value, electrons move back from Capacitor 210, through Connecting Wire 220 and onto Capacitor Disk A 230 causing Capacitor Disk A 230 to have no net electric charge.

[00163] As the electric field of the standing EM wave decreases from a zero value to a negative maximum value as depicted by the lower dashed line of Fig. 1, electrons are pulled onto Capacitor Disk A 230 from Capacitor B 210 through Connecting Wire 220. Capacitor Disk A 230 now has a net negative electric charge and experiences a force in the positive z direction from the effect of being immersed in the negative electric field of the standing EM wave. As the electric field of the standing EM wave increases back to a zero value, electrons move from Capacitor Disk A 230, through

Connecting Wire 220 and back onto Capacitor B 210 causing Capacitor Disk A 230 to have no net electric charge.

[00164] The cycle of electron oscillations on the Thruster Device continues as long as the standing EM wave remains in the resonating cavity. Capacitor Disk A 230 has a net time-averaged force in the positive z direction exerted on it from the effect of the electric field of the standing EM wave acting on a surplus of positive or negative electric charges on Capacitor Disk A 230.

[00165] In addition, the magnetic field of the standing EM wave may exert a time-averaged unbalanced force in the positive z direction on the electric currents moving parallel to the xy plane on Capacitor Disk A 230.

[00166] The magnetic field generated by electric currents oscillating on Connecting Wire 220 may also exert a net, time-averaged unbalanced force in the positive z direction on the electric currents moving parallel to the xy plane on Capacitor Disk A 230 and Capacitor B 210. More force in the positive z-direction may be exerted on the currents located on Capacitor Disk A 230 than negative z-directed forces exerted on Capacitor B 210.

[00167] Cooling Unit 130 draws power from Power Source 140. Cooling Unit 130 has within it a pump that forces neon gas through Lance 131. Cooling Unit 130 also circulates neon gas throughout Cooling Shroud 150. Cooling Shroud 150 is desirably an insulating blanket that is gas-tight. Cooling Shroud 150 encloses Resonating Cavity 200. Housing 100, Coax Cable A 111A, and Coax Cable B 111B pass through Cooling Shroud 150. Gas-tight seals at the connections of Housing 100, Coax Cable A 111A, and Coax Cable B 111B with Cooling Shroud 150 are desirable to prevent neon from passing through these connections. Neon Gas desirably circulates within Cooling Shroud 150 and around Resonating Cavity 200 to maintain the temperature of Resonating Cavity 200 at an operating temperature (for example 75K or below in an embodiment utilizing type II superconducting materials). Cooling Unit 130 desirably includes a gas pump, a radiator, and a neon gas reserve bottle to provide for loss of neon gas due to diffusion.

[00168] Control Unit 120 may be an industry standard feedback control device that modulates Cooling Unit 130 operation and EM Wave Generator 110 operation. Control Unit 120 controls:

- Temperature of Resonating Cavity 200 by modulation of neon gas flow rate through Cooling Unit 130.
- Pressure of neon gas within Cooling Shroud 150 through controlled release of additional neon from Cooling Unit 130 into Cooling Shroud 150.
- Modulates thrust generated by the exemplary embodiment by controlling electric field strength of the standing EM wave within Resonating Cavity

200 by modulation of power from Power Source 140 to EM Wave Generator 110.

Superconducting Devices:

[00169] Capacitor Disk A 230, Connecting Wire 220, Capacitor B 210, and Resonating Cavity 200 may all be operated at superconducting temperatures for their respective surface layer materials of construction. Many materials and manufacturing techniques are known that may create a surface coating of a superconducting material. In the exemplary embodiment, superconducting surfaces are prepared by layering a superconductor over a buffer layer that is layered over a substrate. In an exemplary embodiment, the three layers are desirably: YBCO formed on a buffer layer of yttrium stabilized MgO and CeO2, which has been formed on a nickel alloy substrate. This exemplary technique for manufacturing a superconducting layer of YBCO using a buffer layer of yttrium stabilized MgO and CeO2 was developed by the Department of Energy's Los Alamos National Laboratory and is known in the art.

[00170] A variety of other materials may be used for the superconductor layer, the buffer layer and, the substrate. For example, the superconducting layer may include a number of different materials such as $HgBa_2Ca_{22}Cu_3O_8$; niobium; $Tl_2Ba_2CaCu_2O_8$; NbSn alloys; Type I superconductors; or Type II superconductors, the buffer layer may include materials such as Ag on MgO; $LaAlO_3$; Gd_2O_3; or LSAT (a solid solution of $LaAlO_3$ and Sr_2AlTaO_6), and the substrate layer may include a number of materials such as copper; steel; aluminum; or titanium. These lists are not intended to be limiting and a number of other materials known to those skilled in the art may be used as well. Further it is noted that the use of the buffer layer and the substrate is not necessary when using a superconductor that may be manufactured without the need for a buffer layer or substrate layer. For example, resonating cavities and superconducting devices made of pure Niobium, or other Type I or Type II superconductors are known.

[00171] In this exemplary embodiment, Resonating Cavity 200 is desirably a completely sealed cavity with an internal diameter along the wave resonating axis of 0.9375 meters giving Resonant Cavity 200 a first harmonic operating frequency of 160 MHz. The inside surfaces of the cavity may be covered in YBCO and the outside of the cavity is made of a Ni alloy. Heat transfer from Resonating Cavity 200 to the neon gas circulating within Cooling Shroud 150 occurs at the nickel-neon metal-gas interface. Resonating Cavity 200 may be operated with a vacuum on the inside, and with a neon gas blanket on the outside. The mechanical connections of Housing 100 and Coax Cables A 111A and 111B to Resonating Cavity 200 walls are desirably made of insulating materials to minimize heat migration into Resonating Cavity 200. A variety of materials may be used. For example, an insulating Aerogel tile gasket may be used between Housing 100 and Resonating Cavity 200 walls to insulate against heat transfer between Housing 100 and Resonating Cavity 200.

[00172] Any material with suitable insulating and structural properties may be substituted for the insulators connecting Resonating Cavity 200 to the Coax Cables A 111A, 111B and Housing 100.

[00173] The Thruster Device: The Thruster Device includes Capacitor Disk A 230, Connecting Wire 220, Capacitor B 210, and Plug 231. Fig. 3 depicts the components of the Thruster Device, Cooling Unit 130, Lance 131, and Non-Conducting Support 201.

[00174] All surfaces of Capacitor Disk A 230, Connecting Wire 220, and Capacitor B 210 are coated with a layer of YBCO according to the description above. The entire Thruster Device and Non-Conducting Support 201 are desirably symmetrical about an axis parallel to the z axis and running through the geometric center of Capacitor Disk A 230, Connecting Wire 220, and Capacitor B 210. Fig. 3 depicts these components in cross section.

[00175] During system operation, Cooling Unit 130 may force cooled neon gas through Lance 131. Plug A 231 is a gas tight seal that seals the opening in the center of Capacitor Disk A 230. Plug A 231 prevents neon gas located within the Thruster Device from entering the vacuum within Resonating Cavity 200. Plug A 231 may be made from any suitable non-conducting material meeting the mechanical criteria of the gas seal. Plug A 231 for the exemplary embodiment is desirably made of ceramic. After ejection from Lance 131, the cooled neon gas then circulates in the negative z direction through the hollow centers of Capacitor Disk A 230, Connecting Wire 220, Capacitor B 210, and Non-Conducting Support 201. The cooled neon gas from Cooling Unit 130 is desirably be below the wall temperature of the Capacitor Disk A 230, Connecting Wire 220, and Capacitor B 210 and may cool these components. The neon gas exits the center of Non-Conducting Support and enters Cooling Shroud 150. The neon gas then temperature equilibrates with the neon gas within the cooling shroud. Neon gas within the cooling shroud is continuously pulled into Cooling Unit 130 and cooled by radiative heat transfer within a radiator in Cooling Unit 130. Heat from Cooling Unit 130 may be radiated from the radiator of Cooling Unit 130 to deep space.

[00176] Non-Superconducting Devices: The devices incorporated into exemplary embodiments of the present invention which are not operated in a superconducting state may be designed according to the performance specifications listed below. All of these systems are known by those skilled in the art and numerous examples are available in the literature for the operation and performance characteristics of these devices.

[00177] Non-Conducting Support 201: This device is a gas-impermeable connector between Resonating Cavity 200 and Capacitor B 210. Neon gas circulates through the inside of Non-Conducting Support 201. The outside of Non-Conducting support 201 is exposed to the vacuum inside Resonating Cavity 200. Non-Conducting Support 201 may be made of a variety of materials know to those skilled in the art. Non-Conducting Support 201 is capable of transferring the unbalanced force exerted on the Thruster Device to Resonating Cavity 200. In addition, Non-Conducting Support 201 is capable of containing ~1 atmosphere of neon gas pressure exerted by circulating neon gas within Non-Conducting Support 201. Non-Conducting Support 201 may also be made of a material that does not mechanically couple to the 160 MHz frequency force being transferred through Non-Conducting Support 201.

[00178] Cooling Unit 130 and Cooling Shroud 150: During normal system operation, heat is generated in the walls of Resonating Cavity 200, in the components of the Thruster Device carrying AC electric current, and in Coax Cables A 111A, and 111B that feed resonating EM energy into Resonating Cavity 200. In order to provide continuous, or pulsed, thrusting heat is desirably removed from these components. A variety of techniques known to one skilled in the art are available to remove heat from the devices mentioned.

[00179] In an exemplary embodiment, circulating neon gas may cool the outside walls of Resonating Cavity 200, the inside walls of the components of the Thruster Device, and the portion of Coax Cables 111A and 111B that are within Cooling Shroud 150. Cooling Shroud 150 is a gas-tight flexible multilayer insulating Mylar film that is inflated with neon from Cooling Unit 130. Insulating Mylar films are routinely used for insulating applications and are known to those skilled in the art.

[00180] Neon may circulate around Resonating Cavity 200 by convection, and/or by a pump located within Cooling Unit 130. Neon may also be injected by Cooling Unit 130 into the center cavity of the Thruster Device by Lance 131 that is located inside the Thruster Device. Neon may further circulate through a radiator that is part of Cooling Unit 130. Circulating neon temperature is desirably maintained at an operating temperature within Cooling Shroud 150 (for example 70°K).

[00181] In an exemplary embodiment, Cooling Unit 130 may include:

1) A pump capable of moving at least 2 grams/s of neon gas at 70K and 1 atm. pressure through Lance 131 and through Cooling Shroud 150.
2) A radiator that is capable of radiating 4 watts of heat at 70° K. Neon circulates within the radiator of Cooling Unit 130 and dissipates heat energy through the radiator to deep space.
3) A feedback control loop regulating circulating pump operation to control temperature within Cooling Shroud 150 to within +/- 2K from set point temperature of 70 K.

[00182] A variety of other Cooling Unit 150 configurations are possible and are known to those skilled in the art. These alternative configurations for Cooling Unit 150 may be configured to remove heat from the system according to the specifications that the system maintains the operating temperature of all superconducting materials below the critical temperature of the superconductor. Some cooling systems that may also be used to maintain system operating temperatures include: reverse Brayton systems, pulsed tube systems, and/or multi-staged Stirling systems

[00183] EM wave Generator 110: The system may desirably utilize a low noise high quality quartz master reference oscillator (MRO) as the frequency source. The inherent characteristics of the quartz crystal provide the high stability and precision frequency desired to maximize the efficiency of exemplary embodiments of the present invention. The MRO may provide a frequency output of 160 MHz at a power output level of 3 watts while consuming less than 30W of DC power. There are several potential sources of supply for the MRO including Wenzel Associates, Spectrum Microwave and Symmetricon. All suppliers have high stability and precision frequency MROs used in instrumentation and satellite applications. The MRO may be packaged in an aluminum housing with a volume of approximately 100 in^3 and weighing less than three pounds. The crystal may be housed within an oven to minimize frequency drift versus changes in temperature.

[00184] EM Wave Generator 110 desirably provides all power conditioning necessary to maintain 3 watts of 160 MHz EM wave energy into Resonating Cavity 200

[00185] The MRO output may be coupled into Resonating Cavity 200 using antenna probes. The antenna probe may be formed using the center conductor of Coaxial Cable A 111A and Coax Cable B 111B connecting the MRO to Resonating Cavity 200.

[00186] The Power Source: The exemplary embodiment desirably uses power industry standard photovoltaic cells used in space applications. The total power requirement for operation of the exemplary embodiment is desirably less than 100 watts at 160 Volts DC to operate both the EM Wave Generator 110 and the Cooling Unit 130. However it is noted that other power sources, such as nuclear power sources and batteries, may be used as well.

