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(54) **Title:** ROTATIONAL INERTIAL DRIVE SYSTEM AND BEARING SYSTEMS FOR ELECTROACTIVE POLYMER DEVICES

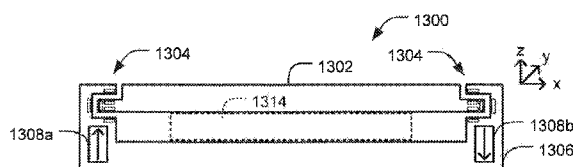


FIG. 13

(57) **Abstract:** An apparatus is disclosed, which includes a movable surface having a first end and a second end. The first and second ends are arranged on opposite ends of the movable surface. At least a first actuator is coupled to the first end of the movable surface. At least a second actuator is coupled to the second end of the movable surface. The at least first and second actuators are operably out-of-phase relative to each other and are in a rotational inertial configuration about a moment of inertia defined by the movable surface. Also disclosed is a magnetic bearing configured to suspend the movable surface. In addition, a magnetic bearing retention system is disclosed.

ROTATIONAL INERTIAL DRIVE SYSTEM AND BEARING SYSTEMS FOR ELECTROACTIVE POLYMER DEVICES

RELATED APPLICATIONS

5 This application claims the benefit, under 35 USC § 119(e), of U.S. Provisional Application No.: 61/666,127 filed June 29, 2012 entitled “MAGNETIC SURFACE BEARING”, U.S. Provisional Application No.: 61/615,915 filed March 27, 2012 entitled “ROTATIONAL INERTIAL DRIVE SYSTEM TO MINIMIZE ACTUATOR POWER REQUIREMENTS FOR
10 TABLET AND SIMILAR HANDHELD DEVICES” and U.S. Provisional Application No.: 61/740,609 filed December 21, 2012 entitled “MAGNETIC SURFACE BEARING MECHANISM” the entirety of which is incorporated herein by reference.

15 **FIELD OF THE INVENTION**

 The present invention is directed in general to rotational inertial drive systems for devices comprising actuators. More particularly, the present invention is directed to a rotational inertial drive system to minimize actuator power requirements for devices comprising electroactive polymer cartridges and
20 actuators. The present invention also is directed to magnetic bearings for devices comprising actuators. In particular embodiments, an actuator may comprise an electroactive polymer cartridge.

BACKGROUND OF THE INVENTION

 A tremendous variety of devices used today rely on actuators of one sort or
25 another to convert electrical energy to mechanical energy. Conversely, many power generation applications operate by converting mechanical action into electrical energy. Employed to harvest mechanical energy in this fashion, the same type of device may be referred to as a generator. Likewise, when the structure is employed to convert physical stimulus such as vibration or pressure
30 into an electrical signal for measurement purposes, it may be characterized as a sensor. Yet, the term “transducer” may be used to generically refer to any of the devices.

A number of design considerations favor the selection and use of advanced dielectric elastomer materials, also referred to as “electroactive polymers”, for the fabrication of transducers. These considerations include potential force, power density, power conversion/consumption, size, weight, cost, response time, duty cycle, service requirements, environmental impact, etc. As such, in many applications, electroactive polymer technology offers an ideal replacement for piezoelectric, shape-memory alloy and electromagnetic devices such as motors and solenoids.

An electroactive polymer transducer comprises two electrodes having deformable characteristics and separated by a thin elastomeric dielectric material. When a voltage difference is applied to the electrodes, the oppositely charged electrodes attract each other thereby compressing the polymer dielectric layer therebetween. As the electrodes are pulled closer together, the dielectric polymer film becomes thinner (the Z-axis component contracts) as it expands in the planar directions (along the X- and Y-axes), i.e., the displacement of the film is in-plane. The electroactive polymer film may also be configured to produce movement in a direction orthogonal to the film structure (along the Z-axis), i.e., the displacement of the film is out-of-plane. U.S. Pat. No. 7,567,681 discloses electroactive polymer film constructs which provide such out-of-plane displacement – also referred to as surface deformation or as thickness mode deflection.

The material and physical properties of the electroactive polymer film may be varied and controlled to customize the deformation undergone by the transducer. More specifically, factors such as the relative elasticity between the polymer film and the electrode material, the relative thickness between the polymer film and electrode material and/or the varying thickness of the polymer film and/or electrode material, the physical pattern of the polymer film and/or electrode material (to provide localized active and inactive areas), the tension or pre-strain placed on the electroactive polymer film as a whole, and the amount of voltage applied to or capacitance induced upon the film may be controlled and varied to customize the features of the film when in an active mode.

Numerous applications exist that benefit from the advantages provided by such electroactive polymer films whether using the film alone or using it in an electroactive polymer actuator. One of the many applications involves the use of electroactive polymer transducers as actuators to produce haptic feedback (the communication of information to a user through forces applied to the user's body) in user interface devices. There are many known user interface devices which employ haptic feedback, typically in response to a force initiated by the user. Examples of user interface devices that may employ haptic feedback include keyboards, keypads, game controller, remote control, touch screens, computer mice, trackballs, stylus sticks, joysticks, etc. The user interface surface can comprise any surface that a user manipulates, engages, and/or observes regarding feedback or information from the device. Examples of such interface surfaces include, but are not limited to, a key (e.g., keys on a keyboard), a game pad or buttons, a display screen, etc.

The haptic feedback provided by these types of interface devices is in the form of physical sensations, such as vibrations, pulses, spring forces, etc., which a user senses either directly (e.g., via touching of the screen), indirectly (e.g., via a vibrational effect such as when a cell phone vibrates in a pocket) or otherwise sensed (e.g., via an action of a moving body that creates a pressure disturbance sensed by the user). The proliferation of consumer electronic media devices such as smart phones, personal media players, portable computing devices, portable gaming systems, electronic readers, etc., can create a situation where a sub-segment of customers would benefit or desire an improved haptic effect in the electronic media device. However, increasing haptic capabilities in every model of an electronic media device may not be justified due to increased cost or increased profile of the device. Moreover, customers of certain electronic media devices may desire to temporarily improve the haptic capabilities of the electronic media device for certain activities.

Use of electroactive polymer materials in consumer electronic media devices as well as the numerous other commercial and consumer applications

highlights the need to increase production volume while maintaining precision and consistency of the films.

Tablet computers and similar handheld devices (e.g., IPads and such) have a significant amount of mass (500 grams to 1500 grams). When trying to use inertial drive actuators to produce tactile feedback to a user holding the device a significant amount of actuator power is required to produce compelling acceleration levels. This increases the size of the actuator, increases the electrical power drive requirements, and increases the cost. Attempts have been made to solve this problem by employing very high haptic frequencies to help reduce actuator power, size, and cost requirements. One example is the use of piezoelectric actuators that employ haptic frequencies in the range of 175-225 Hz. Higher haptic frequencies, however, fall short of providing realistic feedback in haptic devices and are not as compelling for gaming and can be quite annoying at times.

Accordingly, embodiments of the present invention provide actuators operating mechanically out-of-phase thereby changing the haptic signal into a rotational inertial configuration instead of a translational inertial configuration. This configuration significantly reduces the effective mass that the actuator must drive while still producing the same tactile sensation to the hands of the users. This also allows lower frequencies and larger inertial masses to be used which benefits system level design.

Furthermore, conventional handheld devices do not have low friction bearing surfaces that allow a moving surface to support loads and move easily with very little friction relative to a reference surface while also constraining the moving surface from moving beyond preset limits of motion (linear or rotational) without causing significant friction during rest or operation.

Accordingly, embodiments of the present invention provide means for supporting a surface such that it has very little friction relative to a reference surface while constraining the moving surface from moving beyond preset limits of linear or rotational motion without causing significant friction during rest or operation.

Additional shortcomings exist in devices that include bearings between the housing and a movable surface to minimize friction. Because such bearings are extremely small, they often fall out and thus are not retained in the factory installed position.

- 5 Various embodiments of the present invention provide a bearings retention system to retain the bearings in their factory installed positions.

SUMMARY OF THE INVENTION

- 10 An apparatus comprises a movable surface having a first side and a second end. The first and second ends are arranged on opposite ends of the movable surface. At least a first actuator coupled to the first end of the movable surface. At least a second actuator coupled to the second end of the movable surface. The at least first and second actuators are operably out-of-phase relative to each other and are in a rotational inertial configuration about a moment of inertia defined by the movable surface.

- 15 These and other features and advantages of the invention will become apparent to those persons skilled in the art upon reading the details of the invention as more fully described below. In addition, variations of the processes and devices described herein include combinations of the embodiments or of aspects of the embodiments where possible are within the scope of this disclosure
- 20 even if those combinations are not explicitly shown or discussed.

