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(71) Applicant: PEARL CAPITAL DEVELOPMENTS LLC
[US/US]; Corporate Trust Center, 1209 Orange Street,
Wilmington, DE 19801 (US).

(74) Agents: HEMENWAY, S., Craig et al.; 410 Seventeenth
Street, Suite 2200, Denver, CO 80202 (US).

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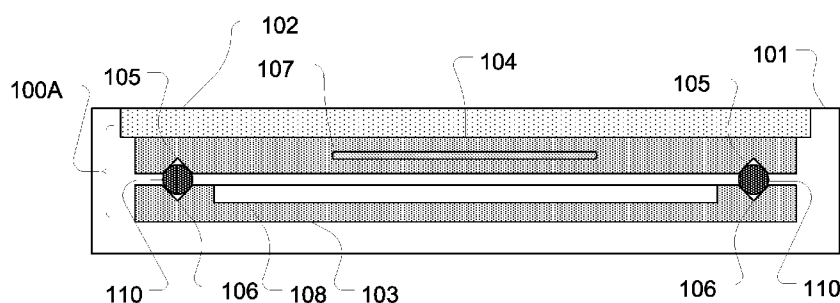


FIG. 1B

(57) Abstract: In an embodiment, an actuator or circuit includes elements moveably coupled via bearings positioned between curved grooves. The bearings and the curves may exert a restorative force to return the elements to an original position after movement and may be spherical, cubic, cylindrical, and/or include gears that interact with groove gears. In some embodiments, an electrical coil may be coplanar with a surface of an element and a hard magnet may be positioned in the center and be polarized to stabilize or destabilize the element with respect to another element. In various embodiments, a magnetic circuit includes an element with an electrical coil wrapped in multiple directions around the element. In some embodiments, an actuator includes attraction elements and exertion of force causes an element to approach, contact, and/or magnetically attach to one of the attraction elements.

MAGNETIC ACTUATORS FOR HAPTIC RESPONSE

Technical Field

[0001] This disclosure relates generally to haptic devices, and more specifically to magnetic actuators that provide a haptic response.

5 Background

[0002] Magnetic actuators, such as those utilized in haptic devices, typically include a first body element that is moveable with relation to a second body element. Such movement may be accomplished through direction of magnetic flux utilizing one or more electrical coils, soft magnets (a material that is not permanently magnetic but can become magnetic in
10 response to the proximity of a magnetic force) coils, and/or one or more hard magnets (materials that are permanently magnetic such as rare-earth magnets). The movement may cause vibrations, which may be provided to a user as haptic output or feedback.

Summary

[0003] The present disclosure discloses magnetic actuators and circuits. In various
15 embodiments, a magnetic actuator or circuit may include a moveable body or bar element that is moveably coupled to a fixed body or bar element via one or more bearings positioned between one or more grooves. In some cases the grooves may be curved such that force exerted causing lateral movement of the moveable body or bar elements cause the bearings to move upward on the curve of the groove such that the bearing moves back down the
20 curve and restores the moveable body or bar elements to an original position after the force is no longer exerted. In various cases, the bearings may be spherical, cubic, cylindrical, and/or include gear elements that interact with one or more gear elements of the grooves. In some cases, the bearings cause the moveable body or bar element to translate vertically as well as move laterally, though in other cases the bearings may only cause the moveable
25 body or bar elements to move laterally.

[0004] In some embodiments, a body element may include one or more electrical coils coplanar with the body element. In various cases, the body element may also include one or more hard magnets positioned in the center of the electrical coil that are polarized to stabilize or destabilize centering of the body element with respect to the another body
30 element.

[0005] In various embodiments, a magnetic circuit may include a first bar element with a plurality of hard magnets and/or soft magnets and a second bar element with one or more electrical coils wrapped around the second bar element. In some cases, the electrical coil may include a first section wrapped in a first direction, a second section wrapped in an

opposing direction, and a middle section that transitions between the first direction and the second direction.

[0006] In one or more embodiments, an actuator may include a fixed body element with first and a second side soft magnets that is moveably coupled to a moveable body element.

5 Exertion of force may cause the moveable body element to move such that the moveable body element approaches and/or contacts the first or second soft side magnet. Such contact may result in a "tap," which may be provided to a user as a tactile output. Upon contact, the moveable body element may magnetically attach to the respective soft side magnet and may remain so after the force is no longer exerted until another force is exerted
10 that detaches the moveable body element and causes it to move to approach the other soft side magnet.

[0007] In some embodiments, an actuator may include a first magnetic attraction element, a second magnetic attraction element, and a moveable member including a first hard magnet, a second hard magnet, and an electrical coil. Exertion of force may cause the moveable
15 member to move such that the first hard magnet approaches and/or contacts the first magnetic attraction element or the second hard magnet approaches and/or contacts the second magnetic attraction element. Such contact may result in a "tap," which may be provided to a user as a tactile output. Upon contact, the respective hard magnet may magnetically attach to the respective magnetic attraction element and may remain so after
20 the force is no longer exerted until another force is exerted that detaches the respective hard magnet and causes the moveable member to move such that the other hard magnet approaches the other magnetic attraction member. In some cases, the magnetic attraction elements may be hard magnets, though in other implementations the magnetic attraction elements may be soft magnets.

25 [0008] It is to be understood that both the foregoing general description and the following detailed description are for purposes of example and explanation and do not necessarily limit the present disclosure. The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate subject matter of the disclosure. Together, the descriptions and the drawings serve to explain the principles of the disclosure.