[00187] Although the invention is illustrated and described herein with reference to specific embodiments, it is not intended to be limited to the details shown. Rather, various modifications may be made in the details within the scope and range of equivalents of the claims and without departing from the invention. In particular, one skilled in the art may understand that many features of the various specifically illustrated embodiments may be mixed to form additional exemplary propulsion systems and methods also embodied by the present invention.

What is Claimed:

1. A resonant cavity propulsion system comprising:

a resonant cavity including a conductive inner surface, the resonant cavity adapted to support a standing electromagnetic (EM) wave with an oscillating electric field vector pointing in a direction substantially normal to a transverse plane;

a thruster including a first conductive end and a second conductive end coupled by an electrically conductive coupling member;

an electrically insulating coupling member to mechanically couple the second conductive end of the thruster to the conductive inner surface of the resonant cavity such that:

the first conductive end of the thruster is substantially centered at an antinode of a lowest energy mode of the standing EM wave in the transverse plane; and

the second conductive end of the thruster is substantially outside of the standing EM wave; and

a frequency generator electrically coupled to the resonant cavity to generate the standing EM wave in the resonant cavity;

wherein EM interactions between the standing EM wave and the thruster produce a force in the direction substantially normal to the transverse plane.

2. A resonant cavity propulsion system according to claim 1, wherein the conductive inner surface of the resonant cavity includes at least one of gold, copper, aluminum, silver, nickel, tungsten, iron, platinum, lead, constantan, manganin, germanium, or nichrome.

3. A resonant cavity propulsion system according to claim 1, wherein a cross-section of the conductive inner surface of the resonant cavity parallel to the transverse plane of the standing EM wave is substantially circular.

4. A resonant cavity propulsion system according to claim 3, wherein:

the lowest energy mode of the standing EM wave has only one antinode in the transverse plane; and

the one antinode of the lowest energy mode of the standing EM wave substantially corresponds to a center of the substantially circular cross-section of the resonant cavity.

5. A resonant cavity propulsion system according to claim 3, wherein at least one of the first conductive end of the thruster or the second conductive end of the thruster is substantially spherically shaped.

6. A resonant cavity propulsion system according to claim 3, wherein the first conductive end of the thruster has an oblate spheroidal shape.

7. A resonant cavity propulsion system according to claim 1, wherein the conductive inner surface of the resonant cavity includes a cowl portion with an opening for the electrically conductive coupling member of the thruster to pass through, the cowl portion of the conductive inner surface of the resonant cavity shaped such that the second conductive end of the thruster is substantially shielded from the standing EM wave.

8. A resonant cavity propulsion system according to claim 1, wherein:

the standing EM wave generated in the resonant cavity has more than one antinode in the transverse plane;

the thruster includes one first conductive end, one second conductive end, and one electrically conductive coupling member corresponding to each antinode of the standing EM wave; and

the electrically insulating coupling member mechanically couples each second conductive end of the thruster to the conductive inner surface of the resonant cavity such that:

each first conductive end of the thruster is substantially centered at one antinode of the standing EM wave in the transverse plane; and

each second conductive end of the thruster is substantially outside of the standing EM wave.

9. A resonant cavity propulsion system according to claim 1, wherein the resonant cavity is adapted such that no modes of the supported standing EM wave have nodes that substantially correspond to the antinode of the lowest energy mode of the standing EM wave in which the first conductive end of the thruster is substantially centered.

10. A resonant cavity propulsion system according to claim 1, wherein an interior volume of the resonant cavity is substantially evacuated.

11. A resonant cavity propulsion system according to claim 1, wherein the first conductive end, the second conductive end, and the electrically conductive coupling member of the thruster include at least one of gold, copper, aluminum, silver, nickel, tungsten, iron, platinum, lead, constantan, manganin, germanium, or nichrome.

12. A resonant cavity propulsion system according to claim 1, wherein a first surface area of the first conductive end of the thruster is less than or equal to a second surface area of the second conductive end of the thruster.

13. A resonant cavity propulsion system according to claim 1, wherein the thruster is shaped and arranged within the resonant cavity to substantially prevent arcing between the thruster and the conductive inner surface of the resonant cavity when the thruster is subjected to the standing EM wave.

14. A resonant cavity propulsion system according to claim 1, wherein at least one of a portion of a surface of the thruster or a portion of the conductive inner surface of the resonant cavity is coated with an electrically insulating material to substantially prevent arcing between the thruster and the conductive inner surface of the resonant cavity when the thruster is subjected to the standing EM wave.

15. A resonant cavity propulsion system according to claim 1, wherein the electrically insulating coupling member formed of at least one of a ceramic material, a glass, polystyrene, Aerogel, silicon nitride, boron nitride, aluminum nitride, aluminum oxide, polyurethane, or a polyamide.

16. A resonant cavity propulsion system according to claim 1, further comprising a cooling unit thermally coupled to the resonant cavity to substantially maintain an inner surface temperature of the conductive inner surface of the resonant cavity at a predetermined temperature.

17. A resonant cavity propulsion system according to claim 16, wherein:

the first conductive end, the second conductive end, and the electrically conductive coupling member of the thruster include a superconducting material having a thruster critical temperature;

the electrically insulating coupling member has a high thermally conductivity; and

the predetermined temperature is selected such that a thruster temperature of the thruster is maintained at less than the thruster critical temperature.

18. A resonant cavity propulsion system according to claim 16, wherein:

the conductive inner surface of the resonant cavity includes a superconducting material having a cavity critical temperature; and

the predetermined temperature is less than the cavity critical temperature.

19. A resonant cavity propulsion system according to one of claims 17 or 18, wherein the superconducting material is at least one of niobium, copper, YBCO, $Bi_2Sr_2CuCu_2O_8$, YaBaCuO, LaBaCuO, Nb_3Sn, TlBaCuO, $La_{2-x}Ba_xCuO_4$, $La_{2-x}Sr_xCuO_4$, PbMoS, V_3Ga, NbN, Nb_3Al, $Nb_3(AlGe)$, Nb_3Ge, a type I superconductor, a type II superconductor, or high temperature superconductor with T_c higher than 4 K.

20. A resonant cavity propulsion system according to claim 16, wherein the cooling unit includes at least one of a radiative cooling element, a Peltier cooling element, a dilution refrigerator, a vapor-compression refrigerator, a reverse turbo-Brayton cooler, a sorption cooler, a cryogenic cooling element, a Stirling cooling

element, a pulse tube cooling element, a Joule-Thompson cooling element, a reverse Brayton cooler, or a magnetic cooler.

21. A resonant cavity propulsion system according to claim 1, wherein the first conductive end of the thruster includes a telescoping element to vary at least one of a size or a shape of the first conductive end of the thruster.

22. A resonant cavity propulsion system according to claim 1, wherein the electrically conductive coupling member of the thruster includes a telescoping element to vary a position of the first conductive end of the thruster within the resonant cavity.

23. A resonant cavity propulsion system according to claim 1, wherein the electrically insulating coupling member includes a telescoping element to vary a position of the thruster within the resonant cavity.

24. A resonant cavity propulsion system according to claim 1, further comprising:

a housing mechanically coupled to the resonant cavity to hold and orient the resonant cavity; and

control circuitry electrically coupled to the housing to control the orientation of the transverse plane of the resonant cavity relative to the housing.

25. A resonant cavity propulsion system according to claim 24, wherein the housing includes a 3-axis gimbal to allow 6-axis control of the orientation of the transverse plane of the resonant cavity relative to the housing.

26. A resonant cavity propulsion system comprising:

a resonant cavity including a conductive inner surface, the resonant cavity adapted to support a standing electromagnetic (EM) wave with an oscillating electric field vector pointing in a direction substantially normal to a transverse plane;

a thruster including a conductive end and an electrically conductive coupling member, the electrically conductive coupling member coupled between the conductive inner surface of the resonant cavity and the conductive end of the thruster such that the conductive end of the thruster is substantially centered at an antinode of a lowest energy mode of the standing EM wave in the transverse plane; and

a frequency generator electrically coupled to the resonant cavity to generate the standing EM wave in the resonant cavity;

wherein EM interactions between the standing EM wave and the thruster produce a force in the direction substantially normal to the transverse plane.

27. A method of generating a unidirectional force using a resonant cavity, the method comprising the steps of:

a) generating a standing electromagnetic (EM) wave in the resonant cavity, the standing EM wave having an oscillating electric field vector pointing in a direction substantially normal to a transverse plane;

b) arranging a thruster within the resonant cavity such that:

a first conductive end of the thruster is substantially centered at an antinode of a lowest energy mode of the standing EM wave in the transverse plane; and

a second conductive end of the thruster is substantially outside of the standing EM wave; and

c) interacting the standing EM wave with conduction charges within the thruster to produce the unidirectional force in the direction substantially normal to the transverse plane.

28. A method according to claim 27, wherein step (a) includes using a frequency generator electrically coupled to the resonant cavity to generate the standing EM wave in the resonant cavity.

29. A method according to claim 27, wherein step (b) includes mechanically coupling the second conductive end of the thruster to an inner conductive surface of the resonant cavity using an electrically insulating coupling member.

30. A method according to claim 27, wherein step (c) includes the steps of:

c1) driving the conduction charges of the thruster between the first conductive end of the thruster and the second conductive end of the thruster to generate a charge surplus in the first conductive end of the thruster that varies substantially in phase with the oscillating electric field vector of the standing EM wave; and

c2) generating the unidirectional force based on electrostatic interactions between the varying charge surplus in the first conductive end of the thruster and the oscillating electric field vector of the standing EM wave.

31. A method according to claim 27, wherein step (c) includes the steps of:

c1) driving the conduction charges of the thruster between the first conductive end of the thruster and the second conductive end of the thruster to generate a current between the first conductive end of the thruster and the second conductive end of the thruster that varies substantially out of phase with the oscillating electric field vector of the standing EM wave; and

c2) generating the unidirectional force based on magnetic interactions between the oscillating current in the thruster and an oscillating magnetic field vector of the standing EM wave.

32. A method according to claim 27, wherein step (c) includes the steps of:

c1) driving the conduction charges of the thruster between the first conductive end of the thruster and the second conductive end of the thruster to generate a current between the first conductive end of the thruster and the second conductive end of the thruster that varies substantially out of phase with the oscillating electric field vector of the standing EM wave; and

c2) generating the unidirectional force based on a difference in Lorentz forces on the oscillating current due to the standing EM wave at the first conductive end of the thruster and Lorentz forces on the oscillating current due to the standing EM wave at the second conductive end of the thruster.