BRIEF DESCRIPTION OF THE DRAWINGS

- The invention is best understood from the following detailed description when read in conjunction with the accompanying drawings. To facilitate understanding, the same reference numerals have been used (where practical) to
- 25 designate similar elements are common to the drawings. Included in the drawings are the following:

 Figs. 1A and 1B illustrate a top perspective view of a transducer before and after application of a voltage in accordance with one embodiment of the present invention;

- 30 Fig. 2A illustrates an exemplary electroactive polymer cartridge in accordance with one embodiment of the present invention;

Fig. 2B illustrates an exploded view of an electroactive polymer actuator, inertial mass and actuator housing in accordance with one embodiment of the present invention;

Fig. 3 illustrates a device with a conventional single inertial mass inertial
5 drive system;

Fig. 4 illustrates a device with at least two inertial masses coupled to corresponding actuators operating mechanically out-of-phase;

Fig. 5 illustrates the principle of kinetic energy of a solid disk;

Fig. 6 is a schematic diagram of a circuit for driving actuators out-of-phase
10 and consequently driving the inertial masses out-of-phase;

Fig. 7 is a schematic diagram of a circuit for driving actuators out-of-phase and consequently driving the inertial masses out-of-phase;

Fig. 8 illustrates a device with multiple actuators located along opposite ends of a device, where the multiple actuators are coupled to corresponding
15 inertial masses operating mechanically out-of-phase;

Fig. 9 illustrates a device with multiple actuators located along all sides of a device, where the multiple actuators are coupled to corresponding inertial masses operating mechanically out-of-phase;

Fig. 10 illustrates a movable surface of a device capable of moving in three
20 dimensions;

Fig. 11 illustrates a sectional view of a device comprising a movable surface and magnetic bearing, where the movable surface is capable of moving within preset limits in three dimensions;

Fig. 12 illustrates a detail view of the device comprising a movable surface
25 illustrated in Fig. 11;

Fig. 13 illustrates a sectional view of a device comprising a movable surface on a magnetic bearing capable of moving within preset limits in three dimensions and two inertial masses coupled to corresponding actuators operating mechanically out-of-phase;

Fig. 14 illustrates a sectional view of a device comprising a movable surface on a bearings retention system, where the movable surface is capable of moving within preset limits; and

Fig. 15 illustrates a detail view of the bearings portion of the device and movable surface illustrated in Fig. 14.

Variation of the invention from that shown in the figures is contemplated.

DETAILED DESCRIPTION OF THE INVENTION

Examples of electroactive polymer devices and their applications are described, for example, in U.S. Pat. Nos. 7,394,282; 7,378,783; 7,368,862; 7,362,032; 7,320,457; 7,259,503; 7,233,097; 7,224,106; 7,211,937; 7,199,501; 7,166,953; 7,064,472; 7,062,055; 7,052,594; 7,049,732; 7,034,432; 6,940,221; 6,911,764; 6,891,317; 6,882,086; 6,876,135; 6,812,624; 6,809,462; 6,806,621; 6,781,284; 6,768,246; 6,707,236; 6,664,718; 6,628,040; 6,586,859; 6,583,533; 6,545,384; 6,543,110; 6,376,971; 6,343,129; 7,952,261; 7,911,761; 7,492,076; 7,761,981; 7,521,847; 7,608,989; 7,626,319; 7,915,789; 7,750,532; 7,436,099; 7,199,501; 7,521,840; 7,595,580; and 7,567,681, and in U.S. Patent Application Publication Nos. 2009/0154053; 2008/0116764; 2007/0230222; 2007/0200457; 2010/0109486; and 2011/128239, and PCT Publication No. WO2010/054014, the entireties of which are incorporated herein by reference.

In various embodiments, the present invention provides an apparatus, comprising a movable component having a first end and a second end, wherein the first and second ends are arranged opposite each other on the movable component, at least a first actuator coupled to the first end of the movable component, and at least a second actuator coupled to the second end of the movable component, wherein the at least first and second actuators are operably out-of-phase relative to each other and are in a rotational inertial configuration about a moment of inertia defined by the movable component.

These and other embodiments of the present invention are described in detail hereinbelow. Prior to describing such processes, however, Figs. 1-2 provide a brief description of general electroactive polymer structures.

Accordingly, the description now turns to Figs. 1A and 1B, which illustrate an example of an electroactive polymer film or membrane **10** structure. A thin elastomeric dielectric film or layer **12** is sandwiched between compliant or stretchable electrode plates or layers **14** and **16**, thereby forming a capacitive structure or film. The length “l” and width “w” of the dielectric layer, as well as that of the composite structure, are much greater than its thickness “t”. Preferably, the dielectric layer has a thickness in the range from about 10 μm to about 100 μm , with the total thickness of the structure in the range from about 15 μm to about 10 cm. Additionally, it is desirable to select the elastic modulus, thickness, and/or the geometry of electrodes **14**, **16** such that the additional stiffness they contribute to the actuator is generally less than the stiffness of the dielectric layer **12**, which has a relatively low modulus of elasticity, i.e., less than about 100 MPa and more preferably less than about 10 MPa, but is likely thicker than each of the electrodes. Electrodes suitable for use with these compliant capacitive structures are those capable of withstanding cyclic strains greater than about 1% without failure due to mechanical fatigue.

As seen in Fig. 1B, when a voltage is applied across the electrodes, the unlike charges in the two electrodes **14**, **16** are attracted to each other and these electrostatic attractive forces compress the dielectric film **12** (along the Z-axis). The dielectric film **12** is thereby caused to deflect with a change in electric field. As electrodes **14**, **16** are compliant, they change shape with dielectric layer **12**. In the context of the present disclosure, “deflection” refers to any displacement, expansion, contraction, torsion, linear or area strain, or any other deformation of a portion of dielectric film **12**. Depending on the architecture, e.g., a frame, in which capacitive structure **10** is employed (collectively referred to as a “transducer”), this deflection may be used to produce mechanical work. Various different transducer architectures are disclosed and described in the above-identified patent references.

With a voltage applied, the transducer film **10** continues to deflect until mechanical forces balance the electrostatic forces driving the deflection. The mechanical forces include elastic restoring forces of the dielectric layer **12**, the

compliance or stretching of the electrodes **14**, **16** and any external resistance provided by a device and/or load coupled to transducer **10**. The resultant deflection of the transducer **10** as a result of the applied voltage may also depend on a number of other factors such as the dielectric constant of the elastomeric material and its size and stiffness. Removal of the voltage difference and the induced charge causes the reverse effects.

In some cases, the electrodes **14** and **16** may cover a limited portion of dielectric film **12** relative to the total area of the film. This may be done to prevent electrical breakdown around the edge of the dielectric or achieve customized deflections in certain portions thereof. Dielectric material outside an active area (the latter being a portion of the dielectric material having sufficient electrostatic force to enable deflection of that portion) may be caused to act as an external spring force on the active area during deflection. More specifically, material outside the active area may resist or enhance active area deflection by its contraction or expansion.

The dielectric film **12** may be pre-strained. The pre-strain improves conversion between electrical and mechanical energy, i.e., the pre-strain allows the dielectric film **12** to deflect more and provide greater mechanical work. Pre-strain of a film may be described as the change in dimension in a direction after pre-straining relative to the dimension in that direction before pre-straining. The pre-strain may include elastic deformation of the dielectric film and be formed, for example, by stretching the film in tension and fixing one or more of the edges while stretched. The pre-strain may be imposed at the boundaries of the film or for only a portion of the film and may be implemented by using a rigid frame or by stiffening a portion of the film.

The transducer structure of Figs. 1A and 1B and other similar compliant structures and the details of their constructs are more fully described in many of the referenced patents and publications disclosed herein.

Fig. 2A illustrates an exemplary electroactive polymer cartridge **12** having an electroactive polymer transducer film **26** placed between rigid frame **8** where the electroactive polymer film **26** is exposed in openings of the frame **8**. The

exposed portion of the film **26** includes two working pairs of thin elastic electrodes **32** on either side of the cartridge **12** where the electrodes **32** sandwich or surround the exposed portion of the film **26**. The electroactive polymer film **26** can have any number of configurations. However, in one example, the

5 electroactive polymer film **26** comprises a thin layer of elastomeric dielectric polymer (e.g., made of acrylate, silicone, urethane, thermoplastic elastomer, hydrocarbon rubber, fluoroc elastomer, copolymer elastomer, or the like). When a voltage difference is applied across the oppositely-charged electrodes **32** of each working pair (i.e., across paired electrodes that are on either side of the film **26**),

10 the opposed electrodes attract each other thereby compressing the dielectric polymer layer **26** therebetween. The area between opposed electrodes is considered the active area. As the electrodes are pulled closer together, the dielectric polymer **26** becomes thinner (i.e., the Z-axis component contracts) as it expands in the planar directions (i.e., the X- and Y-axes components expand) (See

15 Figs. 1B for axis references). Furthermore, in variations where the electrodes contain conductive particles, like charges distributed across each electrode may cause conductive particles embedded within that electrode to repel one another, thereby contributing to the expansion of the elastic electrodes and dielectric films. In alternate variations, electrodes do not contain conductive particles (e.g.,

20 textured sputtered metal films). The dielectric layer **26** is thereby caused to deflect with a change in electric field. As the electrode material is also compliant, the electrode layers change shape along with dielectric layer **26**. As stated hereinabove, deflection refers to any displacement, expansion, contraction, torsion, linear or area strain, or any other deformation of a portion of dielectric

25 layer **26**. This deflection may be used to produce mechanical work. As shown, the dielectric layer **26** can also include one or more mechanical output bars **34**. The bars **34** can optionally provide attachment points for either an inertial mass (as described below) or for direct coupling to a substrate in the electronic media device.

30 In fabricating a transducer, an elastic film **26** can be stretched and held in a pre-strained condition usually by a rigid frame **8**. In those variations employing a

four-sided frame, the film can be stretched bi-axially. If the opening of the frame is circular, the film can be stretched radially. It has been observed that pre-strain improves the dielectric strength of the polymer layer 26, thereby enabling the use of higher electric fields and improving conversion between electrical and mechanical energy, i.e., the pre-strain allows the film to deflect more and provide greater mechanical work. Preferably, the electrode material is applied after pre-straining the polymer layer, but may be applied beforehand. The two electrodes provided on the same side of layer 26, referred to herein as same-side electrode pairs, i.e., electrodes on the top side of dielectric layer 26 and electrodes on a bottom side of dielectric layer 26, can be electrically isolated from each other. The opposed electrodes on the opposite sides of the polymer layer form two sets of working electrode pairs, i.e., electrodes spaced by the electroactive polymer film 26 form one working electrode pair and electrodes surrounding the adjacent exposed electroactive polymer film 26 form another working electrode pair. Each same-side electrode pair can have the same polarity, whereas the polarity of the electrodes of each working electrode pair is opposite each other. Each electrode has an electrical contact portion configured for electrical connection to a voltage source. In some variations, the same-side electrodes may be electrically connected together with a bus bar.