30 Brief Description of the Drawings

[0009] Figure 1A is a top view illustrating a track pad incorporated into an electronic device.

[0010] Figure 1B is a cross sectional side view of the electronic device taken along line 1B in Figure 1A including a first embodiment of a magnetic actuator.

[0011] Figure 1C is a bottom view of the first moveable body element of Figure 1B.

35 [0012] Figure 1D is a top view of the second moveable body element of Figure 1B.

[0013] Figure 1E is a close up side view of a first moveable body element groove of the first moveable body element of Figure 1C.

[0014] Figure 1F is a cross sectional side view of the electronic device taken along line 1F in Figure 1A illustrating an example flow of magnetic flux.

5 [0015] Figure 1G illustrates a cross sectional side view of an alternative embodiment of the second moveable body element of Figure 1B taken along line 1G of Figure 1D.

[0016] Figure 1H is a close up side view of alternative embodiment of the first moveable body element groove of the first moveable body element of Figure 1E.

10 [0017] Figure 1I is a cross sectional side view of the electronic device taken along line 1B in Figure 1A including a second embodiment of a magnetic actuator.

[0018] Figure 1J is a close up view of a bearing and a second moveable body element groove of Figure 1I.

[0019] Figure 2A is a cross sectional side view of a first implementation of a third embodiment of a magnetic actuator.

15 [0020] Figure 2B is a cross sectional side view of a second implementation of the magnetic actuator of Figure 2A.

[0021] Figure 3A is a cross sectional side view of a first implementation of a fourth embodiment of a magnetic actuator.

20 [0022] Figure 3B illustrates the magnetic actuator of Figure 3A after the application of a first electrical current to an electrical coil of the magnetic actuator.

[0023] Figure 3C illustrates the magnetic actuator of Figure 3B after the application of a second electrical current to the electrical coil of the magnetic actuator.

[0024] Figure 3D is a front plan view of a second implementation of the fourth embodiment of a magnetic actuator.

25 [0025] Figure 3E is a cross sectional view of the magnetic actuator of Figure 3D taken along line 3E in Figure 3D

[0026] Figure 3F illustrates the magnetic actuator of Figure 3E after the application of a first electrical current to an electrical coil of the magnetic actuator.

30 [0027] Figure 3G illustrates the magnetic actuator of Figure 3F after the application of a second electrical current to the electrical coil of the magnetic actuator.

[0028] Figure 3H illustrates the magnetic actuator of Figure 3D with a housing surrounding parts of the magnetic actuator.

[0029] Figure 4A is a front view of a first embodiment of a magnetic circuit.

[0030] Figure 4B is a side view of the magnetic circuit of Figure 4A.

35 [0031] Figure 4C is a front view of a second embodiment of a magnetic circuit.

[0032] Figure 4D is a front view of a third embodiment of a magnetic circuit.

[0033] Figure 4E is a front view of a fourth embodiment of a magnetic circuit.

Detailed Description

[0034] The description that follows includes sample systems, methods, and computer program products that embody various elements of the present disclosure. However, it should be understood that the described disclosure may be practiced in a variety of forms in addition to those described herein.

[0035] In many magnetic actuators, a first body element and a second body element may be connected via one or more centering springs. When the first and second body elements move with respect to each other from an original position, the centering spring may exert a restorative force upon the first and second body elements. This restorative force may operate to bring the first and second body elements back to the original position so that the first and second body elements are positioned for subsequent movement.

[0036] The present disclosure discloses magnetic actuators and circuits. In various embodiments, a magnetic actuator or circuit may include a first element that is moveably coupled to a second element via one or more bearings positioned between one or more grooves. In some cases the grooves may be curved. The bearings and the curves may exert a restorative force to return the first and second elements to an original position after movement. In various cases, the bearings may be spherical, cubic, cylindrical, and/or include gear elements that interact with one or more gear elements of the grooves.

[0037] In some embodiments, a second element may include one or more electrical coils are coplanar with a surface of the second element. In various cases, the second element may also include one or more hard magnets positioned in the center of the electrical coil that are polarized to stabilize or destabilize centering of the second element with respect to a first element.

[0038] In various embodiments, a magnetic circuit may include a second element with one or more electrical coils wrapped around the second element. In some cases, the electrical coil may include a first section wrapped in a first direction, a second section wrapped in an opposing direction, and a middle section that transitions between the first direction and the second direction.

[0039] In one or more embodiments, an actuator may include a first element with first and second side soft magnets that is moveably coupled to a second element. Exertion of force may cause the second element to move such that the second body element approaches and/or contacts the first or second soft side magnet. Such contact may result in a "tap," which may be provided to a user as a tactile output. Upon contact, the second element may magnetically attach to the respective soft side magnet and may remain so after the force is

no longer exerted until another force is exerted that detaches the second element and causes it to move to approach the other soft side magnet.

[0040] In other embodiments, an actuator may include a first magnetic attraction element, a second magnetic attraction element, and a moveable member including a first hard magnet,

5 a second hard magnet, and an electrical coil. Exertion of force may cause the moveable member to move such that the first hard magnet approaches and/or contacts the first magnetic attraction element or the second hard magnet approaches and/or contacts the second magnetic attraction element. Upon contact, the respective hard magnet may magnetically attach to the respective magnetic attraction element and may remain so after
10 the force is no longer exerted until another force is exerted that detaches the respective hard magnet and causes the moveable member to move such that the other hard magnet approaches the other magnetic attraction member.