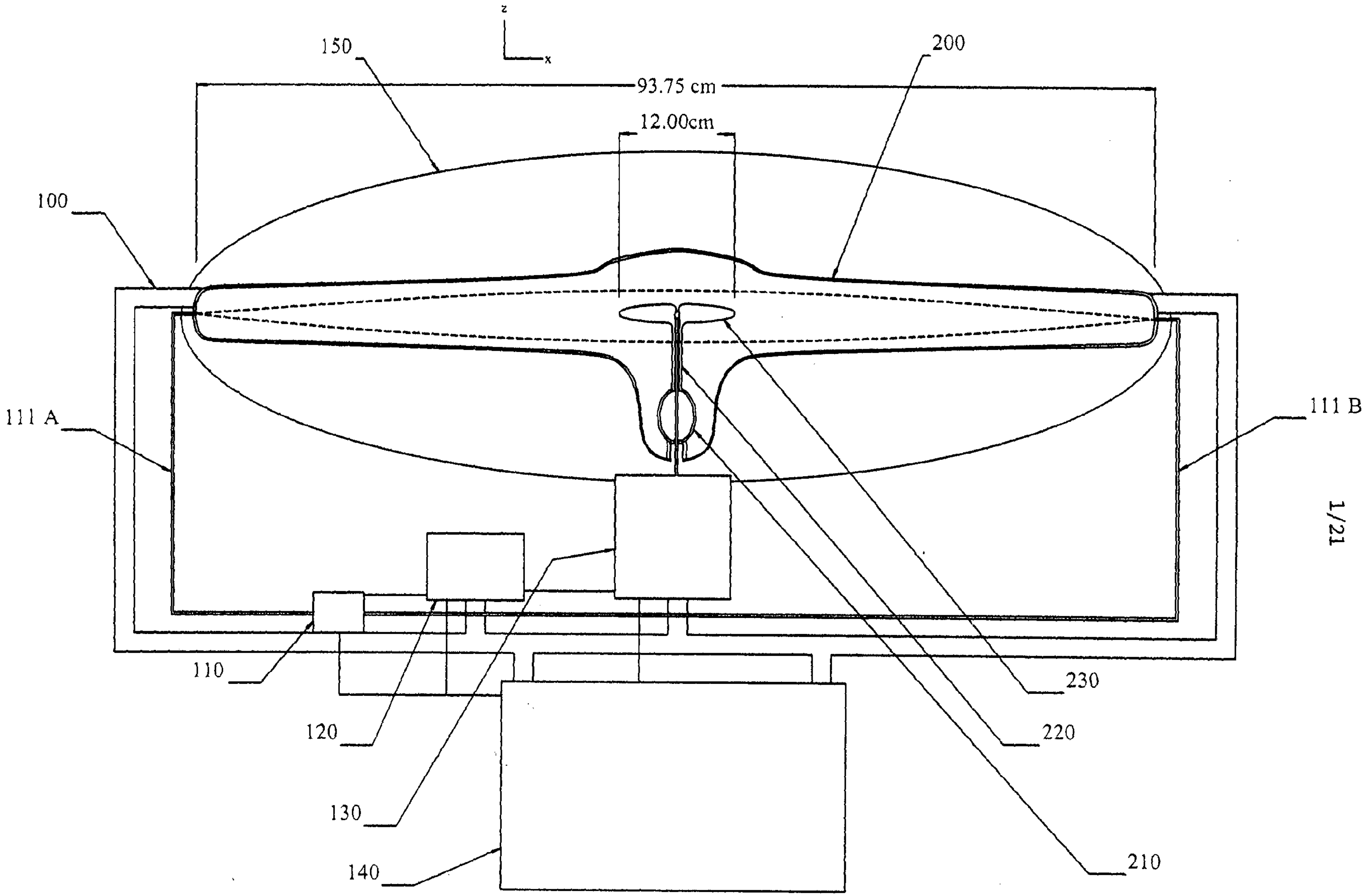
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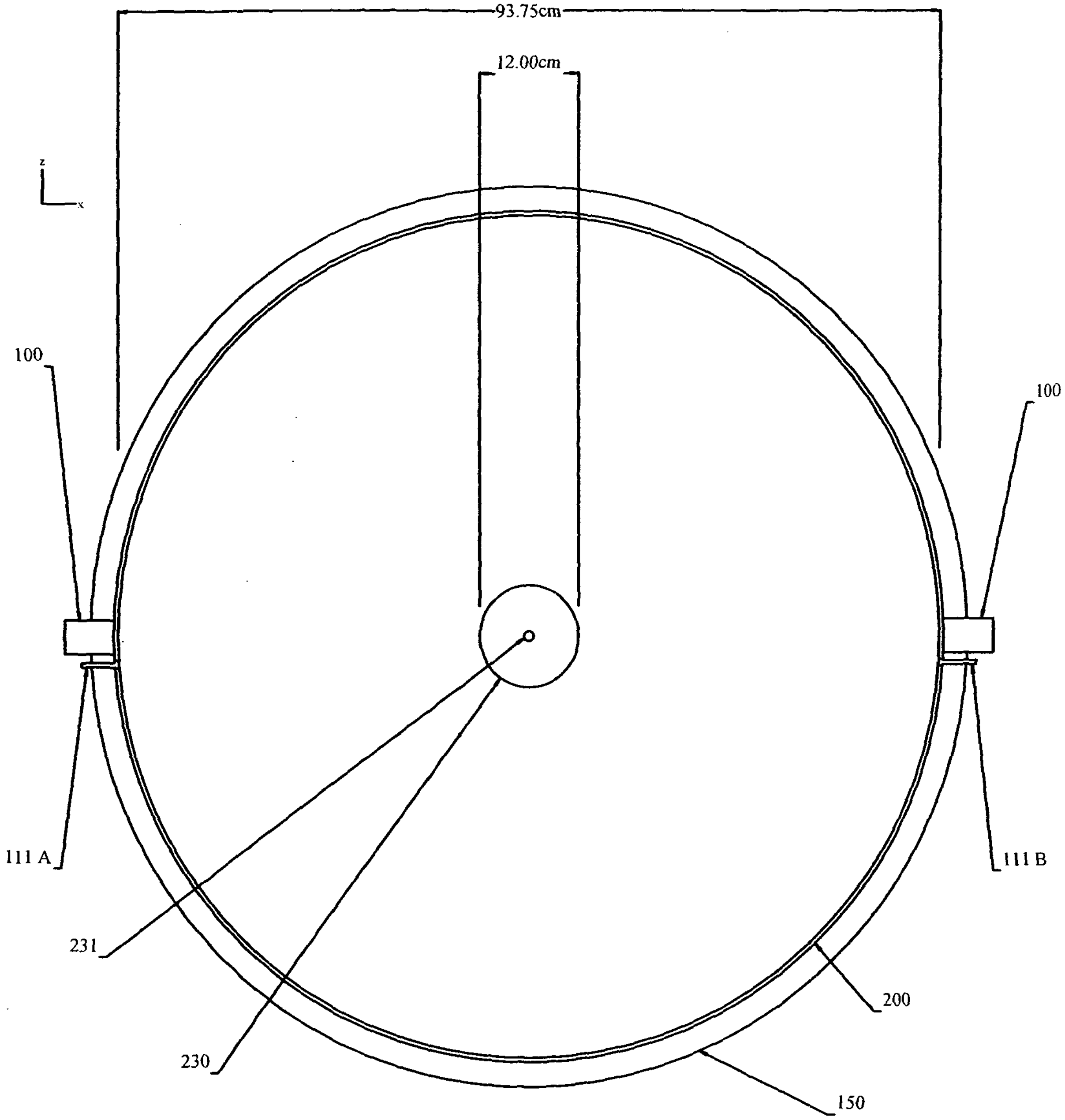
Figure 1



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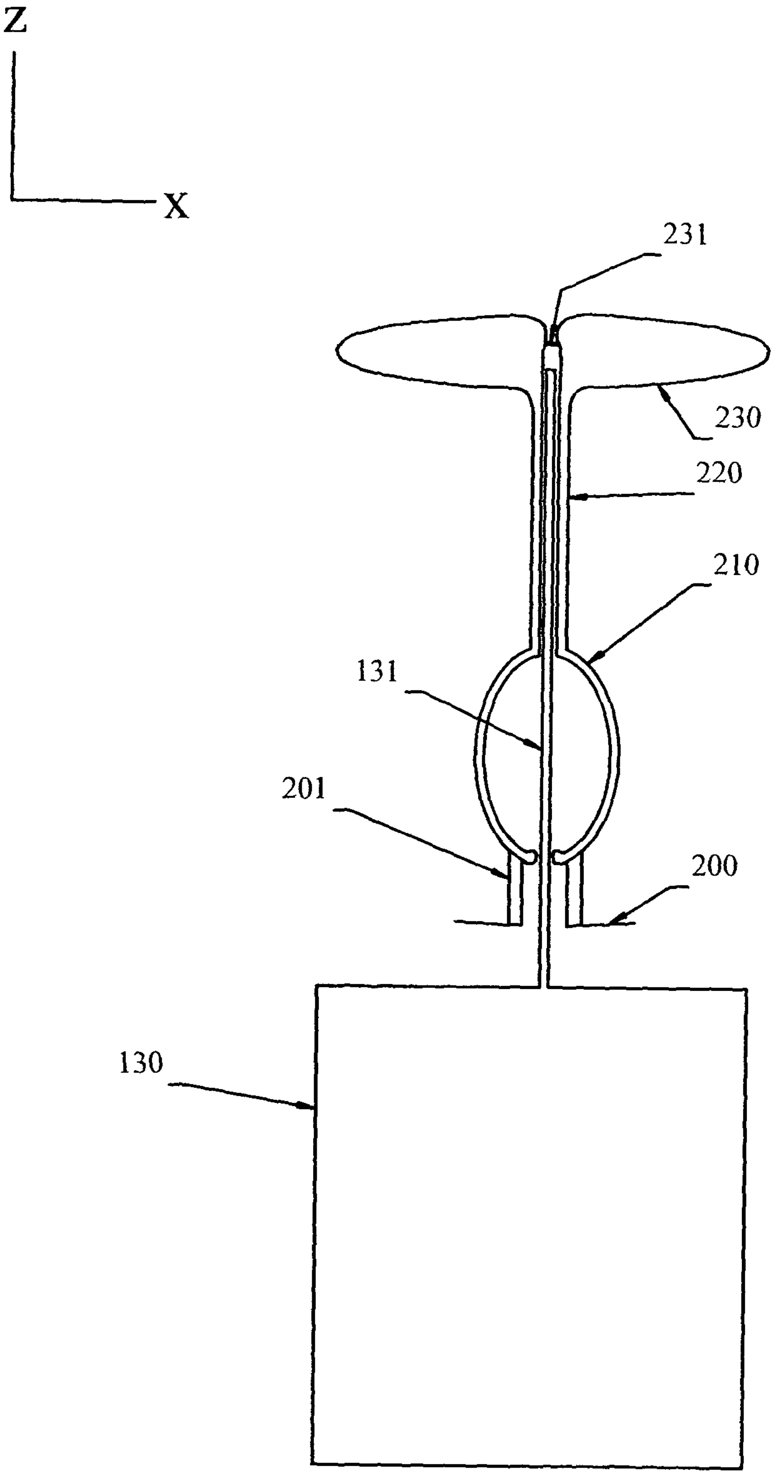

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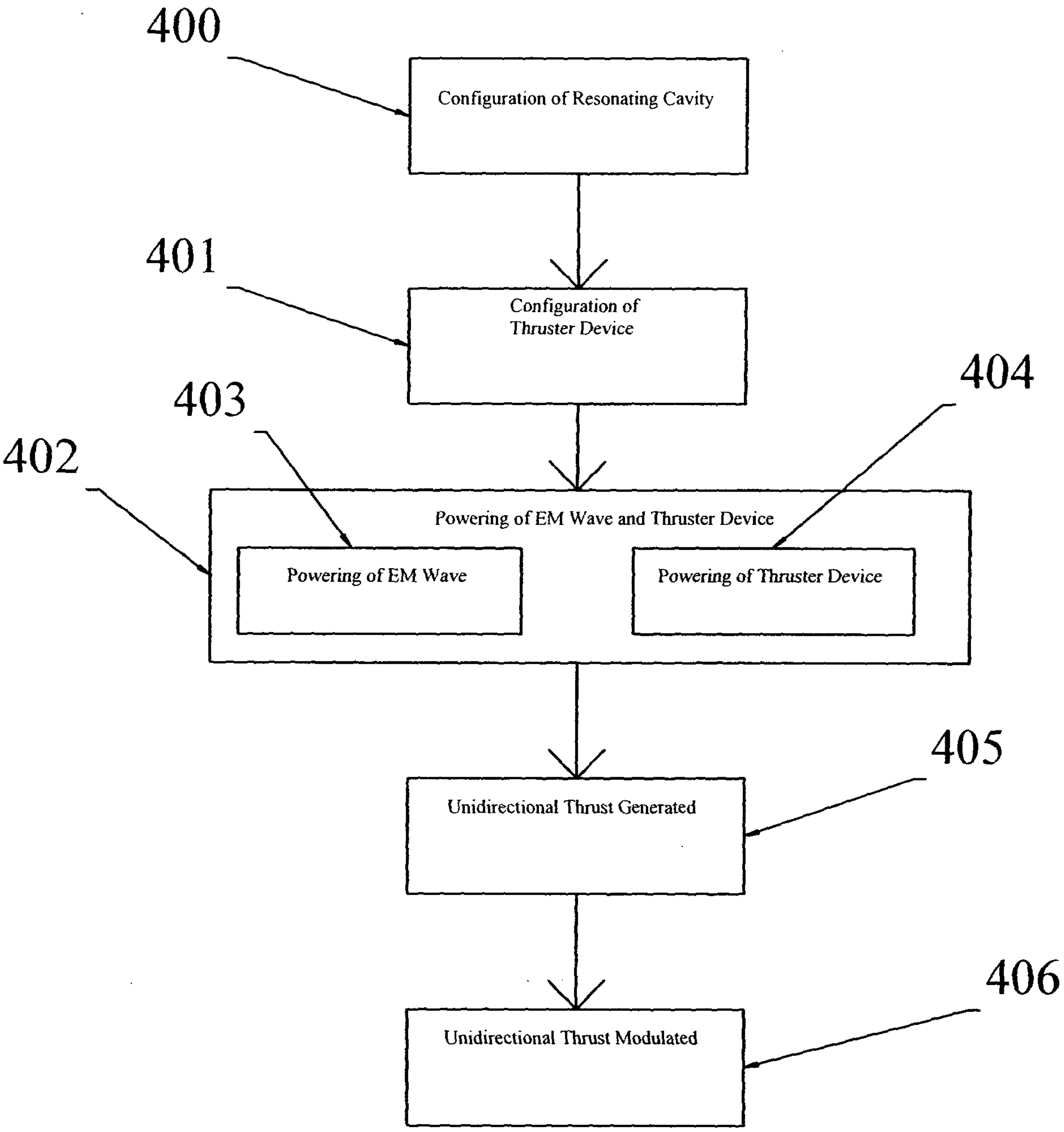
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Configuration of Resonating Cavity
401
Configuration of Thruster Device
403
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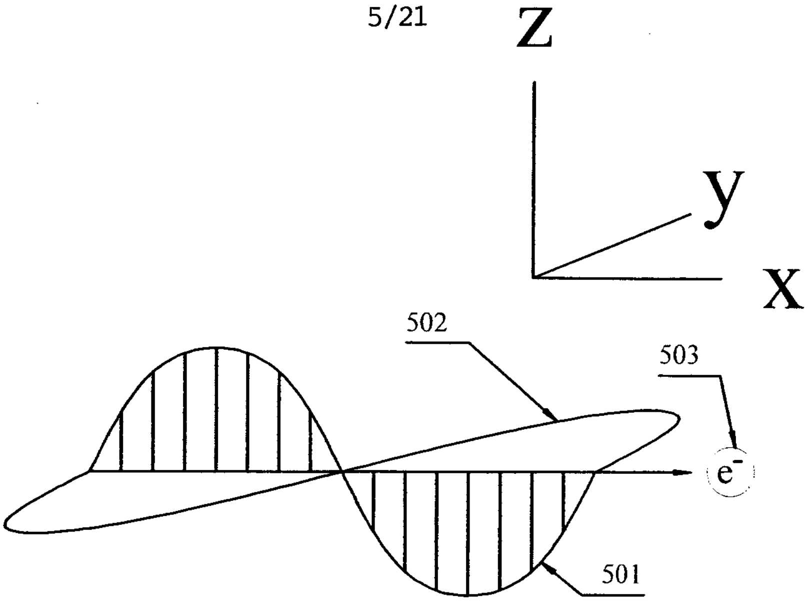
402
Powering of EM Wave and Thruster Device
Powering of EM Wave
Powering of Thruster Device
405
Unidirectional Thrust Generated
406
Unidirectional Thrust Modulated