In one variation as shown in Fig. 2A, the electrodes 32 are connected to a voltage source via a flex connector 30 having leads 22, 24 that can be connected to the opposing poles of the voltage source. The cartridge 12 also includes conductive vias 18, 20. The conductive vias 18, 20 can provide a means to electrically couple the electrodes 8 with a respective lead 22 or 24 depending upon the polarity of the electrodes.

The cartridge 12 illustrated in Fig. 2A shows a 3-bar actuator configuration. However, the devices and processes described herein are not limited to any particular configuration, unless specifically claimed. Preferably, the number of the bars 34 depends on the active area desired for the intended application. The total amount of active area, e.g., the total amount of area between electrodes, can be varied depending on the mass that the actuator is trying

to move and the desired frequency of movement. In one example, selection of the number of bars is determined by first assessing the size of the object to be moved, and then the mass of the object is determined. The actuator design is then obtained by configuring a design that will move that object at the desired frequency range. Clearly, any number of actuator designs is within the scope of the disclosure.

An electroactive polymer actuator for use in the processes and devices described herein can then be formed in a number of different ways. For example, the electroactive polymer can be formed by stacking a number of cartridges together, having a single cartridge with multiple layers, or having multiple cartridges with multiple layers. Manufacturing and yield considerations may favor stacking single cartridges together to form the electroactive polymer actuator. In doing so, electrical connectivity between cartridges can be maintained by electrically coupling the vias together so that adjacent cartridges are coupled to the same voltage source or power supply.

The cartridge shown in Fig. 2A includes three pairs of electrodes separated by a single dielectric layer. In one variation, as shown in Fig. 2B, two or more cartridges are stacked together to form an electroactive actuator that is coupled to an inertial mass. Alternatively, the electroactive actuator can be coupled directly to the electronic media device through an attachment plate or frame (this plate or frame may be permanent or temporary). As discussed below, the electroactive actuator can be placed within a cavity that allows for movement of the actuator as desired. The pocket can be directly formed in a housing of a haptic case. Alternatively, pocket can be formed in a separate case positioned within the housing of the device. If the latter, the material properties of the separate case can be selected based upon the needs of the actuator. For example, if the main body of the haptic housing assembly is flexible, the separate case can be made rigid to provide protection to the electroactive actuator and/or the mass. In any event, variations of the device and processes described herein include size of the cavity with sufficient clearance to allow movement of the actuator and/or mass but a close enough

tolerance so that the cavity 52 barrier (e.g., the haptic housing or separate case 56) serves as a limit to prevent excessive movement of the electroactive actuator 14. Such a feature prevents the active areas of the actuator 14 from excessive displacement that can shorten the life of the actuator or otherwise damage the actuator.

Fig. 3 illustrates a device 300 with a conventional single inertial mass inertial drive actuator 302 system. The device 300 includes a body 303, a screen 306, and optionally handles 308a, 308b. The inertial drive actuator 302 is generally mounted below the screen 306 and offset from the center of mass 310.

Thus, when the inertial drive actuator 302 is activated it moves laterally as indicated by arrows A and B to give the user holding the handles 308a, 308b a haptic feedback (e.g., acceleration, vibration, and the like). The lateral movement of the inertial drive actuator 302 in the direction of arrows A and B is referred to as translational (or linear) inertia.

Such devices 300, e.g., tablet computers and similar handheld devices (e.g., IPADS and such), have a significant amount of mass (500 g to 1500 g) relative to the inertial actuator. When trying to use inertial drive actuators 304 to produce tactile feedback to a user holding the device 300 a significant amount of actuator power is required to produce compelling acceleration levels. This increases the size of the actuator 304, increases the electrical power drive requirements, and increases the cost. Attempts have been made to solve this problem by employing very high haptic frequencies to help reduce actuator power, size, and cost requirements. One example is the use of piezoelectric actuators that employ haptic frequencies in the range of 175-225 Hz. Higher haptic frequencies, however, fall short of providing realistic feedback in haptic devices and are not as compelling for gaming and can be quite annoying at times.

Accordingly, embodiments of the present invention provide inertial actuators which provide the haptic signal with a rotational inertial configuration instead of a translational inertial configuration. This configuration significantly reduces the effective mass that the actuator must drive while still producing the same tactile sensation to the hands of the users. This also allows lower

frequencies and larger inertial masses to be used which benefits system level design. In one embodiment, the present invention provides rotational inertial actuators. In another embodiment, the present invention provides rotational inertial actuators comprising electroactive polymer cartridges mounted to inertial masses. These and other embodiments are described hereinbelow.

In one embodiment of this invention, a single inertial mass inertial drive actuator can be situated on one of the handles **308a** or **308b** with motion parallel to the length of the handle when activated to create a rotational torque.

Fig. 4 illustrates another embodiment wherein a device **400** comprises at least two actuators **402a**, **402b** coupled to corresponding handles **404a**, **404b** of the device. The two actuators **402a**, **402b** operate mechanically out-of-phase to provide a rotational drive force **408** in the same direction. The device **400** includes a body **403**, a screen **406**, and optionally handles **404a**, **404b**. The rotational inertial drive system minimizes actuator power requirements for devices having a mass that is significantly larger than the mass of the actuator. Although the arrangement in FIG. 4 shows a rotational drive force in a clockwise direction, it will be appreciated that the orientation of the two actuators **402a**, **402b** may be reversed such that the rotational drive force is induced in the opposite direction shown in Fig.4, e.g., counterclockwise. It will further be appreciated that only one of the two actuators **402a**, **402b** creates the momentum in the forward or the reverse direction.

The rotational inertial drive system configuration depicted in Fig. 4 employs rotational dynamics to minimize actuator requirements and enables lower haptic frequencies to be used. The two actuators **402a**, **402b** operate mechanically out-of-phase to thereby change the haptic signal into a rotational inertial configuration about a moment of inertia **410** rather than the translational inertial configuration as shown in Fig. 3. This significantly reduces the effective mass that the actuators **402a**, **402b** must drive but still produces the same tactile sensation to the hands of the user.

Therefore, the rotational inertial drive system depicted in Fig. 4 enables lower haptic frequencies and larger inertial masses to be used which benefits

system level design. Generally speaking, to produce lower haptic frequencies with conventional translational inertial drive systems requires more actuator power (which is undesirable) but are far more desirable for user experience. Larger inertial masses in general reduce actuator power requirements, which is an advantage. Less actuator, e.g., electroactive actuator, mass is used because the moment of inertia **410** determines the effective mass and not the whole body mass. Accordingly, the rotational inertial drive system can be configured around a lower effective mass, which is an advantage

A comparison of rotational versus linear (translational) inertia in regards to moving the edge of a solid disk will be described in connection with Fig. 5, illustrates the principle of kinetic energy of a solid disk **500**.

With reference to the solid disk **500** shown in Fig. 5, the disk **500** has a radius r , mass m , lies in the x - y plane, and rotates about axis z .

The rotational inertia of the disk **500** is given by:

$$I_z = \frac{1}{2}mr^2 \quad (1)$$

Linear inertia is simply given by:

$$I_{lin} = m \quad (2)$$

The rotational kinetic energy of the solid disk **500** is given by:

$$U_{rot} = \frac{1}{2}I\omega^2 = \frac{1}{2}\left(\frac{1}{2}mr^2\right)\omega^2 = \frac{1}{4}m(r\omega)^2 \quad (3)$$

The linear kinetic energy of the solid disk **500** is given by:

$$U_{linear} = \frac{1}{2}mv^2 \quad (4)$$

Consider an incremental displacement at the perimeter of the disk **500** of linear distance x or arc length s in a time t . The displacement has some velocity:

$$v_{lin} \cong r\omega, \quad \text{for small angular rotations } \theta \quad (5)$$

The ratio of rotational kinetic energy to linear kinetic energy is given by:

$$\frac{U_{rot}}{U_{linear}} = \frac{0.25mv_{lin}^2}{0.5mv_{lin}^2} = 0.5 \quad (6)$$

Energy ratio is the same as the Power ratio:

$$P = \frac{\Delta U}{\Delta t} \quad (7)$$

$$\frac{P_{rot}}{P_{lin}} = \frac{\left(\frac{\Delta U_{rot}}{\Delta t} \right)}{\left(\frac{\Delta U_{lin}}{\Delta t} \right)} = \frac{\Delta U_{rot}}{\Delta U_{lin}} = \frac{U_{rot}}{U_{lin}} = 0.5 \quad (8)$$

Therefore, the rotational mode always takes half the instantaneous power of the linear mode. Taking the integral to arrive at average power does not change that ratio. Accordingly, this factor of 0.5 will hold for any arbitrary waveform, sinusoidal or otherwise.

Fig. 6 is a schematic diagram of a circuit **600** for driving actuators **602a**, **602b** coupled to inertial masses **604a**, **604b** out-of-phase and consequently driving the inertial masses **604a**, **604b** out-of-phase. An energy source produces a drive voltage V to drive the actuators **602a**, **602b** coupled to inertial masses **604a**, **604b**. The drive voltage V used to drive the actuators **602a**, **602b** is in phase, therefore, the actuators **602a**, **602b** are physically oriented in opposite directions relative to each other such that they can be driven mechanically out-of-phase relative to each other. The circuit **600** provides an economical solution to driving the inertial masses **604a**, **604b** out-of-phase and thereby changing the haptic signal into a rotational inertial configuration instead of a translational inertial configuration. This configuration significantly also reduces the effective mass of the inertial masses **604a**, **604b** that the corresponding actuators **602a**, **602b** must drive while still producing the same tactile sensation to the hands of the users. This also allows lower frequencies and larger inertial masses to be used which benefits system level design. It will be appreciated that in one embodiment, the actuators **602a**, **602b** may be electroactive polymer actuators as disclosed herein in connection with Figs. 1 and 2. In other embodiments, the actuators **602a**, **602b** may be selected from a variety of other actuators including, but not limited to, piezoelectric, solenoid, voicecoil and other mechanical motors.