[0041] Figure 1A is a top view illustrating a track pad 102 incorporated into an electronic device 101. The electronic device may be any electronic device that includes a track pad
15 such as a desktop computer, a laptop computer, a wearable device, a smart phone, a digital media player, a mobile computing device, a tablet computing device, and so on.

[0042] Figure 1B is a cross sectional side view of the electronic device 101 taken along the line 1B in Figure 1A. As illustrated, a first embodiment of a magnetic actuator 100A is coupled to the track pad 102.

20 **[0043]** Although the magnetic actuator is illustrated and described herein as coupled to the track pad of the electronic device, it is understood that this is an example. In various implementations, the magnetic actuator may be utilized in a variety of different ways in a variety of different electronic devices. For example, such a magnetic actuator may be coupled to a housing (such as the housing of a tablet computer, mouse, and so on), one or
25 more selection elements (such as one or more keys of a keyboard, buttons of a mouse, touch pads of a tablet computing device, and so on), a wearable device such as a watch, glasses, and so on.

[0044] As illustrated, the magnetic actuator may include a fixed body element 104, a number of bearings 110 (which may be spherical), and a moveable body element 103. The fixed
30 body element may include an electrical coil 107 (which may be coplanar with a surface of the first moveable body element) and a number of first grooves 105. The moveable body element may include a first hard magnet (materials that are permanently magnetic such as rare-earth magnets) 108, a second hard magnet element 109 (see Figures 1D and 1E) (which may have an opposite polarity than the first hard magnet facing a surface of the
35 moveable body element), and a number of second grooves 106. The moveable body element may be attracted to the fixed body element via the first hard magnet and/or the

second hard magnet element. The moveable body element may be separated from the fixed body element by the bearings positioned in the first and second grooves.

[0045] Figure 1C is a bottom view of the fixed body element 104. As illustrated, the first grooves may be curved such that the fixed body element grooves are deeper at a center portion 150 than at either edge portion 151 or 152.

[0046] Figure 1D is a top view of the moveable body element 103. As illustrated, the second grooves 106 may be curved such that the second moveable body element grooves are deeper at a center portion 160 than at either edge portion 161 or 162.

[0047] Application of electrical current to the electrical coil 107 may cause the electrical coil to generate a magnetic field. The magnetic field has a magnetic flux. The magnetic flux may exert a force upon any magnetic material (i.e., the first hard magnet 108 and the second hard magnet 109) within the magnetic field. The vector of the force may vary with the magnetic flux, which may vary according to the position of the magnetic material within the field. This force may cause the moveable body element 103 to move laterally with respect to the fixed body element 104. This movement may cause one or more vibrations, which may be provided to a user as tactile output or feedback. An example of the flow of the magnetic flux 170 can be seen in Figure 1F.

[0048] Thus, returning to Figures 1B-1D, when the moveable body element 103 moves laterally with respect to the fixed body element 104 due to the lateral force, the bearing 110 may move from the deeper center portions 150 and 160 to the narrower edge portions 151, 161 or 152, 162 (depending on the direction of motion). This may force the moveable body element further away vertically from the fixed body element. When the lateral force ceases, gravity and/or other forces may then cause the bearing to move from the narrower edge portions 151, 161 or 152, 162 to the deeper center portions 150 and 160. This may allow the moveable body element to move back vertically closer to the fixed body element.

[0049] As such, the bearings 110 and the grooves 105 and 106 may interact to exert a restorative force on the moveable body element after movement. This restorative force may operate to return the moveable body element to an original position with respect to the fixed body element after the lateral movement.

[0050] Figure 1E is a close-up side view of a first groove of the fixed body element 104 of Figure 1C. As illustrated, the center portion 150 is deeper than the edge portions 151 or 152.

[0051] With reference again to Figure 1C, in addition to the center portion 150 of the first grooves 105 being deeper than the edge portions 151 and 152, the grooves may be curved such that the inside portion of the grooves are deeper than their outside portions. As such, the first grooves may be v-shaped cross-sectionally, u-shaped, or similarly shaped. This may cause the sides of the bearings 110 to contact outside portions of the first grooves at

two points as opposed to the bottom of the bearings contacting the inside portion of the first grooves (e.g., the bottom of the channel formed by the first grooves). With reference again to Figure 1D, the second grooves 106 may be similarly curved.

[0052] Additionally, although the bearings 110 are illustrated and described above as spherical and the first and second grooves 105 and 106 are shown as curved cross sectionally to correspond to the bearings, it is understood that this is an example. In various implementations, the bearings may be cylindrical and include a plurality of gear elements that are configured to interact with gear elements defined in the first and second grooves. Such an implementation may prevent slippage between the bearings and the first grooves and the second grooves. Such an implementation is illustrated in Figure 1H, which illustrates gear elements 192 defined in a first groove 105 interacting with gear elements 191 of a cylindrical bearing 110.

[0053] Figure 1F is a cross sectional side view of the electronic device taken along line 1F in Figure 1A, illustrating an example flow of magnetic flux 170 in response to a specific electrical current applied to the electrical coil 107.

[0054] Although the magnetic actuator 100A is illustrated and described above as including four bearings 110, four first grooves 105, and four second grooves 106, it is understood that this is an example. In various implementations, the magnetic actuator may include any number of bearings and/or grooves (such as one, three, or fifteen).