Figure 4



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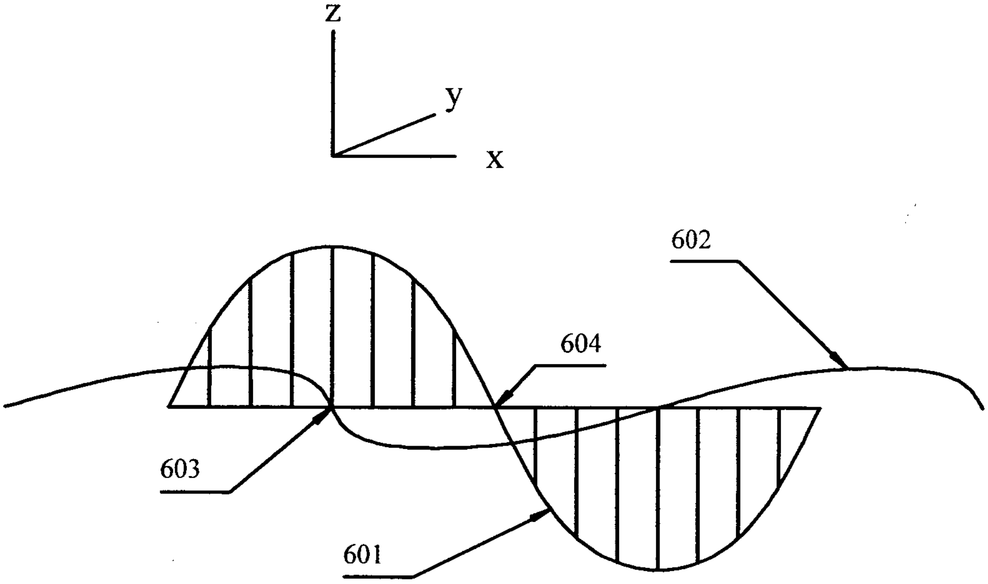

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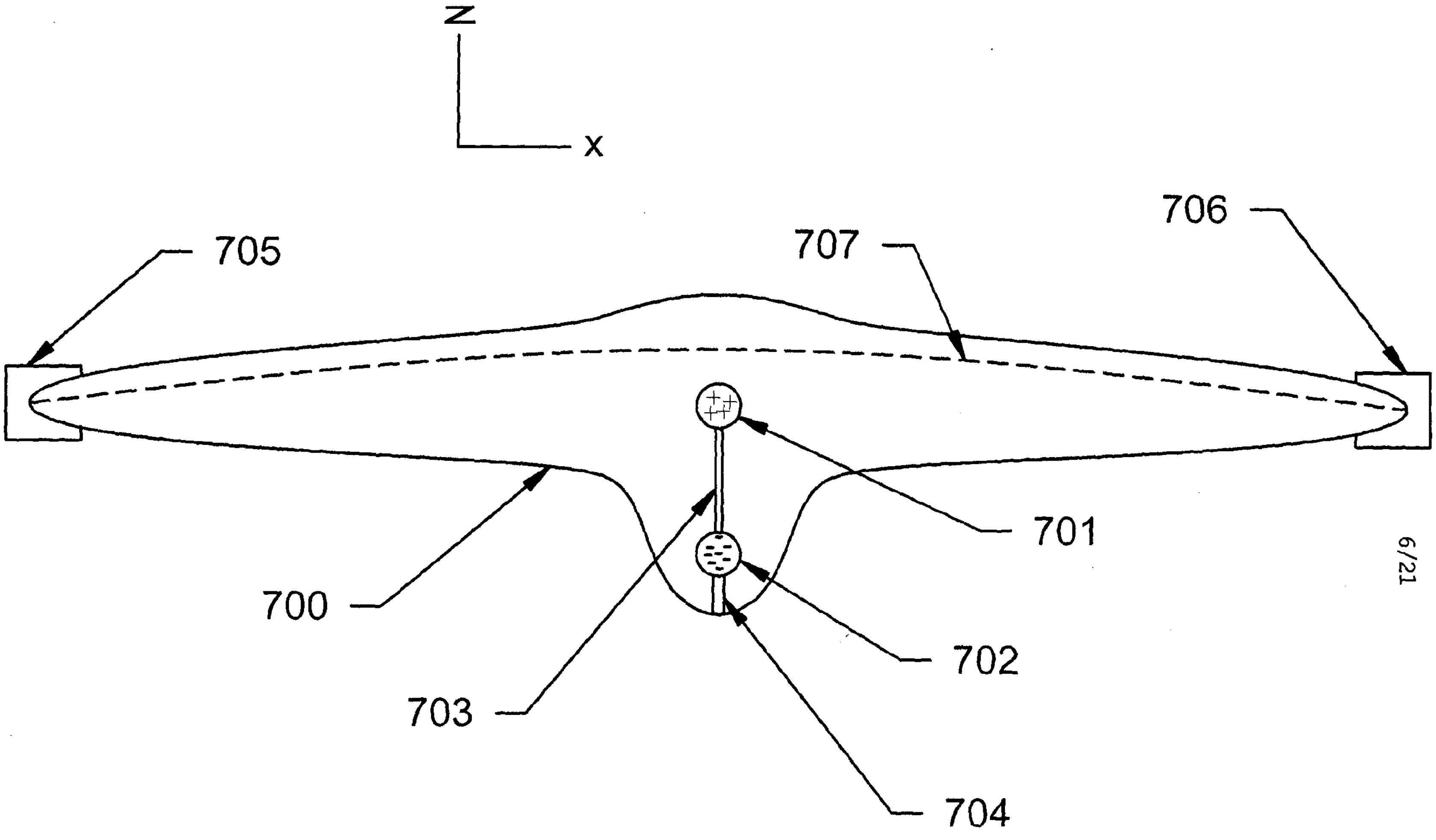

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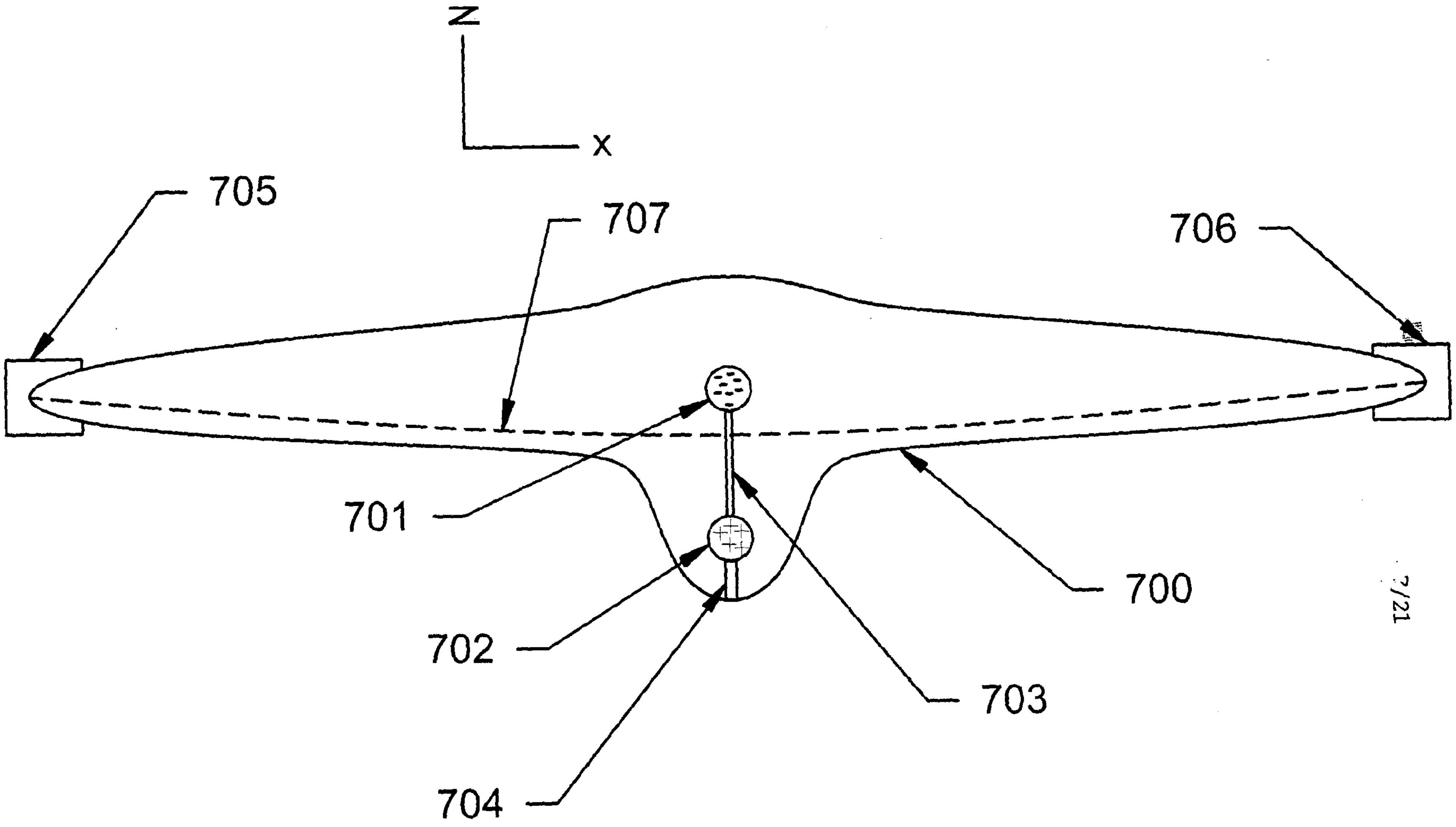