Fig. 7 is a schematic diagram of a circuit **700** for driving actuators **702a**, **702b** coupled to inertial masses **704a**, **704b** out-of-phase and consequently

driving the inertial masses **704a**, **704b** out-of-phase. The drive voltage source **V** is inverted by inverter **706** to produce a second drive voltage $-V$ that is out-of-phase relative to drive voltage **V**. The actuators **702a**, **702b** are coupled to inertial masses **704a**, **704b**. Because two drive voltages **V**, $-V$ are out-of-phase relative to each other, the actuators **702a**, **702b** are physically oriented in the same direction relative to each other such that they can be driven mechanically out-of-phase relative to each other. The circuit **700** provides a more flexible solution to driving the inertial masses **704a**, **704b** out-of-phase and thereby changing the haptic signal into a rotational inertial configuration instead of a translational inertial configuration. This configuration significantly also reduces the effective mass of the inertial masses **704a**, **704b** that the corresponding actuators **702a**, **702b** must drive while still producing the same tactile sensation to the hands of the users. This also allows lower frequencies and larger inertial masses to be used which benefits system level design. It will be appreciated that in one embodiment, the actuators **702a**, **702b** may be electroactive polymer actuators as disclosed herein in connection with Figs. 1 and 2. In other embodiments, the actuators **702a**, **702b** may be selected from other actuators including, but not limited to, piezoelectric, solenoid, voicecoil and other mechanical motors.

Fig. 8 illustrates a device **800** with multiple actuators **802a₁** to **802a_n** and **802b₁** to **802b_n** located along opposite ends of a device **800**, where the multiple actuators **802a₁**-**802a_n** are coupled to corresponding inertial masses **804a₁** to **804a_n**, operating mechanically out-of-phase to form a rotational drive force about the moment of inertia **810**. A first set of up to *n* actuators **802a₁**-**802a_n** are disposed along one side **808a** of the device **800** in the same (in-phase) physical orientation relative to each other. A second set of *n* actuators **802b₁**-**802b_n** are disposed along the opposite end **808b** of the device **800** in the same (in-phase) physical orientation relative to each other but in opposite physical orientation, and hence out-of-phase, relative to the first set of *n* actuators **802b₁**-**802b_n**.

Because the first and second set of actuators are physically oriented out-of-phase, a single voltage source can be used to drive the first and second set of actuators **802a₁**-**802a_n** and **802b₁**-**802b_n** as described in connection with the

circuit 600 in Fig. 6. If the physical orientation of the first or second set of actuators $802a_1$ - $802a_n$ and $802b_1$ - $802b_n$ is reversed such that the first and second set of actuators $802a_1$ - $802a_n$ and $802b_1$ - $802b_n$ are physically oriented in the same direction, then the inertial masses $804a_1$ - $804a_n$ and $804b_1$ - $804b_n$ can be driven mechanically out-of-phase with the circuit 700 described in connection with Fig. 7. Accordingly, the first set of actuators $802a_1$ - $802a_n$ is driven by the voltage source V and the second set of actuators of actuators $802b_1$ - $802b_n$ is driven by $-V$.

Fig. 9 illustrates a device 900 with multiple actuators $902a_1$ to $902a_n$, $902b_1$ to $902b_n$, $902c_1$ to $902c_n$, and $902d_1$ to $902d_n$ located along all sides of a device 900, where the multiple actuators $902a_1$ - $902a_n$, $902b_1$ - $902b_n$, $902c_1$ - $902c_n$, and $902d_1$ - $902d_n$ are coupled to corresponding inertial masses $904a_1$ - $904a_n$, $904b_1$ - $904b_n$, $904c_1$ - $904c_n$, and $904d_1$ - $904d_n$ operating mechanically out-of-phase to form a rotational drive force about the moment of inertia 910. A first set of up to n actuators $902a_1$ - $902a_n$ are disposed along one first end 908a of the device 900 in the same (in-phase) physical orientation relative to each other. A second set of n actuators $902b_1$ - $902b_n$ are disposed along a second end 908b of the device 900 in the same (in-phase) rotational physical orientation relative to each other and to the first set of actuators $902a_1$ - $902a_n$. A third set of n actuators $902c_1$ - $902c_n$ are disposed along a third side 908c of the device 900 in the same (in-phase) physical orientation relative to each other but in opposite physical orientation than the first set of actuators $902a_1$ - $902a_n$. A fourth set of n actuators $902d_1$ - $902d_n$ are disposed along a fourth side 908d of the device 900 in the same (in-phase) physical orientation relative to each other but in opposite physical orientation than the second set of actuators $902b_1$ - $902b_n$.

Because the actuators are physically oriented out-of-phase, a single voltage source can be used to drive all the actuators $902a_1$ - $902a_n$, $902b_1$ - $902b_n$, $902c_1$ - $902c_n$, and $902d_1$ - $902d_n$ as described in connection with the circuit 600 in Fig. 6. If the physical orientation of the third set of actuators $902c_1$ - $902c_n$ and the fourth set of actuators $902d_1$ - $902d_n$ is reversed such that the first and third set of actuators $902a_1$ - $902a_n$ and $902c_1$ - $902c_n$ are physically oriented in the same direction and the second and fourth set of actuators $902b_1$ - $902b_n$ and $902d_1$ - $902d_n$

are physically oriented in the same direction, then the inertial masses **904a₁** to **904a_n**, **904b₁** to **904b_n**, **904c₁** to **904c_n**, and **904d₁** to **904d_n** can be driven mechanically out-of-phase using the are driven by the same voltage source V and the can be driven mechanically out-of-phase with the circuit **700** described in connection with Fig. 7. Accordingly, the first and second set of actuators **902a₁**-**902a_n** and **902b₁**-**902b_n** are driven by the voltage source V and the third and fourth set of actuators **902c₁**-**902c_n** and **902d₁**-**902d_n** are driven by -V.

As used herein, actuators said to be physically or mechanically oriented out-of-phase relative to each other generally refers to the actuators being oriented in opposite directions relative to each other or simply about 180 degrees out-of-phase. Likewise, voltage sources, or other energy sources, said to be out-of-phase relative to each other generally refers to the energy sources about 180 degrees out-of-phase relative to each other.

Fig. 10 illustrates a movable component **1000** of a device capable of moving in three dimensions. The movable component **1000** can move in plane **1002** or in directions orthogonal **1004** to the plane **1002**.

Fig. 11 illustrates a sectional view of a device **1100** comprising a movable component **1102** on a magnetic bearing **1104**, where the movable component **1102** is capable of moving within preset limits in three dimensions. The device **1100** includes a housing or frame **1106** comprising a slot **1108** sized to receive a ridge **1110** portion projecting outwardly from the perimeter edges of the movable component **1102**. The movement of the movable component **1102** is restricted within the slot **1108** by at least one of the inside walls of the slot. A plurality of magnets **1112** are positioned along the slot **1108** and ridge **1110** to produce a magnetic bearing **1104** that supports the component **1102** while the component **1102** is in motion. An actuator **1114** is coupled to the movable surface **1104** on one side and to the reference frame **1106** on the other side. Thus, when the actuator **1114** is activated, the movable surface **1102** moves relative to the frame **1106**.

The magnetic bearing **1104** provides a means to support the component **1102** such that it has very little friction relative to the frame **1106** reference

surface. In one embodiment the component **1102** is a touch panel or screen that provides haptic motion by the actuator **1114** in response to user input via the panel/screen. To move the screen such that the user feels the haptic motion, it is desirable to have the screen suspended via a very low friction bearing surface so that the screen is free to move within a range of motion in a given plane (using Cartesian coordinates let us choose the XY plane as an example). The screen should be free to move within the XY plane, constrained in the Z axis, and constrained within preset limits in the X and Y axes.

Fig. 12 illustrates a detail view of the magnetic bearing **1104** of the device **1100** and movable component **1102** illustrated in Fig. 11. The magnets **1112** are arranged with opposing North poles (N) facing each other to produce a magnetic bearing **1104** that supports the weight of the movable component **1102**. It will be appreciated that opposing South poles (S) facing each other may be used to implement the magnetic bearing **1104**. The magnetic bearing **1104** uses magnetic forces to suspend and/or constrain the surface within the prescribe range of motion, bearing loads in the Z axis. By arraying magnets **1112** at various locations around the screen, a very low friction bearing, that uses little or no power can be created. Similarly, magnets **1112** can be arrayed to provide non contacting motion guides or stops to constrain the surface into the desired plane of motion, within the desired range of motion within that plane.

Employing magnetic repulsion to create low friction bearing surfaces **1104** enables the moving component **1102** to support loads and move easily and also constrains the moving component **1102** from moving beyond the preset limits of motion (linear or rotational) without causing significant friction during rest or operation. Minor mechanical compliance may be provided when subjected to forces normal to the bearing component **1102** as well as a non-linear restoring force. Magnetic suspension by the magnetic bearing surface **1104** has very low static and dynamic friction, which is important in making a moving haptic touch component **1102** as the forces used and range of motion are small.