[0055] Figure 1G illustrates a cross sectional side view of an alternative embodiment of the moveable body element 103 of Figure 1B, taken along line 1G of Figure 1D. As illustrated, at least one soft magnet 180 (a material that is not permanently magnetic but can become magnetic in response to the proximity of a magnetic force) may be positioned beneath the first hard magnet 108 and/or the second hard magnet 109 such that the first hard magnet and/or the second hard magnet are positioned between the soft magnet and the fixed body element 104. In some implementations, the soft magnet may be composed at least partially of a ferrous metal such as steel.

[0056] Figure 1I is a cross sectional side view of the electronic device taken along line 1B in Figure 1A, including a second embodiment of a magnetic actuator 100I. As illustrated, in this embodiment the bearings 110 are cubes. Further, the first grooves 105 include curved areas 141 and 143 that curve inward toward center point 142. Similarly, the second grooves 106 include curved areas 145 and 147 that curve inward toward center point 143.

[0057] As such, when the moveable body element 103 moves laterally with respect to the fixed body element 104 due to the application of force, the cube bearings may roll along the corresponding curved areas. When the force ceases, gravity and/or other forces may then cause the cube bearings to roll back along the corresponding curved areas. This may

provide a restorative force that may operate to return the moveable body element to an original position with respect to the fixed body element after movement.

[0058] The relationship between the dimensions of the cube and the dimensions of the curved areas 141, 143, 145, and/or 147 may determine whether or not the cube bearings 110 move the moveable element 103 in a purely lateral direction or whether the cube bearings force the moveable body element to translate vertically as well as laterally.

[0059] Figure 1J is a close up view of a bearing 110 and a second groove 106 of Figure 1I. The lines 149 indicate the movement of the moveable element 103 that may result based on a center point 148 of the cube bearings. Given the dimensions of the cube bearing illustrated, the center point corresponds to the lowest line 149, which is curved to indicate that the moveable body element would translate vertically during lateral movement.

However, if the cube bearing was large enough that the center point corresponded to the top line 149, the moveable body element would only move laterally and would not translate vertically.

[0060] Although the moveable body element 103 has been illustrated and described above as moveable with respect to the fixed body element 104, it is understood that this is an example. In various implementations, the body element 104 may be moveable with respect to a fixed body element 103.

[0061] Figure 2A is a cross sectional side view of a first implementation of a third embodiment of a magnetic actuator 200. In some implementations, such a magnetic actuator may be coupled to a device such as the track pad 102 of Figure 1A.

[0062] Returning to Figure 2A, as illustrated, the magnetic actuator 200 may include a first body element 211 that is moveably coupled to a second body element 212 such that the second body element is capable of lateral movement with respect to the first body element.

The first body element may include a soft magnet 201, a first hard magnet 203, and a second hard magnet 204 (which may have an opposite polarity than the first hard magnet facing a surface of the first body element). The second body element may include an electrical coil 205 wound in a circular arrangement to have a first side 206, a second side 207, and a gap in the center. The second body element may also include a center hard magnet positioned in the gap in the center of the electrical coil and a second soft magnet element 202 positioned underneath the electrical coil.

[0063] In response to application of an electrical current, the first and second sides of the electrical coil 206 and 207 may generate a magnetic field. The magnetic field has a magnetic flux 209. The magnetic flux may exert a force upon any magnetic material (i.e., the first hard magnet 203 and the second hard magnet 204) within the magnetic field. The vector of the force may vary with the magnetic flux, which may vary according to the position of the magnetic material within the field. This force may cause the second body element 212

to move laterally with respect to the first body element 211. This movement may cause one or more vibrations, which may be provided to a user as tactile output or feedback.

[0064] In this first implementation, the center hard magnet 208 may be polarized to oppose the direction of the magnetic flux 209. This opposition may destabilize centering of the first body element 211 with respect to the second body element 212 because the polarities of the sides of the center hard magnet 208 repel the respective polarities of the undersides of the first and second hard magnets 203 and 204. Instead, as a result of the opposition and repulsion, the second body element may be more stable when offset from center in either lateral direction with respect the first body element than when centered with respect to the first body element. In implementations where the second body element has an original position centered with respect to the first body element, this may cause resistance to the second moveable body element returning to the original centered position with respect to the first moveable body element after the lateral movement 210.

[0065] In other implementations, the second body element 212 may have an original position that is offset with respect to the first body element 211 and that may be disrupted by the lateral movement 210 of the second body element. In such implementations, the opposition of the center hard magnet 208 to the direction of the magnetic flux 209 may provide a restorative force after the lateral movement (caused by the repulsion of the sides of the center hard magnet 208 that the respective polarities of the undersides of the first and second hard magnets 203 and 204) that acts to return the second body element to the original offset position with respect to the first body element after the lateral movement of the second body element.

[0066] The second body element 212 may be moveably coupled to the first body element 211 utilizing a variety of different mechanisms (not shown). For example, in some implementations the second body element may be suspended from the first body element, such as by wire or string. In other implementations, one or more springs, magnetic forces, and so on may moveably couple the second body element to the first body element.

[0067] Figure 2B is a cross sectional side view of a second implementation of the magnetic actuator of Figure 2A. In this second implementation, the center hard magnet 208 may be polarized to complement the direction of the magnetic flux 209. This complementing force may exert a restorative force on the first moveable body element and/or the second moveable body element because the polarities of the sides of the center hard magnet 208 attract the respective polarities of the undersides of the first and second hard magnets 203 and 204. Such restorative force may act to return the second body element 212 to an original position with respect to the first body element 211 after the lateral movement 210 of the second body element.