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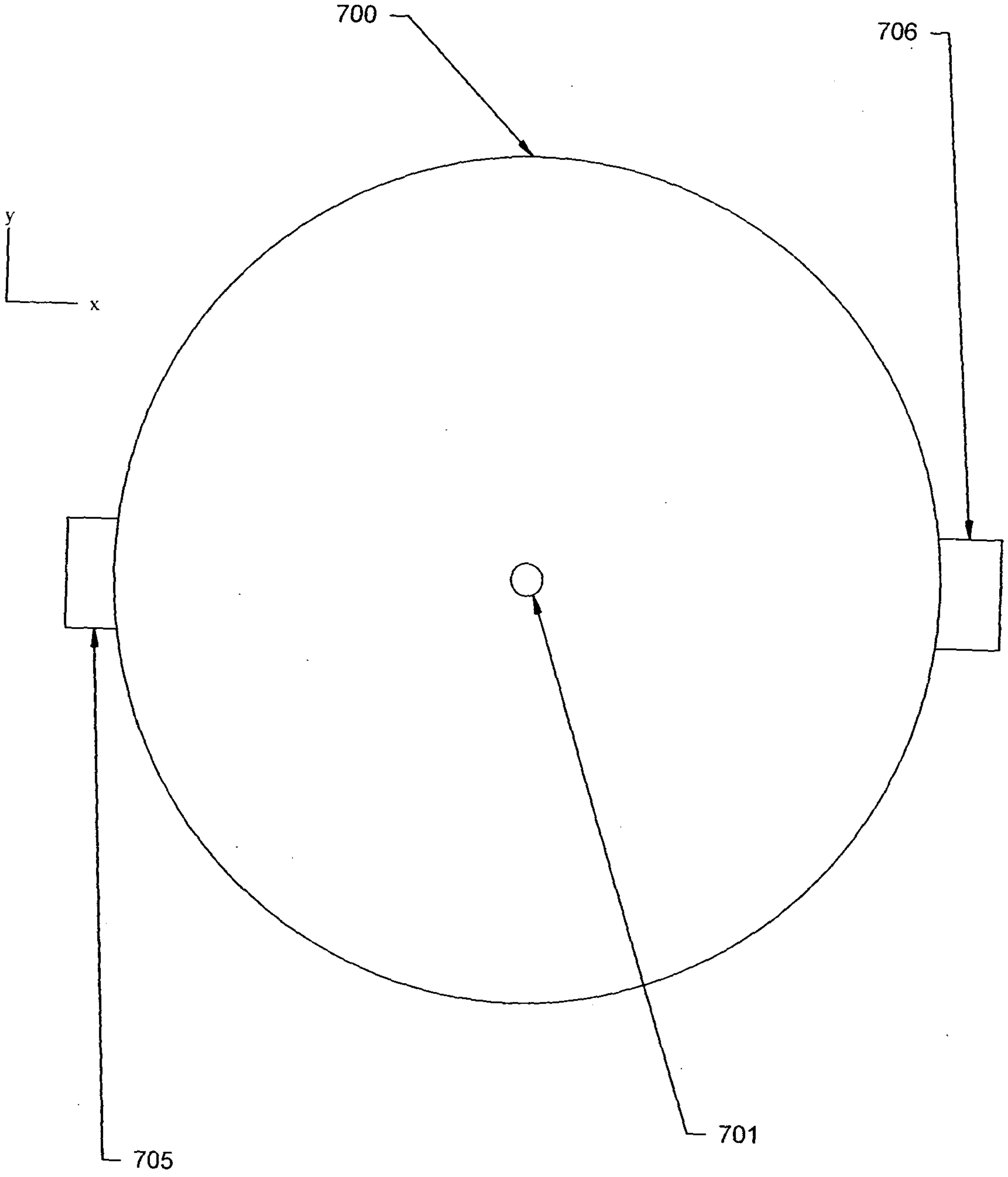

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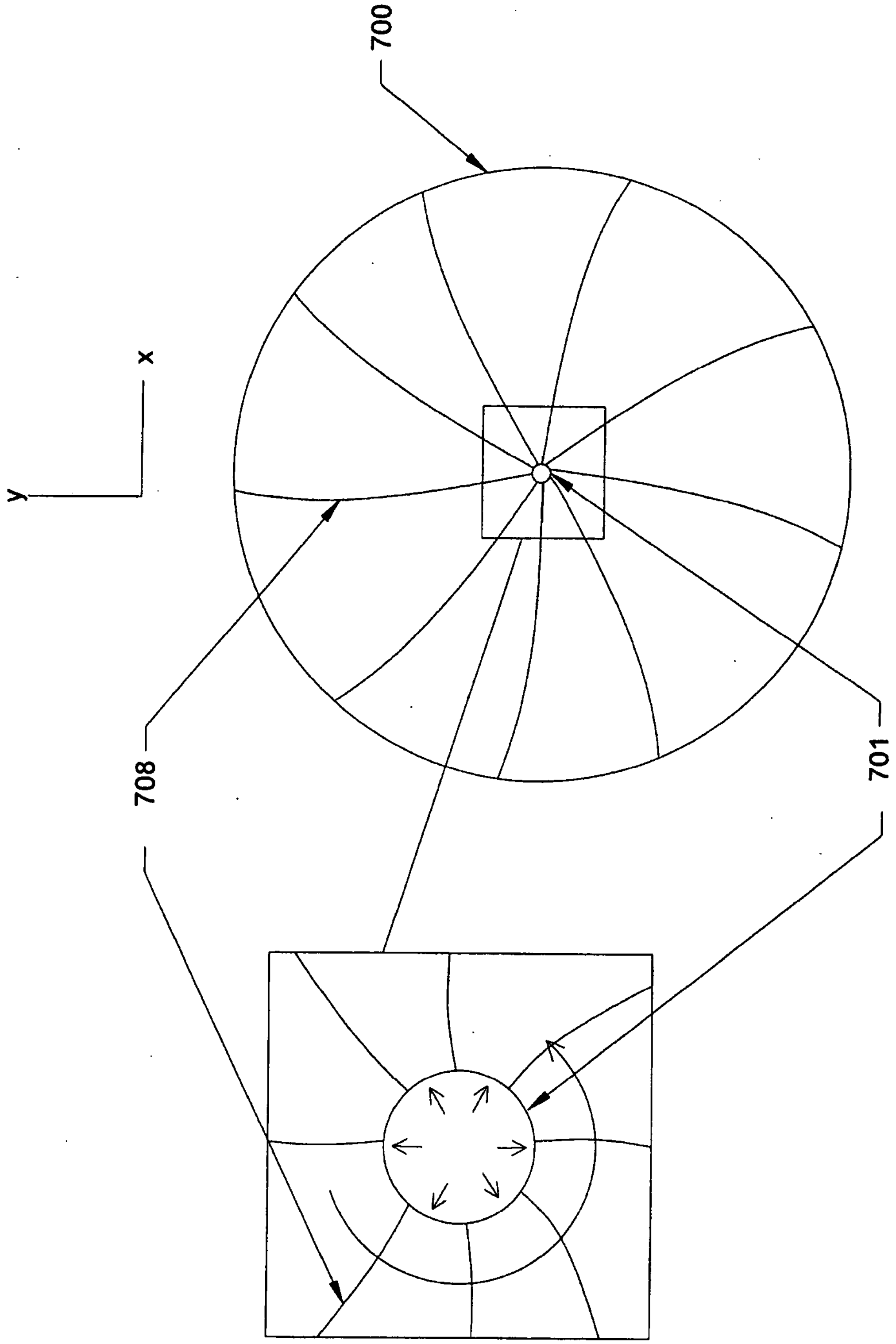

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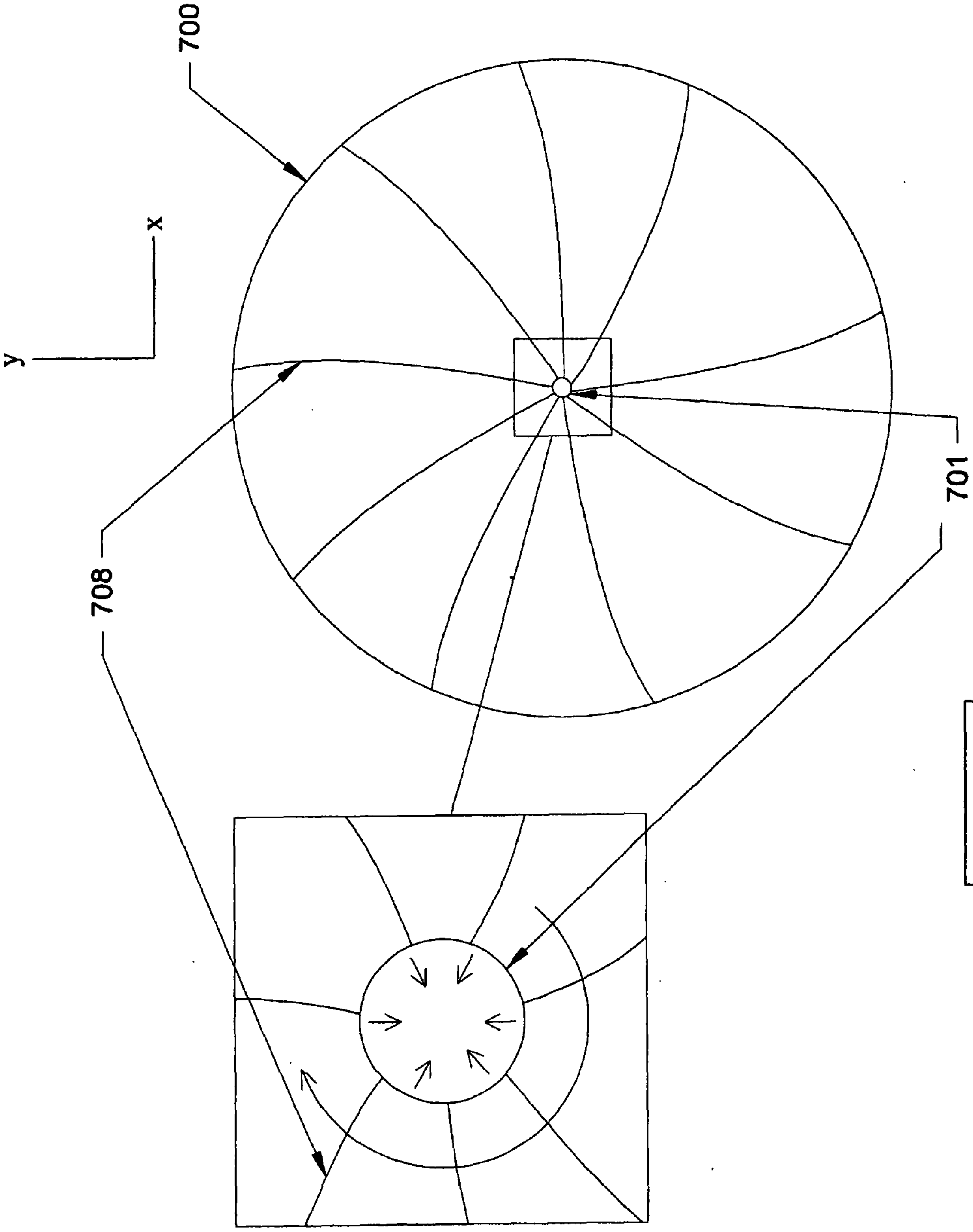

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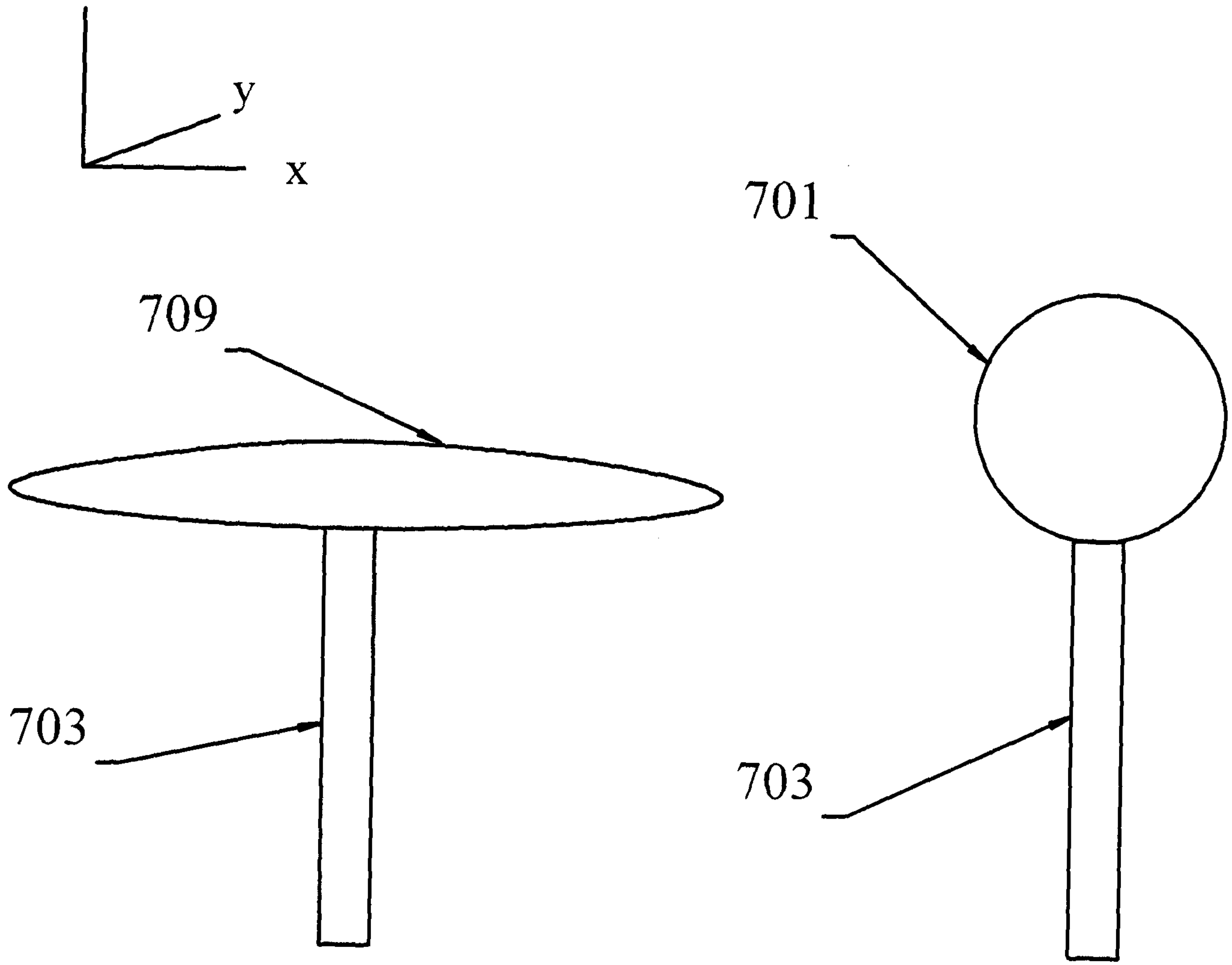