Furthermore, in one embodiment, the magnetic bearing **1104** can be implemented using permanent magnets **1112**. In embodiments utilizing

permanent magnets **1112**, the magnetic bearing **1104** requires no additional electrical power. Additionally, as force is applied normal to the magnetic bearing surface **1112**, the airgap g between opposing magnets **1112** decreases (mechanical compliance), however, as the airgap g decreases, the magnetic repulsion increases with a non-linear relationship. In practice, it will be difficult to load the magnetic bearing **1112** to the point that the airgap g is eliminated and the moving plate touches the reference surface, which would result in additional friction.

In various embodiments, the magnets **1112** may be discrete permanent magnets, a plurality of sintered permanent magnets, or a plurality of resin bonded permanent magnets. In other embodiments, where electrical power is not an issue, electromagnets may be employed to implement the magnetic bearing **1104**.

Furthermore, in some embodiments the actuator **1114** coupled to the movable component **1102** may be pre-biased by a combined magnetic force and a force other than a magnetic force. Such actuators **1114** are configured to be selectively biased to obtain specifically desired performance characteristics. The selection of biasing follows a negative bias spring model in which the spring force increases as the actuator **1114** moves from a preloaded position to its most highly activated position. The model may exclusively employ a negative bias spring, or may further incorporate constant force spring bias and/or a positive or “standard” spring-bias is combined with flat-rate or negative rate biasing. The biasing devices may additionally include biasing components, for example a coil spring, leaf spring, bellows spring, elastomer spring, foam support, air or fluid pressure biasing, etc. or a combination of any of these means or the like, are also contemplated.

Fig. 13 illustrates a sectional view of a device **1300** comprising a movable component **1302** on a magnetic bearing **1304** capable of moving within preset limits in three dimensions and two or more inertial masses coupled to two or more corresponding actuators **1308a**, **1308b** operating mechanically out-of-phase. Thus, the device **1300** combines the benefits of the rotational inertial drive system configuration described in connection with Figs. 4-9 that employs rotational dynamics to minimize actuator requirements and enables lower haptic frequencies

to be used with the magnetic bearing **1304** described in connection with Figs. 10-12. It will be appreciated that the device **1300** shown in Fig. 13 may employ any of the various embodiments of rotational inertial drive systems described in connection with Figs. 4-9. Optionally, an actuator **1314** may be provided. The
5 actuator **1314** is coupled to the movable component **1304** on one side and to the reference frame **1306** on the other side,

Fig. 14 illustrates a sectional view of a device **1400** comprising a movable component **1402** on a bearings retention system **1404**, where the movable component **1402** is capable of moving within preset limits. Fig. 15 illustrates a
10 detail view of the bearing retention system **1404** portion of the device **1400** and movable component **1402** illustrated in Fig. 14. The device **1400** includes a housing or frame **1406** comprising a slot **1408** sized to receive a ridge **1410** portion projecting outwardly from the perimeter edges of the movable component **1402**. The movement of the component **1402** is restricted within the slot **1408**.
15 Bearings **1418** made of ferrous materials are interposed between the ridge **1410** portion of the movable component **1402** and interior walls of the slot **1408** to enable the moving component **1402** to move freely within the slot **1408**. Because the bearings **1418** can be quite small and tend to be displaced or lost, a plurality of magnets **1412** are positioned along the slot **1408** to retain the bearings **1418** in
20 place, provided the bearings are made from a ferrous material. The bearings **1418** are located in predefined cup-like fixtures **1414**. Magnets **1416** are located within the slot **1408** formed within the frame body **1406** of the device **1400**. Thus, the magnets **1416** will retain the ferrous bearings **1418**. In various embodiments, the magnet **1416** is selected from the group consisting of a permanent magnet,
25 sintered permanent magnet, resin bonded permanent magnet, an electromagnet and combinations thereof.

In other embodiments, the device **1400** can be combined with the two or more inertial masses coupled to two or more corresponding actuators operating mechanically out-of-phase. Thus, the device **1400** combines the benefits of the
30 rotational inertial drive system configuration described in connection with Figs. 4-9 that employs rotational dynamics to minimize actuator requirements and enables

lower haptic frequencies to be used with the bearings **1404** described in connection with Figs. 13-15. It will be appreciated that the device **1400** shown in Fig. 14 may employ any of the various embodiments of rotational inertial drive systems described in connection with Figs. 4-9.

5 Any of the devices **400**, **800**, **900**, **1100**, **1300**, and **1400** may be combined with any of the features discussed herein including the rotational inertial drive system, magnetic bearing system, magnetic bearing retention system, and/or the pre-biased actuator systems, without limitations.

10 In some embodiments, the magnetic bearing system may be used to suspend and position an inertial mass rather than a display or touch screen surface. This mass may be driven by a planar actuator such as a 3-bar actuator, or, by other actuator architectures such as rolls, stacks, surface morphing, bimorphs, etc. These embodiments simplify the task of suspending and supporting an inertial mass in that it is very low friction, have graceful travel stops, and may be made in
15 a very robust fashion within multiple form factors. This system has a number of advantages when compared to other more traditional methods of support – e.g. flexure based systems, bearing based systems, etc. – which may require precise bearing systems or complex and often fragile flexures.

20 As for other details of the present invention, materials and alternate related configurations may be employed as within the level of those with skill in the relevant art. The same may hold true with respect to process-based aspects of the invention in terms of additional acts as commonly or logically employed. In addition, though the invention has been described in reference to several examples, optionally incorporating various features, the invention is not to be
25 limited to that which is described or indicated as contemplated with respect to each variation of the invention. Various changes may be made to the invention described and equivalents (whether recited herein or not included for the sake of some brevity) may be substituted without departing from the true spirit and scope of the invention. Any number of the individual parts or subassemblies shown may
30 be integrated in their design. Such changes or others may be undertaken or guided by the principles of design for assembly.

Also, it is contemplated that any optional feature of the inventive variations described may be set forth and claimed independently, or in combination with any one or more of the features described herein. Reference to a singular item, includes the possibility that there are plural of the same items present. More specifically, as used herein and in the appended claims, the singular forms “a,” “an,” “said,” and “the” include plural referents unless the specifically stated otherwise. In other words, use of the articles allow for “at least one” of the subject item in the description above as well as the claims below. It is further noted that the claims may be drafted to exclude any optional element. As such, this statement is intended to serve as antecedent basis for use of such exclusive terminology as “solely,” “only” and the like in connection with the recitation of claim elements, or use of a “negative” limitation. Without the use of such exclusive terminology, the term “comprising” in the claims shall allow for the inclusion of any additional element – irrespective of whether a given number of elements are enumerated in the claim, or the addition of a feature could be regarded as transforming the nature of an element set forth in the claims. Stated otherwise, unless specifically defined herein, all technical and scientific terms used herein are to be given as broad a commonly understood meaning as possible while maintaining claim validity.

WHAT IS CLAIMED IS:

1. An apparatus, comprising:
a movable component having a first end and a second end, wherein the first and
5 second ends are arranged opposite each other on the movable component;
at least a first actuator coupled to the first end of the movable component; and
at least a second actuator coupled to the second end of the movable component;
wherein the at least first and second actuators are operably out-of-phase relative to
each other and are in a rotational inertial configuration about a moment of
10 inertia defined by the movable component.
2. The apparatus according to Claim 1, wherein the at least first and second
actuators are physically oriented in opposite directions relative to each other and
are operably responsive to a single drive voltage.
- 15 3. The apparatus according to Claim 1, wherein the at least first and second
actuators are physically oriented in the same direction relative to each other and
wherein the at least first actuator is operably responsive to a first drive voltage and
the at least second actuator is operably responsive to a second drive voltage that is
20 out-of phase with the first drive voltage.
4. The apparatus according to Claim 3, further comprising an inverter to
receive the first drive voltage and provide the second drive voltage.
- 25 5. The apparatus according to Claim 1, further comprising a magnetic
bearing configured to suspend the movable component.
6. The apparatus according to Claim 1, further comprising a bearing retention
system coupled to the movable component, wherein the bearing retention system
30 comprises at least one magnet.

7. The apparatus according to Claim 1, wherein the at least first and second actuators comprise electroactive polymer cartridges.

8. An apparatus, comprising:

- 5 a housing;
 a movable component moveably coupled to the housing; and
 a magnetic bearing configured to suspend the movable component relative to the housing.

10 9. The apparatus according to Claim 8, wherein the housing comprises a slot and the movable component comprises a ridge projecting outwardly from perimeter edges of the movable component, wherein the ridge is configured to be received within the slot.

15 10. The apparatus according to Claim 9, further comprising a first magnet located in the slot portion of the housing and a second magnet located in the ridge portion of the movable component, wherein the first and second magnets are arranged with opposing poles facing each other to produce a magnetic bearing and suspend the ridge portion of the movable component within the slot portion of the
20 housing.

11. The apparatus according to Claim 9 or 10, wherein movement of the movable component is restricted within the slot by at least one inside wall of the slot.

25

12. The apparatus of Claim 8, further comprising an actuator coupled to the movable component on one side and to the housing on the other side, wherein when the actuator is activated, the movable component moves relative to the housing.

30

13. The apparatus of Claim 8, further comprising:

at least a first actuator coupled to a first end of the movable component; and
at least a second actuator coupled to a second end of the movable component;
wherein the at least first and second actuators are operably out-of-phase relative to
each other and are in a rotational inertial configuration about a moment of
5 inertia defined by the movable component.

14. The apparatus according to Claims 12 or 13, wherein the actuator
comprises an electroactive polymer cartridge.

10 15. The apparatus according to Claim 8, wherein the magnet is selected from
the group consisting of a permanent magnet, sintered permanent magnet, resin
bonded permanent magnet, an electromagnet and combinations thereof.

16. An apparatus, comprising:
15 a housing;
a movable surface moveably coupled to the housing; and
a bearing retention system.