[0068] Although the second body element 212 has been illustrated and described above as moveable with respect to the first body element 211, it is understood that this is an example. In various implementations, the first body element may be moveable with respect to the second body element.

5 [0069] Figure 3A is a cross sectional side view of a first implementation of a fourth embodiment of a magnetic actuator 300A. In some implementations, such a magnetic actuator may be coupled to a device such as the track pad 102 of Figure 1A.

[0070] Returning to Figure 3A, as illustrated, the magnetic actuator 300A may include a moveable body element 302A that is moveably coupled (such as laterally moveably coupled)
10 to a fixed body element 301A. The fixed body element may include a first hard magnet 306A, a second hard magnet 307A, and a soft magnet 303A. The soft magnet may include a top structure 310A, a first side soft magnet 304A, and a second side soft magnet 305A. The moveable body element may include a base element 309A (which may be at least one soft magnet) and an electrical coil 308A.

15 [0071] Although the fixed body element 301A is illustrated and described as incorporating the top structure 310A, the first side soft magnet 304A, and the second side soft magnet 305A into a single soft magnet 303A, it is understood that this is an example. In other implementations the first side soft magnet, the second side soft magnet, and/or the top structure may be formed of separate soft magnets. Additionally, in various implementations
20 the top structure may not be a soft magnet.

[0072] In response to application of an electrical current, the electrical coil 308A may generate a magnetic field. The magnetic field has a magnetic flux. The magnetic flux may exert a force upon any magnetic material (i.e., the first hard magnet 306A and the second hard magnet 307A) within the magnetic field. The vector of the force may vary with the
25 magnetic flux, which may vary according to the position of the magnetic material within the field. This force may cause the moveable body element 302A to approach and/or contact either the first side soft magnet 304A or the second side soft magnet 305A. Such approaches and/or contacts may result in one or more vibrations or taps which may be provided to a user as haptic output or feedback.

30 [0073] When the second moveable body element 302A contacts the first side soft magnet 304A, the second moveable body element may magnetically attach to the first side soft magnet. Subsequently, the second moveable body element may remain magnetically attached to the first side soft magnet even after the electrical current that resulted in the movement of the second moveable body element is no longer applied to the electrical coil
35 308A. A similar effect may occur when the second moveable body element contacts the second side soft magnet 305A.

[0074] Figure 3B illustrates the magnetic actuator 300A of Figure 3A after the application of a first electrical current to the electrical coil 308A, resulting in a lateral force being applied to the second moveable body element 302A. As illustrated, the second moveable body element approaches, contacts, and magnetically attaches to the first side soft magnet 304A.

5 This contact may result in a “tap” which may be provided to a user as haptic output or feedback.

[0075] The second moveable body element 302A may remain magnetically attached to the first side soft magnet 304A even after the first electrical current is no longer applied to the electrical coil 308A. The second moveable body element may remain magnetically attached

10 to the first side soft magnet until a second electrical current is applied to the electrical coil.

[0076] Figure 3C illustrates the magnetic actuator 300A of Figure 3B after the application of the second electrical current to the electrical coil 308A, resulting in a lateral force (opposite to the lateral force illustrated in Figure 3B) being applied to the second moveable body element 302A. As illustrated, the second moveable body element approaches, contacts,

15 and magnetically attaches to the first side soft magnet 304A.

[0077] Although the moveable body element 302A has been illustrated and described above as moveable with respect to the fixed body element 301A, it is understood that this is an example. In various implementations, the body element 301A may be moveable with respect to a fixed body element 302A.

20 [0078] Figure 3D is a front plan view of a second implementation of the fourth embodiment of a magnetic actuator 300B. In some implementations, such a magnetic actuator may be coupled to a device such as the track pad 102 of Figure 1A.

[0079] Returning to Figure 3D, as illustrated, the magnetic actuator 300B may include a first magnetic attraction element 303B, a second magnetic attraction element 308B, and a

25 moveable member 301B. The first magnetic attraction element may include a first aperture 302B, the second magnetic attraction element may include a second aperture 307B, and the moveable member may be configured to move by passing and/or extending through the first aperture and/or the second aperture. The moveable member may be a shaft and may include a first hard magnet 304B, a second hard magnet 306B, and at least one electrical

30 coil 305B that is at least partially positioned or wrapped around the first hard magnet and/or the second hard magnet.

[0080] Figure 3E is a cross sectional view of the magnetic actuator 300B taken along line 3E in Figure 3D. As illustrated, the first magnetic attraction element 303B and the second magnetic attraction element 308B may be hard magnets that are polarized towards each

35 other. However, it is understood that this is an example and in various implementations the first magnetic attraction element and the second magnetic attraction element may be soft

magnets. Similarly, the first hard magnet 304B and the second hard magnet 306B may be polarized towards each other.

[0081] In response to application of an electrical current, the electrical coil 305B may generate a magnetic field. The magnetic field has a magnetic flux. The magnetic flux may exert a force upon any magnetic material (i.e., the first hard magnet 304B and the second hard magnet 306B) within the magnetic field. The vector of the force may vary with the magnetic flux, which may vary according to the position of the magnetic material within the field. This force may cause the moveable member 301B to move such that the first hard magnet 304B approaches and/or contacts the first magnetic attraction element 303B or the second hard magnet 306B approaches and/or contacts the second magnetic attraction element 308B. Such approaches and/or contacts may result in one or more vibrations or taps which may be provided to a user as haptic output or feedback.