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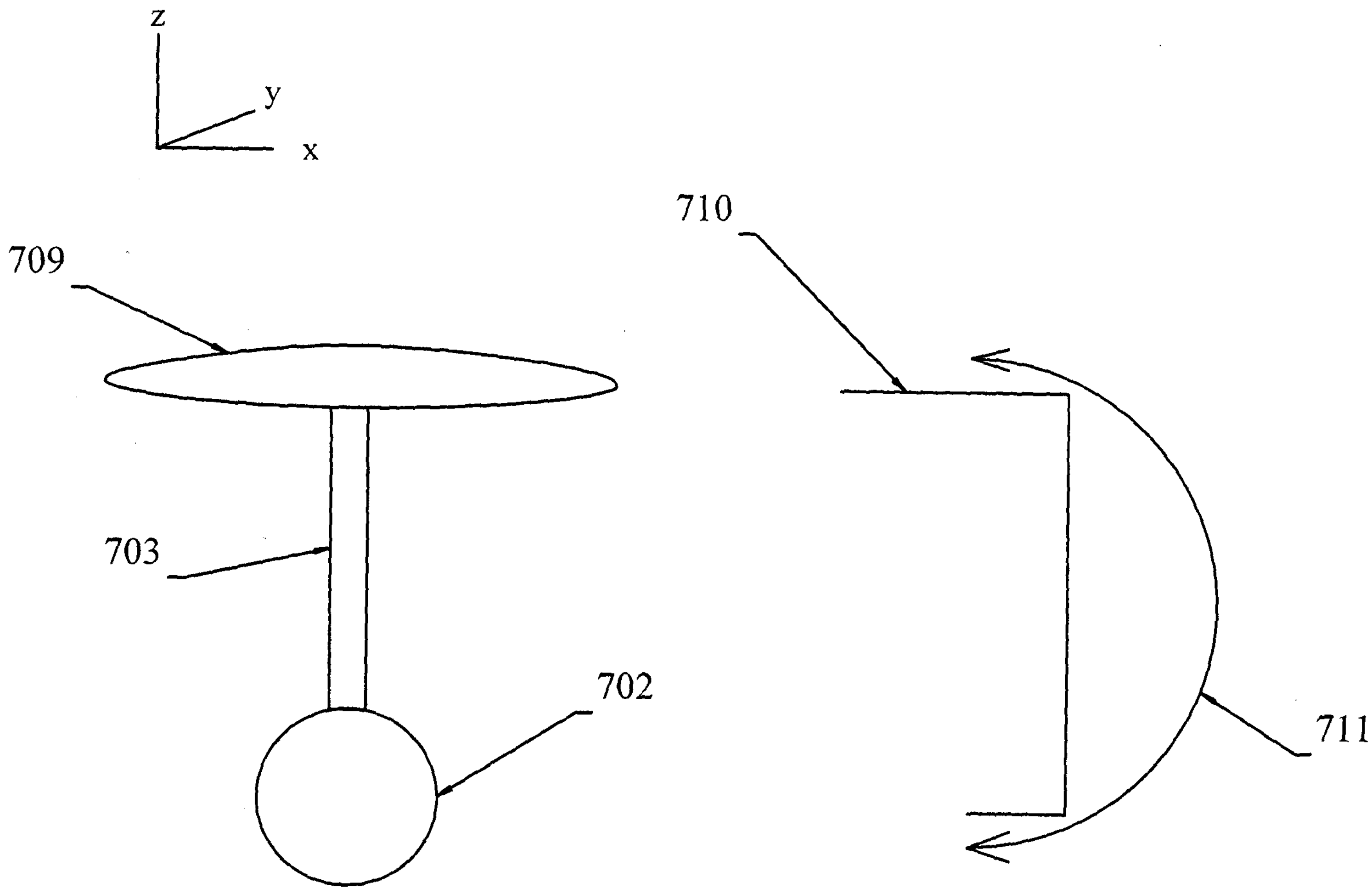

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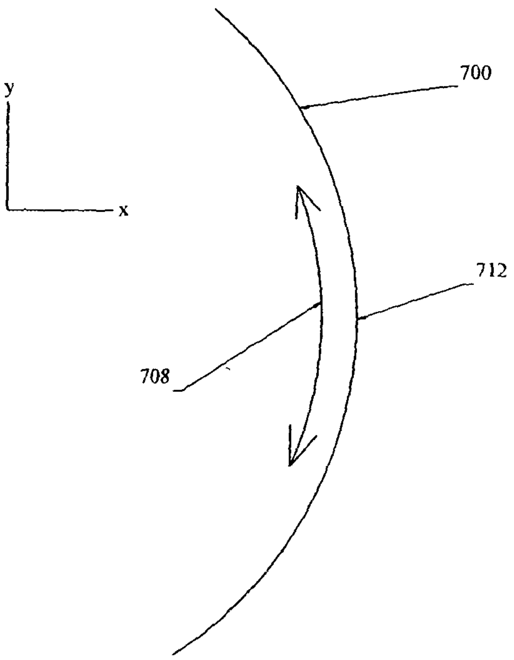

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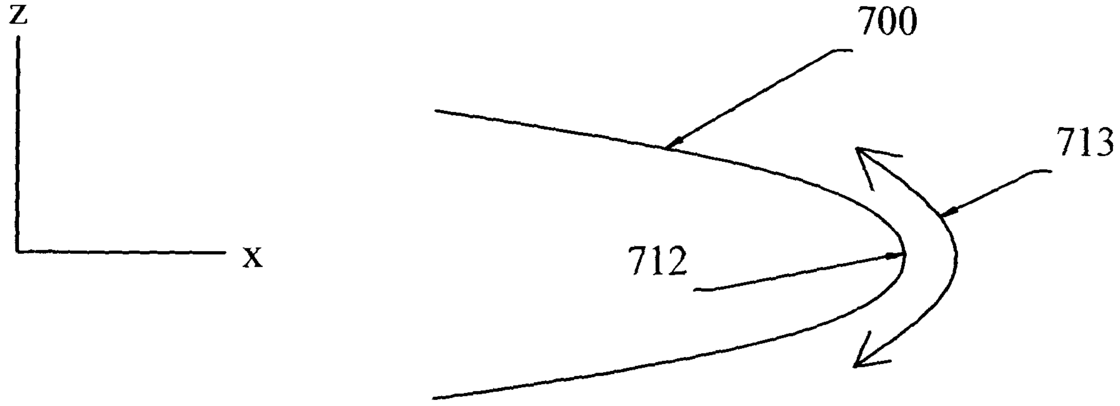

Figure 12B

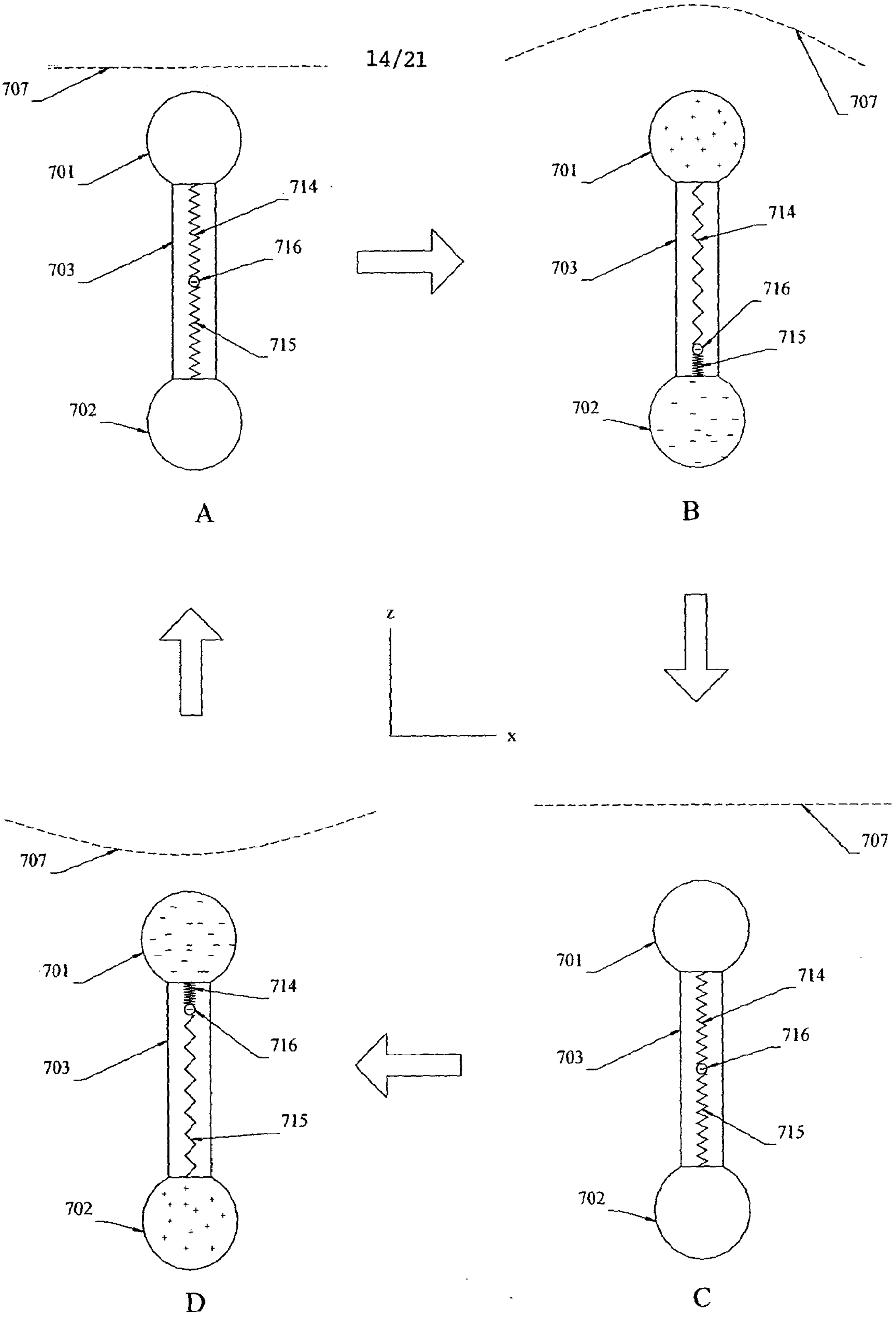
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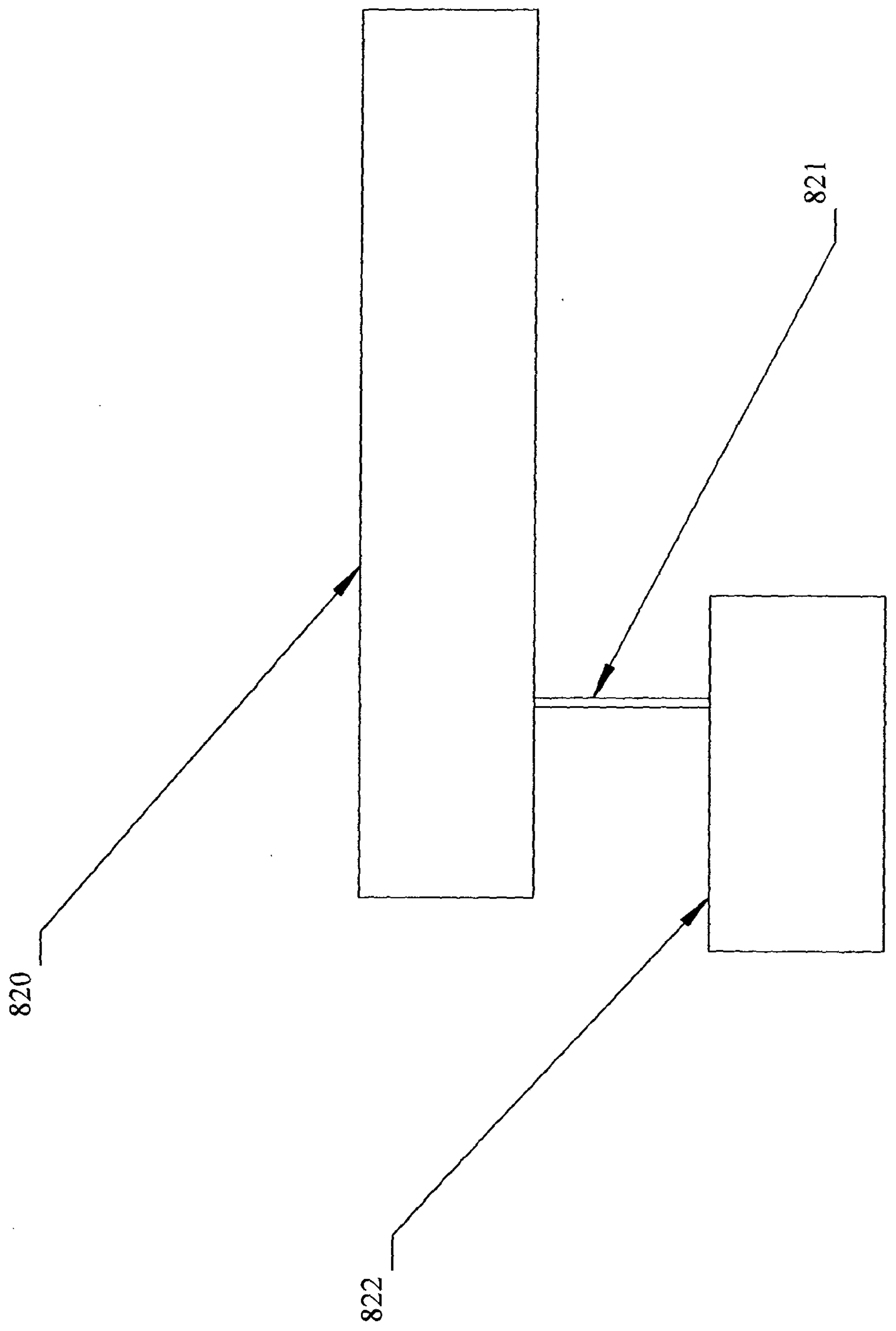
Figure 13