17. The apparatus according to Claim 16, wherein the bearing retention system
20 comprises a ferrous bearing disposed between the housing and the movable
surface and a magnet located in the housing to magnetically retain the ferrous
bearing.

18. The apparatus according to Claim 16, wherein the magnet is selected from
25 the group consisting of a permanent magnet, sintered permanent magnet, resin
bonded permanent magnet, an electromagnet and combinations thereof.

19. The apparatus of Claim 16, further comprising an actuator coupled to the
movable surface on one end and to the housing on the other end, wherein when
30 the actuator is activated, the movable surface moves relative to the housing.

20. The apparatus according to any one of Claims 1 to 17 wherein the movable component or surface is selected from the group consisting of a touch screen, a sensor panel, and a display panel.

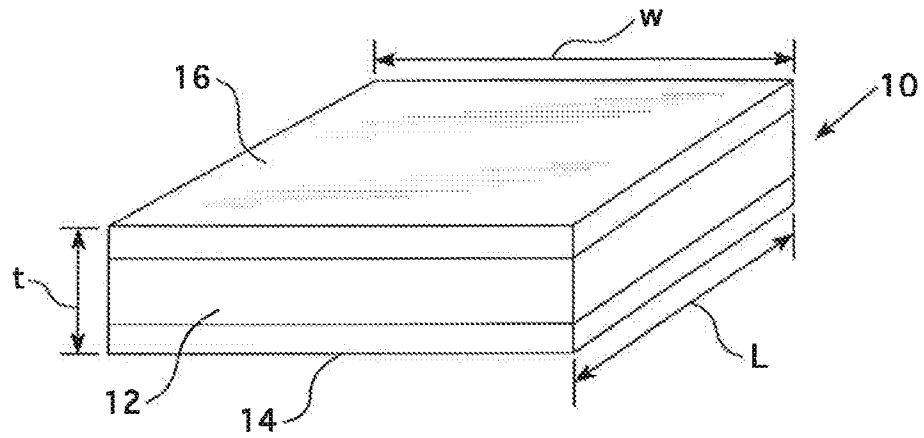


FIG. 1A

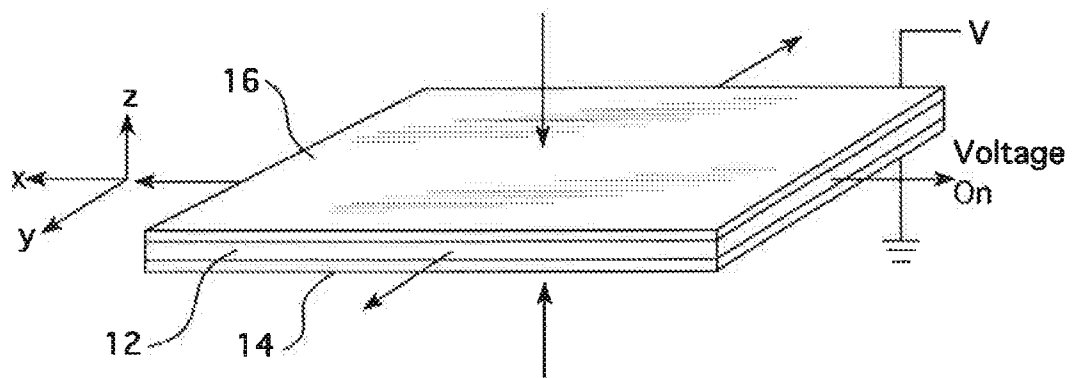


FIG. 1B

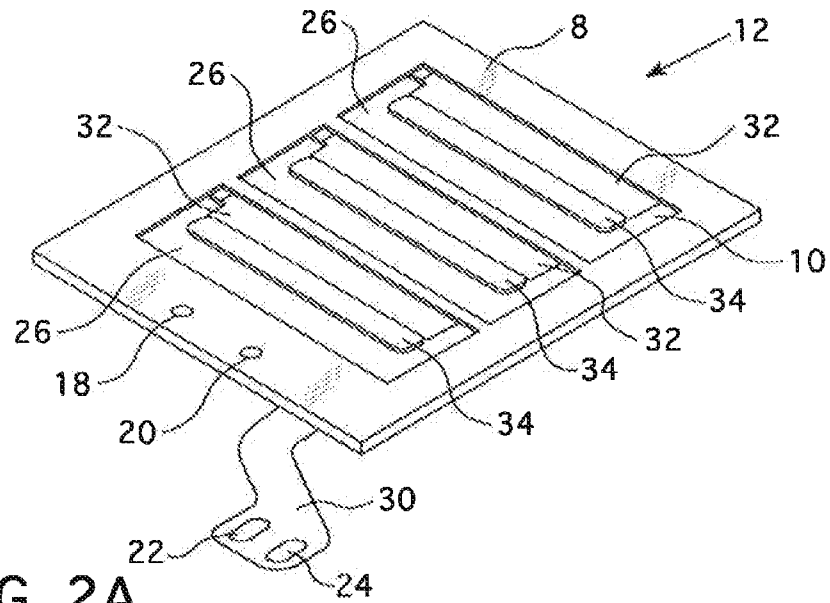


FIG. 2A

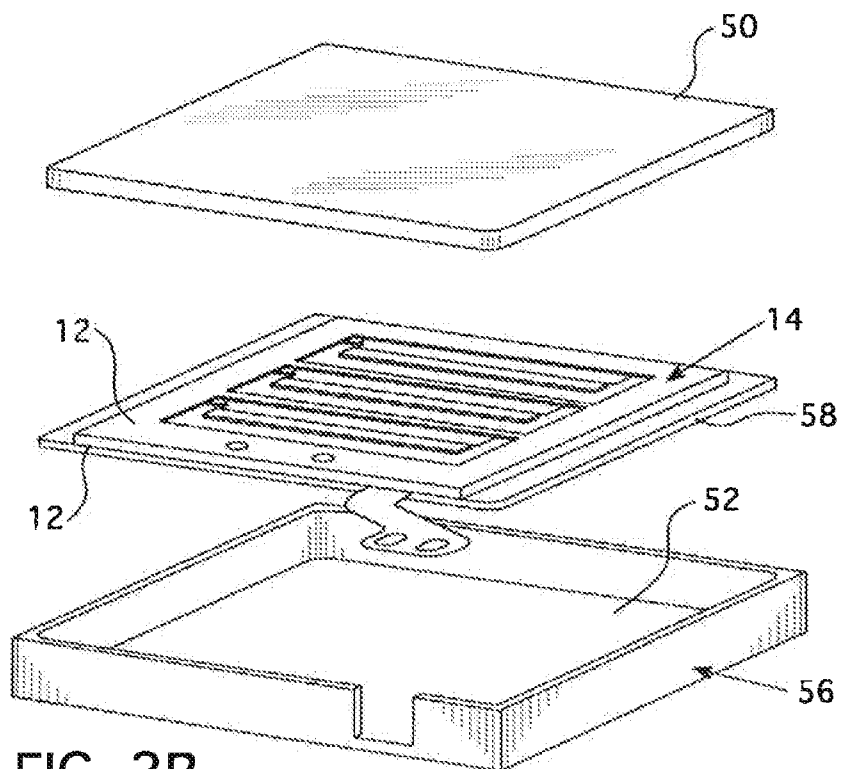


FIG. 2B

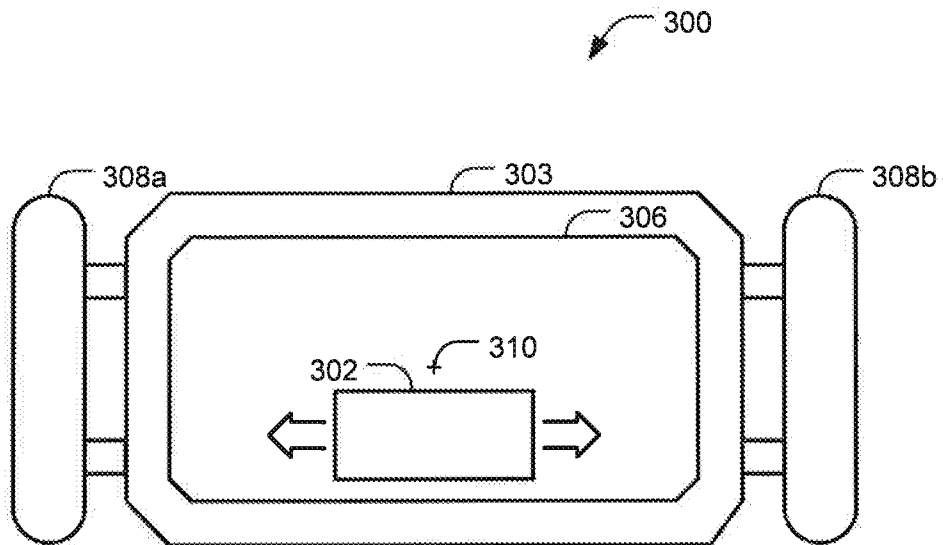


FIG. 3

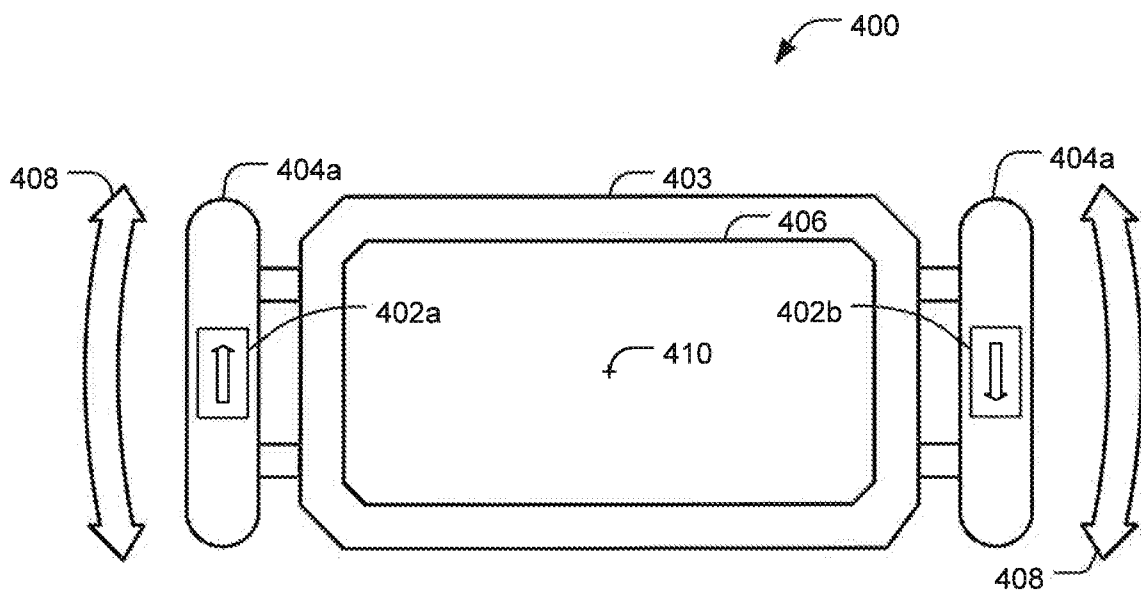


FIG. 4

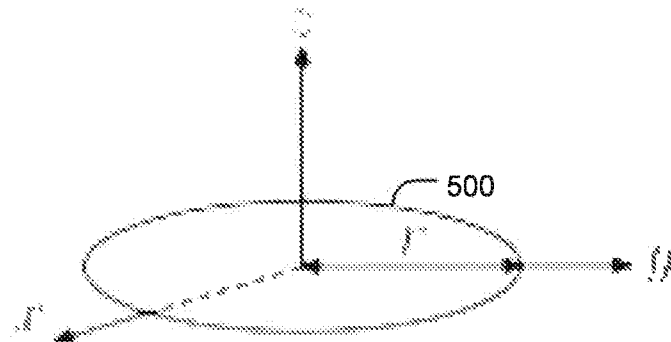


FIG. 5

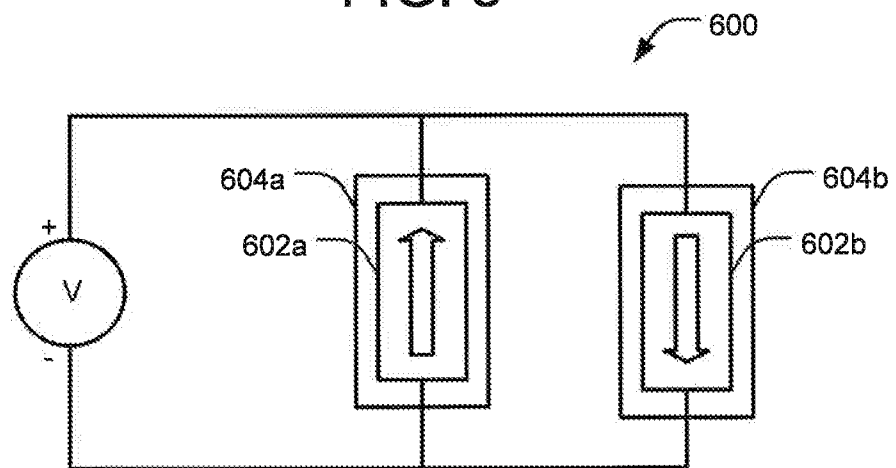


FIG. 6

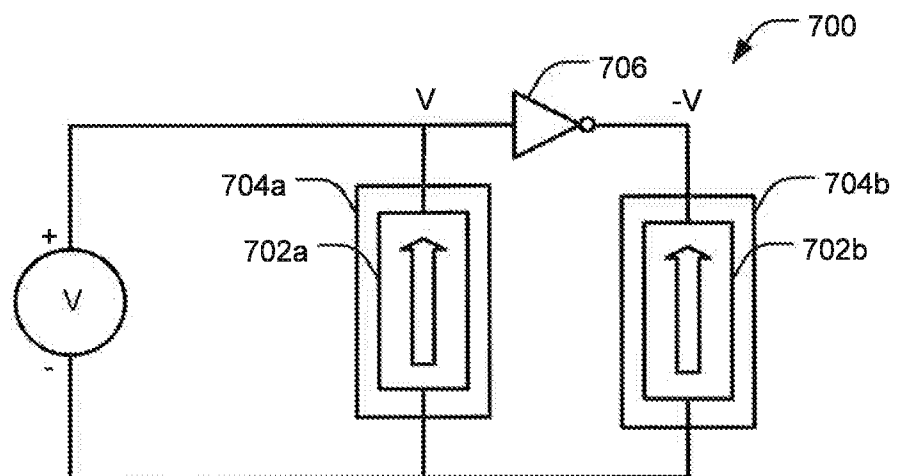


FIG. 7

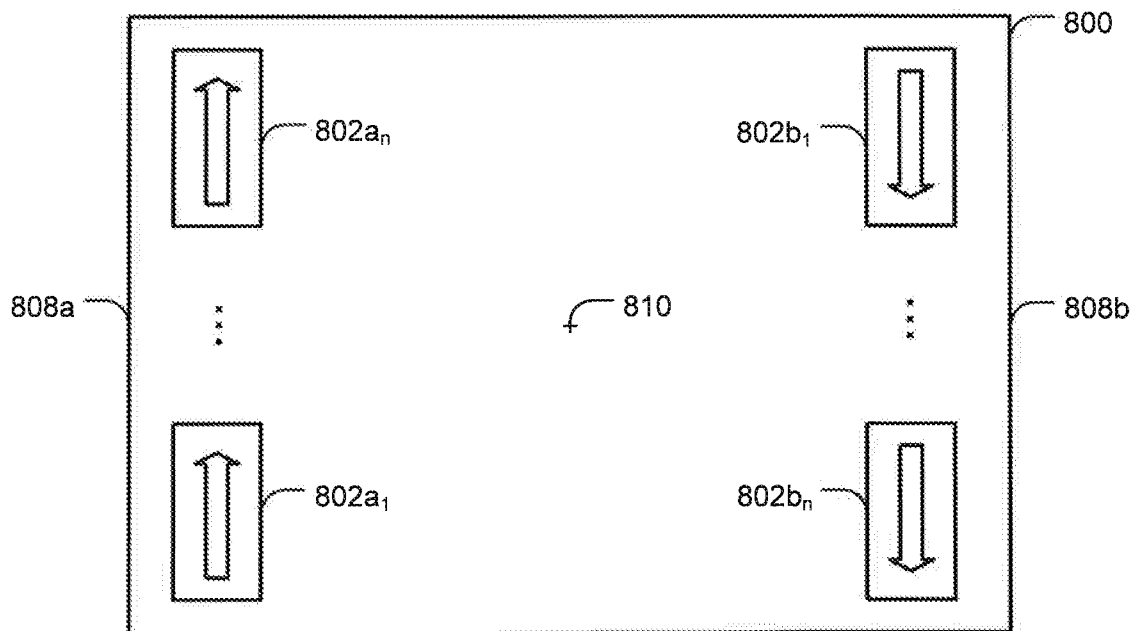


FIG. 8