[0082] When the first hard magnet 304B contacts the first magnetic attraction element 303B, the first hard magnet may magnetically attach to the first magnetic attraction element. Subsequently, the first hard magnet may remain magnetically attached to the first magnetic attraction element even after the force is no longer exerted upon the moveable member 301B. A similar effect may occur when the second hard magnet 306B contacts the second magnetic attraction element 308B.

[0083] Figure 3F illustrates the magnetic actuator 300B of Figure 3E after the application of a first electrical current to an electrical coil 305B, resulting in a force being applied to the moveable member 301B. As illustrated, the moveable member moves such that the first hard magnet 304B approaches, contacts, and magnetically attaches to the first magnetic attraction element 303B. This contact may result in a "tap" which may be provided to a user as haptic output or feedback.

[0084] The first hard magnet 304B may remain magnetically attached to the first magnetic attraction element 303B even after the first electrical current is no longer applied to the electrical coil 305B. The first hard magnet may remain magnetically attached to the first magnetic attraction element a second electrical current is applied to the electrical coil, resulting in a force being applied to the moveable member 301B (opposite to the force shown in Figure 3F) such that the first hard magnet detaches from the first magnetic attraction element and the second hard magnet 306B approaches the second magnetic attraction element 308B.

[0085] Figure 3G illustrates the magnetic actuator 300B of Figure 3F after the application of a second electrical current to the electrical coil 305B. As illustrated, the second hard magnet 306B approaches, contacts, and magnetically attaches to the second magnetic attraction element 308B.

[0086] Figure 3H illustrates the magnetic actuator of Figure 3D with a housing 310B surrounding parts of the magnetic actuator. As illustrated, in some implementations, such a housing may surround the first hard magnet 304B, the second hard magnet 306B, the electrical coil 305B, the first magnetic attraction element 303B, the second magnetic attraction element 308B, and at least part of the moveable member 301B. As also illustrated, the housing may include a first housing aperture 309B and a second housing aperture 311B and the moveable member 301B may be configured to move by passing and/or extending through the first housing aperture and/or the second housing aperture.

[0087] Figure 4A is a front view of a first embodiment of a magnetic circuit 400A. In some implementations, such a magnetic circuit may be a magnetic actuator. In various implementations, such a magnetic circuit may be coupled to a device such as the track pad 102 of Figure 1A.

[0088] Returning to Figure 4A, as illustrated, the magnetic circuit 400A may include a moveable bar element 401 that is moveably coupled to a fixed bar element 402. The moveable bar element may include a soft magnet 403, a first hard magnet 404, and a second hard magnet 405. The fixed bar element may include an electrical structure 407 (such as a wire, wire insulated in plastic and/or rubber, and/or other electrical coil structure) wound around a bar structure 406 of the fixed bar element.

[0089] As illustrated, the electrical coil structure 407 may have a first section 409 that is wound in a first direction around the bar structure 406 and a second section 408 that is wound in a second direction around the bar structure. The first direction may be opposite of the second direction. Further, the electrical coil structure may include a middle section 410 where the winding in the first direction changes to the second direction. In various cases, the middle section may be attached to the bar structure, such as utilizing adhesive.

[0090] In response to application of an electrical current, the electrical coil structure 407 may generate a magnetic field. The magnetic field has a magnetic flux 414. The magnetic flux may exert a force upon any magnetic material (i.e., the first hard magnet 404 and the second hard magnet 405) within the magnetic field. The vector of the force may vary with the magnetic flux, which may vary according to the position of the magnetic material within the field. This force may cause the moveable bar element 401 to move laterally with respect to the fixed bar element 402. Such movement may result in one or more vibrations which may be provided to a user as haptic output or feedback.

[0091] As illustrated, the moveable bar element 401 may be moveably coupled to the second moveable bar element 402 via bearings 413. As illustrated in Figure 4B, the bearings may be positioned between first grooves 415 and second grooves 416. Movement of the bearings along the first grooves and second grooves may enable the moveable bar element to move laterally with respect to the fixed bar element.

[0092] Although the magnetic circuit 400A is illustrated and described as utilizing the bearings 413 to moveably couple the moveable bar element 401 and the fixed bar element 402, it is understood that this is an example. In other implementations, springs or other moveable attachment mechanisms may be utilized to moveably attach the moveable bar element and the fixed bar element.

[0093] Although the moveable bar element 401 has been illustrated and described above as moveable with respect to the fixed bar element 402, it is understood that this is an example. In various implementations, the body element 402 may be moveable with respect to a fixed body element 401.

[0094] Figure 4C is a front view of a second embodiment of a magnetic circuit 400C. Contrasted with the first embodiment of the magnetic circuit 400A illustrated in Figures 4A and 4B, the magnetic circuit 400C may include an additional moveable bar element 450. The additional moveable bar element may be moveably coupled to an opposite side of the fixed bar element 402 from the moveable bar element 401. The additional moveable bar element may be moveably coupled to the fixed bar element via bearings 455.

[0095] Further contrasted with the magnetic circuit 400A illustrated in Figures 4A and 4B, the moveable bar element 401 of the magnetic circuit 400C may include a first mass adding element 457. The first mass adding element may be positioned between the first hard magnet 404 and the second hard magnet 405 and may function to contribute mass to movement of the first moveable bar element. In some cases, the first mass adding element may be formed from tungsten.