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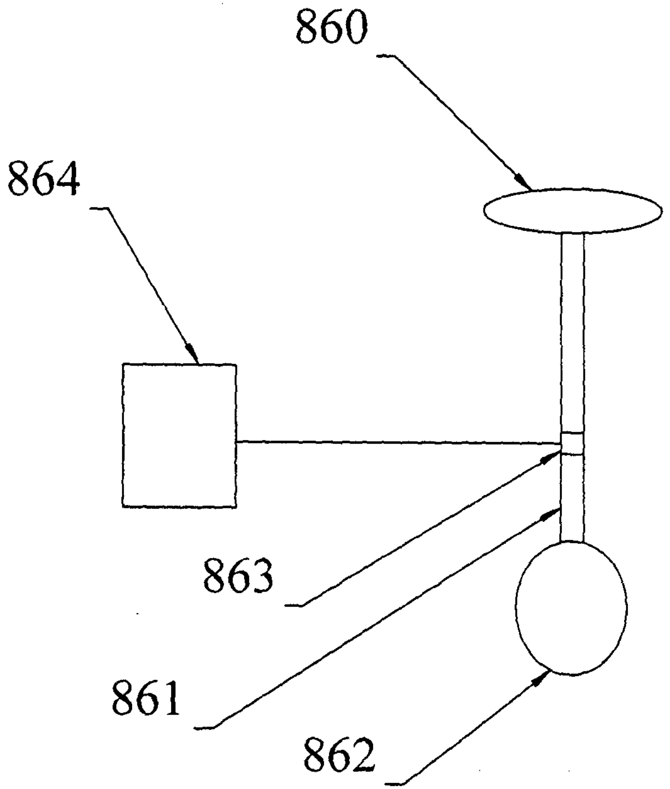

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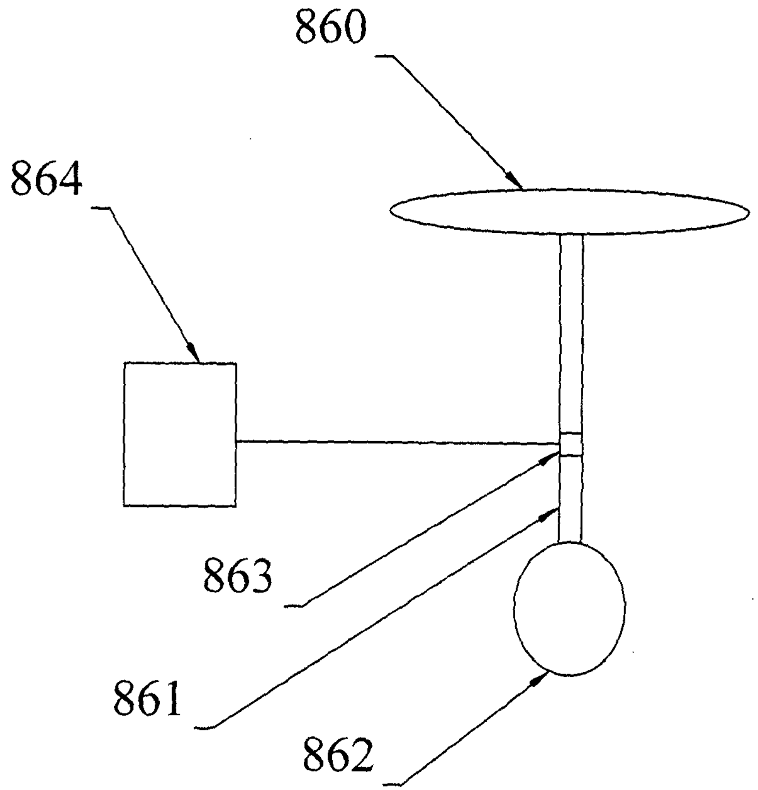

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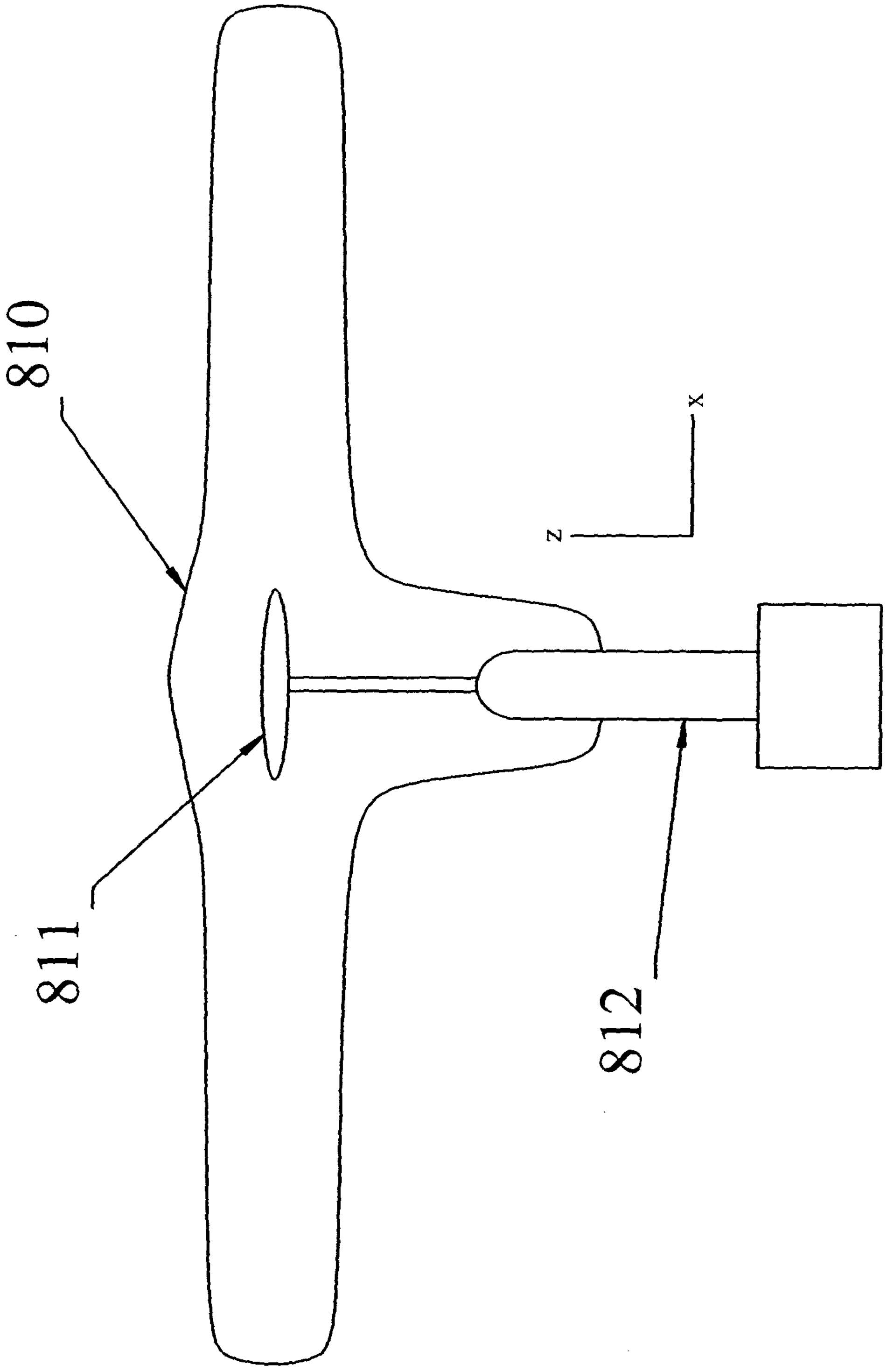

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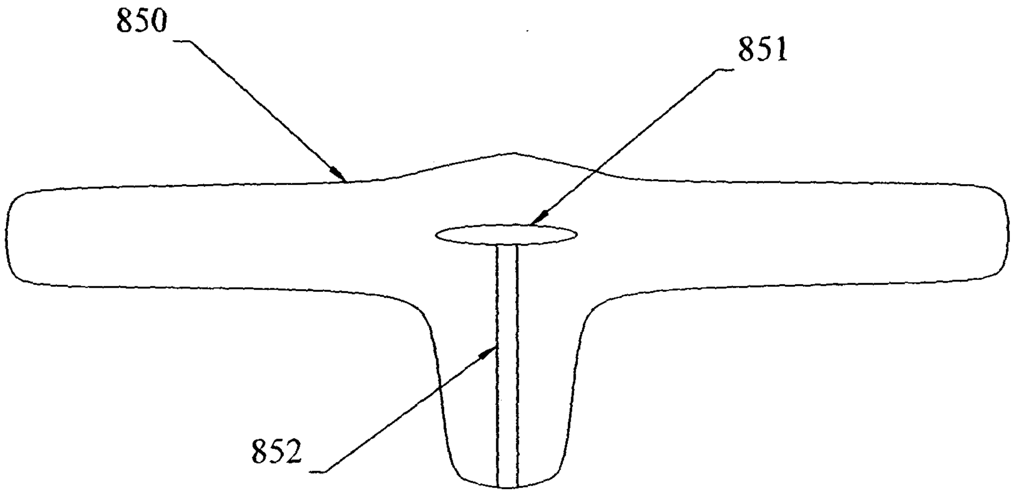