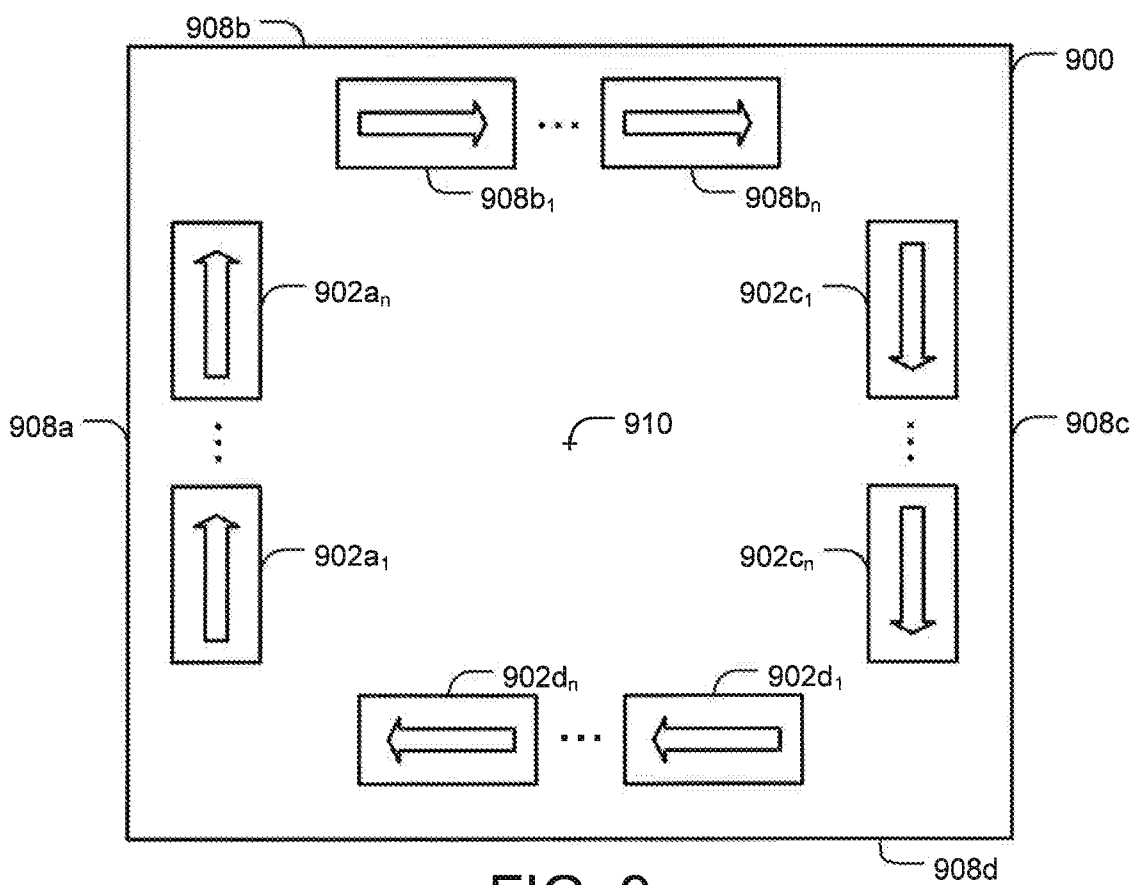
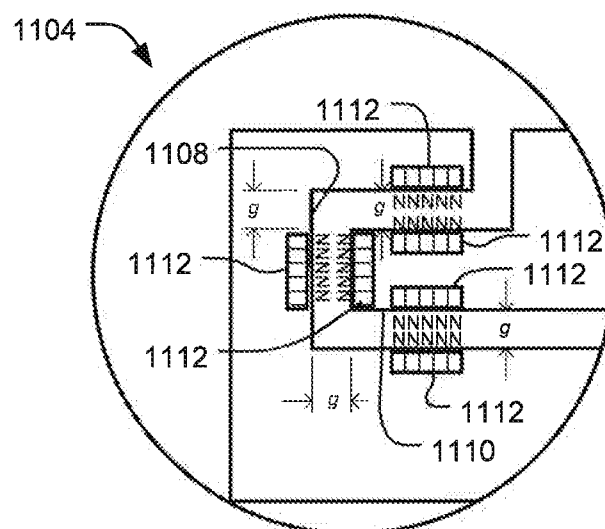
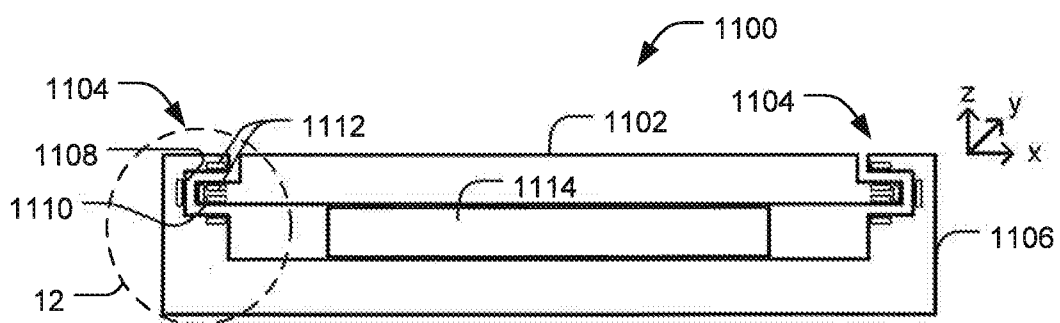
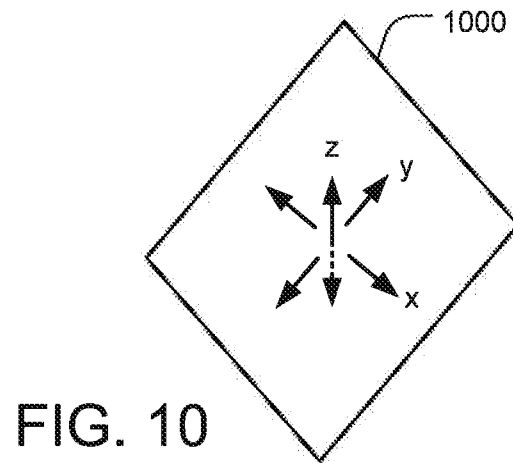


FIG. 9



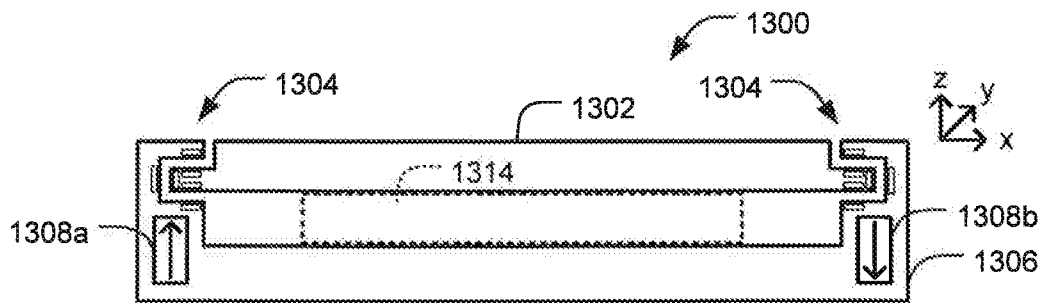


FIG. 13

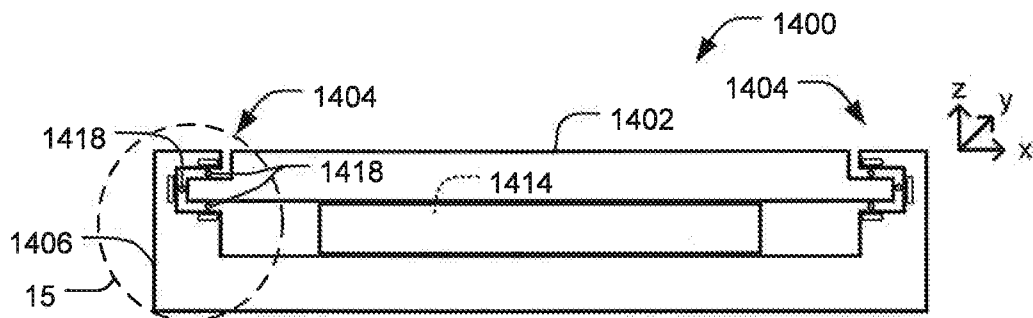


FIG. 14

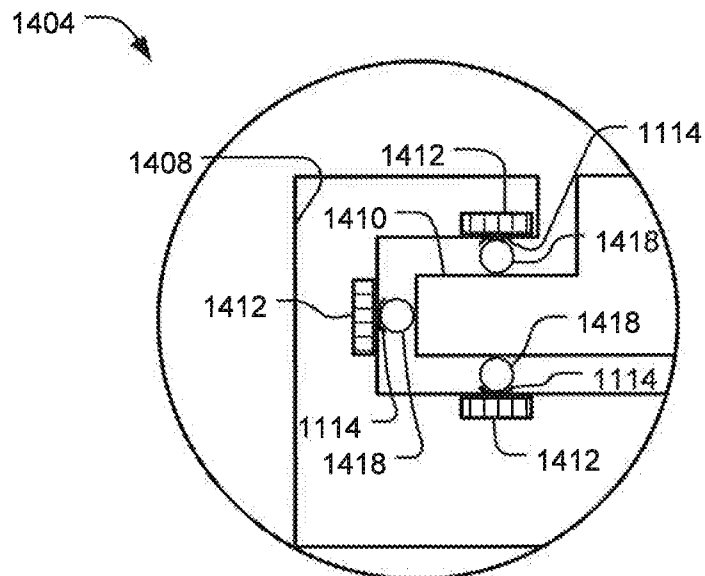


FIG. 15

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/033822**A. CLASSIFICATION OF SUBJECT MATTER****H02N 2/04(2006.01)i, H02N 2/02(2006.01)i**

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H02N 2/04; H02K 7/09; F16C 29/04; A63F 9/24; F16C 32/04; G06F 3/01; G06F 3/041; G09G 5/00; H02N 2/02

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: actuator, rotational, magnetic bearing, bearing retention

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2011-0190058 A1 (JOHN HOUSTON et al.) 04 August 2011 See paragraphs [0157]-[0160], claims 25,27, and figures 16,19.	1-4,7
Y		5,13-14
A		6,8-12,15-19
X	US 2004-0174079 A1 (VALENTIN M. IZRAELEV) 09 September 2004 See paragraphs [0035]-[0037] and figures 1,5.	8,15
Y		5,12-14
A		1-4,6-7,9-11,16-19
X	WO 2012-004629 A1 (NOKIA CORP. et al.) 12 January 2012 See page 11, lines 1-27, claims 1,5-6, and figure 3a.	16
Y		19
A		1-15,17-18
Y	KR 10-2011-0104265 A (SAMSUNG ELECTRO-MECHANICS CO., LTD.) 22 September 2011 See abstract, paragraphs [0023]-[0032] and figure 1.	12,14,19
A		1-11,13,15-18
A	JP 05-118326A (YASKAWA ELECTRIC CORP.) 14 May 1993 See abstract, paragraphs [0005]-[0006], and figures 1-5.	1-19



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

26 June 2013 (26.06.2013)

Date of mailing of the international search report

26 June 2013 (26.06.2013)

Name and mailing address of the ISA/KR

Korean Intellectual Property Office
189 Cheongsu-ro, Seo-gu, Daejeon Metropolitan City,
302-701, Republic of Korea

Facsimile No. 82-42-472-7140

Authorized officer

PARK, Hye Lyun

Telephone No. 82-42-481-3463



INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2013/033822

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2007-0057927 A1 (MICHAEL PRADOS) 15 March 2007 See paragraphs [0066]-[0068] and figures 6-8.	1-19

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/033822

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

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

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 20
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

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

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

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

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

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2013/033822

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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