[0096] The additional moveable bar element 450 may include a soft magnet 451, a third hard magnet 453, and a fourth hard magnet 452. Additionally, the additional moveable bar element may include a second mass adding element 454. The second mass adding element may be positioned between the third hard magnet and the fourth hard magnet.

[0097] Figure 4D is a front view of a third embodiment of a magnetic circuit 400D. As contrasted with the first embodiment of the magnetic circuit 400A illustrated in Figures 4A and 4B, the first grooves 415 and/or the second grooves 416 of the magnetic circuit 400D may include gear elements 461. Additionally, the bearings 413 (which may be cylindrical) may include gear elements 462. Interaction between the gear elements of the bearings and the gear elements of the grooves may enable the moveable bar element to move laterally with respect to the fixed bar element. Such an implementation may prevent slippage between the bearings and the grooves.

[0098] Although the magnetic circuit 400D is illustrated and described as utilizing the gear elements 461, 462, and 463 in the same magnetic circuit as the particular electrical coil structure 407, it is understood that this is an example. In other implementations the gear elements 461, 462, and 463 may be utilized to moveably couple various different moveable

elements without departing from the scope of the present disclosure. For example, in some implementations the gear elements 461, 462, and 463 may be utilized to moveably couple elements such as the fixed body element 104 and the moveable body element 103 of Figures 1B-1E.

5 [0099] Figure 4E is a front view of a fourth embodiment of a magnetic circuit 400E. As contrasted with the first embodiment of the magnetic circuit 400A illustrated in Figures 4A and 4B, the bearings 413 may be cubes. Further, the first grooves 415 may include curved areas 471 and 473 that curve inward toward center point 472. The second grooves 416 may be similarly curved. As such, when the moveable bar element 401 moves laterally with
10 respect to the fixed bar element 402 due to the application of electrical current to the electrical coil structure 407, the cube bearings may roll along the corresponding curved areas. When the lateral movement is ceased, gravity and/or other forces may then cause the cube bearings to roll back along the corresponding curved areas. This may provide a restorative force that may operate to return the moveable bar element to an original position
15 with respect to the fixed bar element after the lateral force is ceased.

[00100] The relationship between the dimensions of the cube and the dimensions of the curved areas 471, 473, 474, and/or 476 may determine whether or not the cube bearings 413 move moveable first bar element 401 in a purely lateral direction or whether the cube bearings force the moveable body element to translate vertically as well as laterally.

20 [00101] As discussed above and illustrated in the accompanying figures, the present disclosure discloses magnetic actuators and circuits. In various embodiments, a magnetic actuator or circuit may include a moveable element that is moveably coupled to a fixed element via one or more bearings positioned between one or more grooves. In some cases the grooves may be curved. The bearings and the curves may exert a restorative force to
25 return the first and second elements to an original position after movement. In various cases, the bearings may be spherical, cube, cylindrical, and/or include gear elements that interact with one or more gear elements of the grooves.

[00102] In some embodiments, a body element may include one or more electrical coils coplanar with a surface of the body element. In various cases, the body element may also
30 include one or more hard magnets positioned in the center of the electrical coil that are polarized to stabilize or destabilize centering of the body element with respect to another element.

[00103] In various embodiments, a magnetic circuit may include a bar element with one or more electrical coils wrapped around the bar element. In some cases, the electrical coil
35 may include a first section wrapped in a first direction, a second section wrapped in an opposing direction, and a middle section that transitions between the first direction and the second direction.

[00104] In one or more embodiments, an actuator may include a fixed element with first and second side soft magnets that is moveably coupled to a moveable element. Exertion of force may cause the moveable element to move such that the moveable body element approaches and/or contacts the first or second soft side magnet. Such contact may result in a “tap,” which may be provided to a user as a tactile output. Upon contact, the moveable element may magnetically attach to the respective soft side magnet and may remain so after the force is no longer exerted until another force is exerted that detaches the moveable element and causes it to move to approach the other soft side magnet.

[00105] In other embodiments, an actuator may include a first magnetic attraction element, a second magnetic attraction element, and a moveable member including a first hard magnet, a second hard magnet, and an electrical coil. Exertion of force may cause the moveable member to move such that the first hard magnet approaches and/or contacts the first magnetic attraction element or the second hard magnet approaches and/or contacts the second magnetic attraction element. Upon contact, the respective hard magnet may magnetically attach to the respective magnetic attraction element and may remain so after the force is no longer exerted until another force is exerted that detaches the respective hard magnet and causes the moveable member to move such that the other hard magnet approaches the other magnetic attraction member.

[00106] In the present disclosure, the methods disclosed may be implemented as sets of instructions or software readable by a device. Further, it is understood that the specific order or hierarchy of steps in the methods disclosed are examples of sample approaches. In other embodiments, the specific order or hierarchy of steps in the method can be rearranged while remaining within the disclosed subject matter. The accompanying method claims present elements of the various steps in a sample order, and are not necessarily meant to be limited to the specific order or hierarchy presented.

[00107] The described disclosure may be provided as a computer program product, or software, that may include a non-transitory machine-readable medium having stored thereon instructions, which may be used to program a computer system (or other electronic devices) to perform a process according to the present disclosure. A non-transitory machine-readable medium includes any mechanism for storing information in a form (e.g., software, processing application) readable by a machine (e.g., a computer). The non-transitory machine-readable medium may take the form of, but is not limited to, a magnetic storage medium (e.g., floppy diskette, video cassette, and so on); optical storage medium (e.g., CD-ROM); magneto-optical storage medium; read only memory (ROM); random access memory (RAM); erasable programmable memory (e.g., EPROM and EEPROM); flash memory; and so on.