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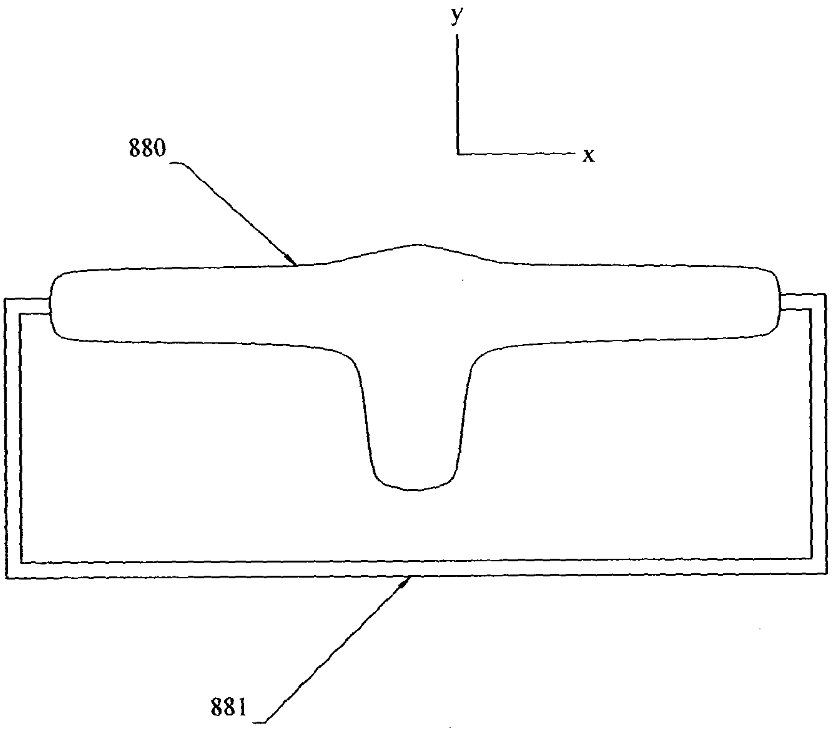

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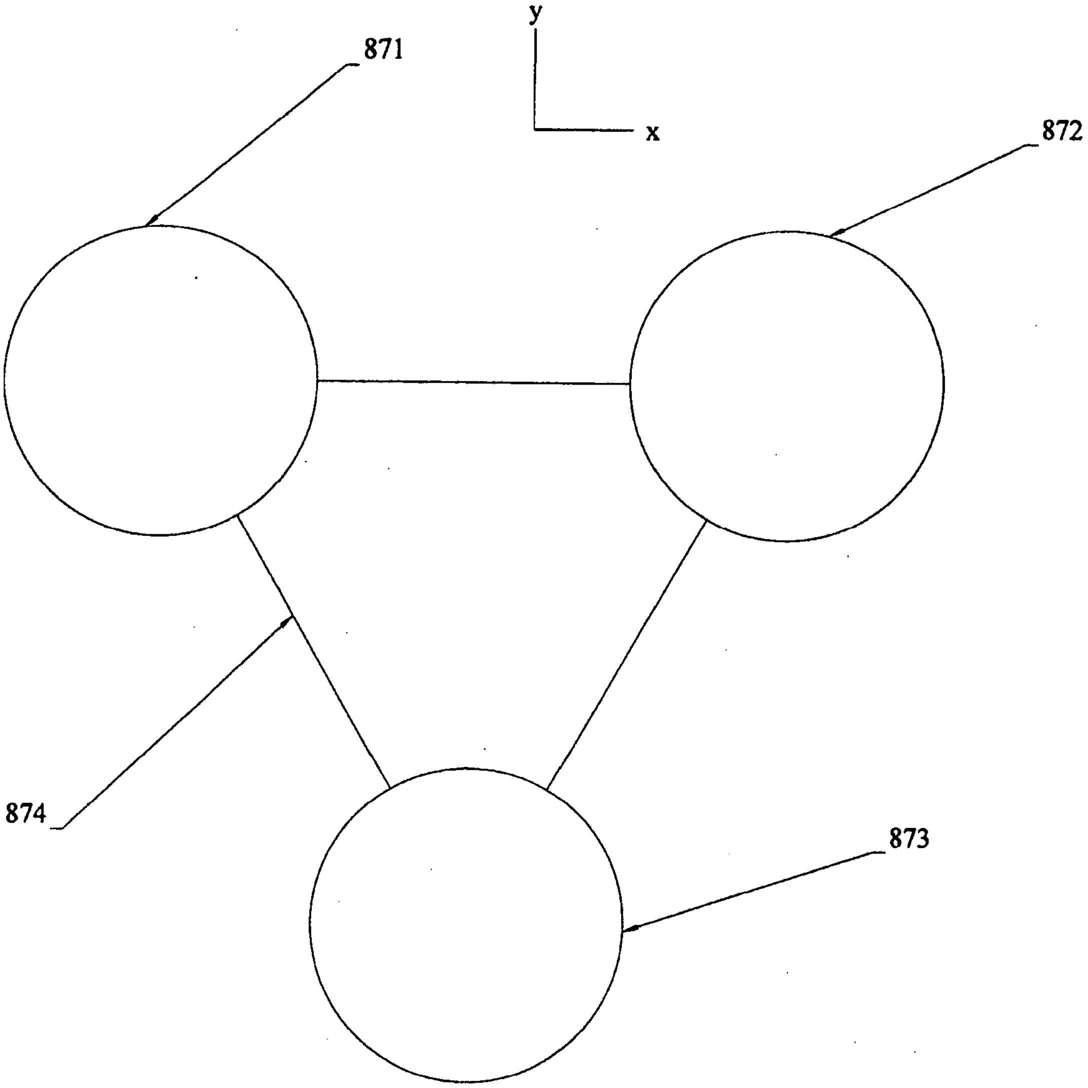

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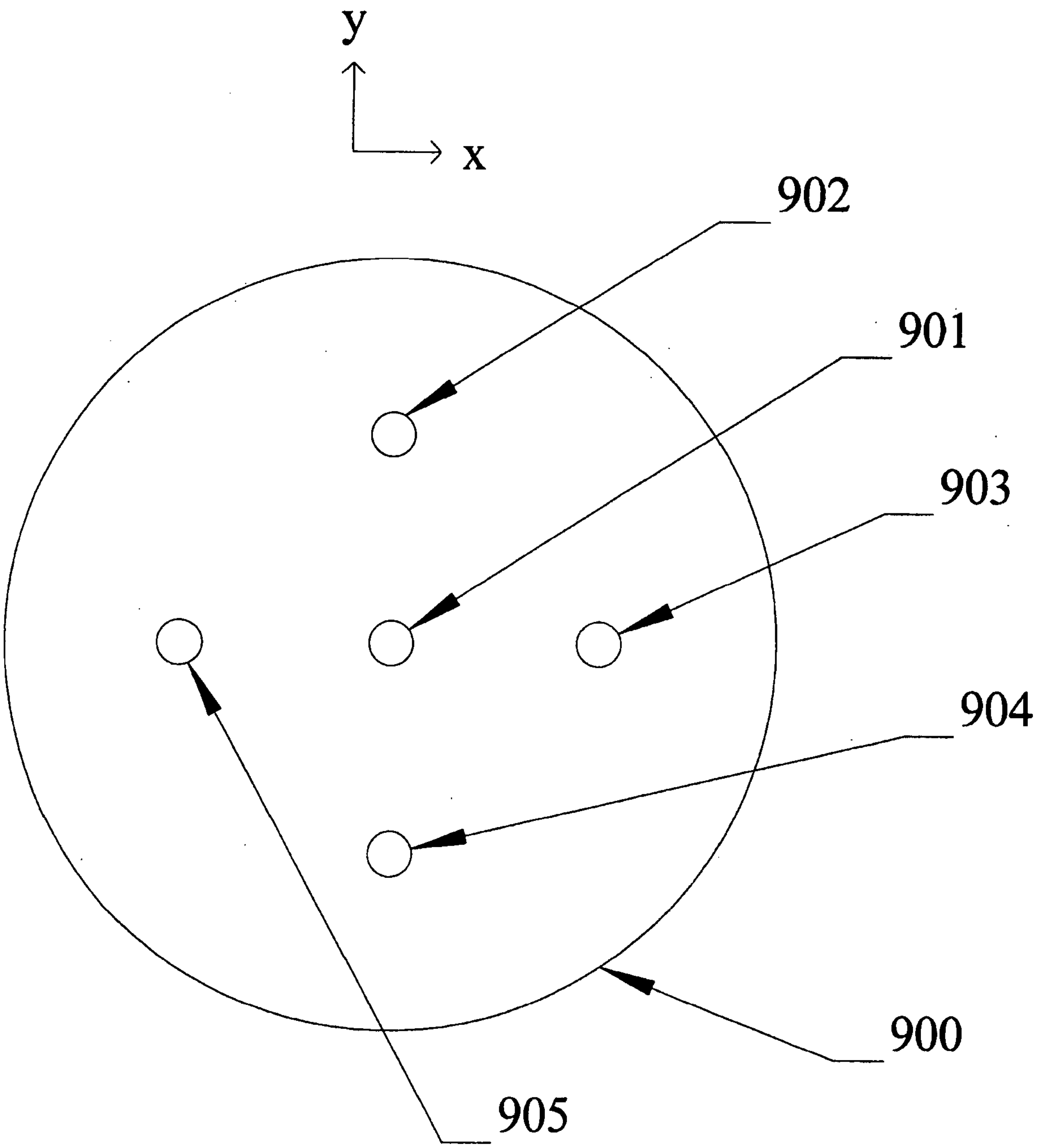

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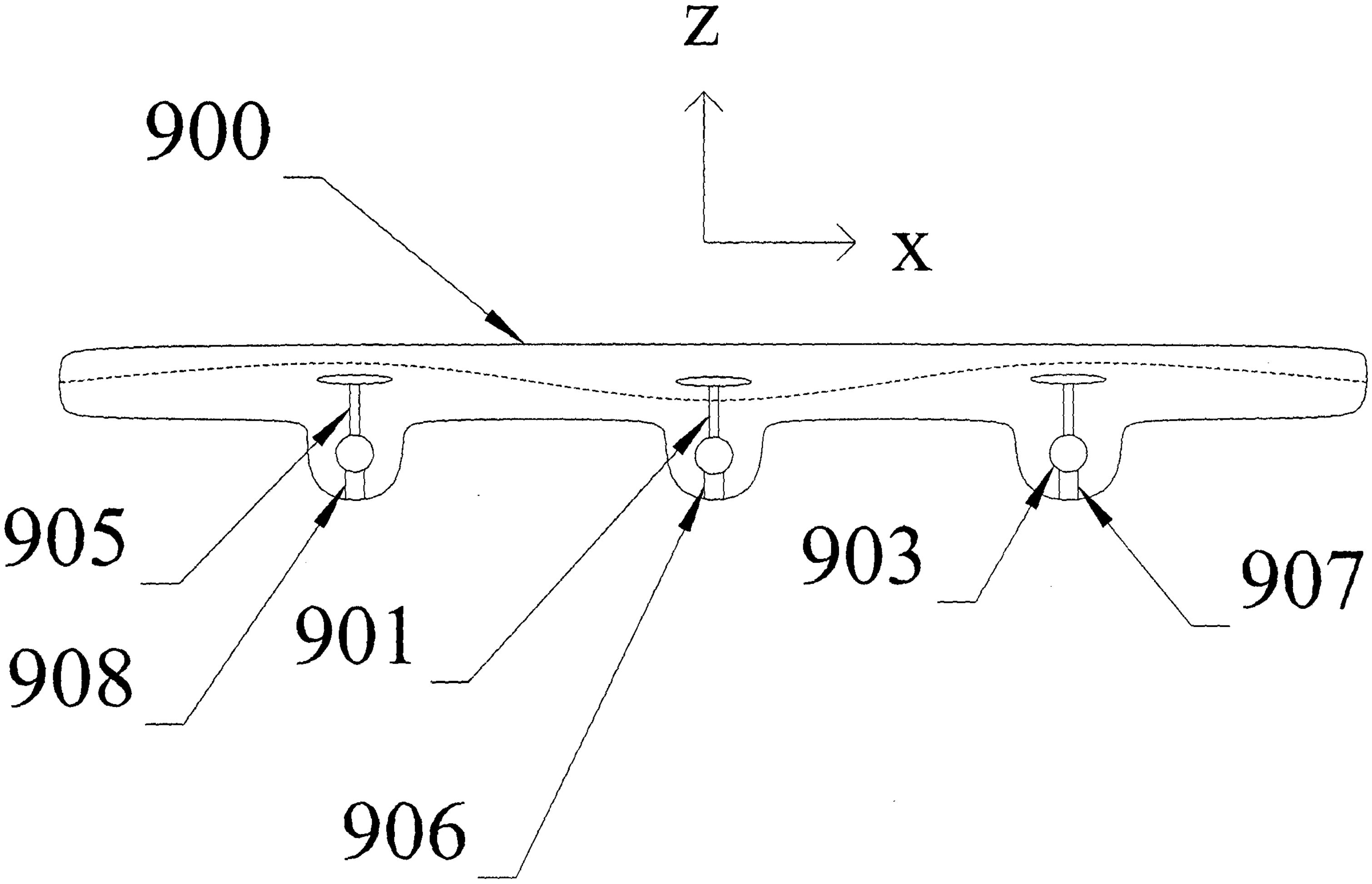

Figure 21