[00108] It is believed that the present disclosure and many of its attendant advantages will be understood by the foregoing description, and it will be apparent that various changes may be made in the form, construction and arrangement of the components without departing from the disclosed subject matter or without sacrificing all of its material

5 advantages. The form described is merely explanatory, and it is the intention of the following claims to encompass and include such changes.

[00109] While the present disclosure has been described with reference to various embodiments, it will be understood that these embodiments are illustrative and that the scope of the disclosure is not limited to them. Many variations, modifications, additions, and

10 improvements are possible. More generally, embodiments in accordance with the present disclosure have been described in the context of particular embodiments. Functionality may be separated or combined in blocks differently in various embodiments of the disclosure or described with different terminology. These and other variations, modifications, additions, and improvements may fall within the scope of the disclosure as defined in the claims that

15 follow.

CLAIMS

We claim:

1. An actuator, comprising:
a fixed body element, including at least one first groove and at least one electrical coil;
a moveable body element, including at least one second groove and a first and
5 second hard magnet; and
at least one bearing positioned between the at least one first groove and the at least one second groove that separates the fixed body element from the moveable body element;
wherein the moveable body element is magnetically attracted toward the fixed body element, the first hard magnet has an opposite polarity facing a surface of the moveable
10 body element than the second hard magnet, and at least one of the at least one first groove or the at least one second groove is curved such that applying a lateral force to the moveable body element causes the at least one bearing to force the moveable body element vertically away from the fixed body element.
2. The actuator of claim 1, wherein ceasing to apply the lateral force causes the at least one bearing to allow the moveable body element to move closer to the fixed body element.
3. The actuator of claim 1, wherein at least one of the at least one first groove or the at least one second groove includes a first plurality of gear elements, the at least one bearing includes a second plurality of gear elements, and the first plurality of gear elements are configured to interact with the second plurality of gear elements.
4. The actuator of claim 3, wherein the at least one bearing is cylindrical.
5. The actuator of claim 1, wherein the at least one bearing and at least one of the at least one first groove or the at least one second groove interact to exert a restorative force to return the fixed body element to an original position with respect to the fixed body element after application of the lateral force.
6. The actuator of claim 1, wherein the actuator provides at least one tactile output to a user of an electronic device.
7. The actuator of claim 1, wherein the at least one bearing is spherical.

8. The actuator of claim 1, wherein the moveable body element further includes at least one soft magnet positioned such that the first and second hard magnets are positioned between the at least one soft magnet and the fixed body element.

9. The actuator of claim 8, wherein the at least one soft magnet comprises a ferrous metal.

10. The actuator of claim 1, wherein the at least one bearing comprises a plurality of bearings, the at least one first groove comprises a plurality of first grooves, the at least one second groove comprises a plurality of second grooves, and each of the plurality of bearings is positioned between one of the plurality of first grooves and one of the plurality of second grooves.

11. The actuator of claim 1, wherein the at least one bearing is cubic.

12. An actuator, comprising:
a first body element comprising a first hard magnet and a second hard magnet; and
a second body element that is moveably coupled to the first body element and comprises at least one electrical coil and at least one center hard magnet positioned in a center of the at least one electrical coil;
wherein the center hard magnet is polarized to at least one of oppose a direction of the magnetic flux or correspond with the direction of the magnetic flux.

13. The actuator of claim 12, wherein the center hard magnet is polarized to correspond with the direction of the magnetic flux and exerts a restorative force to return the second body element to an original position with respect to the first body element after lateral movement.

14. The actuator of claim 12, wherein the center hard magnet is polarized to oppose the direction of the magnetic flux and resists return of the second body element to the original position.

15. The actuator of claim 12, wherein the center hard magnet is polarized to oppose the direction of the magnetic flux and destabilizes centering of the second body element with respect to the first body element.

16. The actuator of claim 12, wherein the first body element further comprises at least a first soft magnet element wherein at least one of the first hard magnet or the a second hard magnet is positioned between the first soft magnet and the second body element.

17. The actuator of claim 12, wherein the second body element further comprises at least a second soft magnet element wherein at least one of the at least one electrical coil or the at least one center hard magnet is positioned between the second soft magnet and the first body element.

18. A magnetic circuit, comprising:

a moveable bar element that includes at least a first hard magnet and a second hard magnet; and

5 a fixed bar element that includes an electrical coil structure wound around the fixed bar element wherein a first section of the electrical coil structure is wound in a first direction around a first area of the fixed bar element and a second section of the electrical coil structure is wound in a second direction around a second area of the fixed bar element; wherein the moveable bar element is moveably coupled to the fixed bar element.

19. The magnetic circuit of claim 18, wherein the first direction and the second direction are opposing directions.

20. The magnetic circuit of claim 18, wherein the electrical coil structure includes a middle section where direction of winding is changed between the first direction and the second direction.

21. The magnetic circuit of claim 18, wherein the middle section is attached to the fixed bar element.

22. The magnetic circuit of claim 21, wherein the middle section is attached to the fixed bar element utilizing adhesive.

23. The magnetic circuit of claim 18, wherein the moveable bar element further comprises at least one soft magnet wherein at least one of the first hard magnet or the second bar magnet is positioned between the at least one soft magnet and the fixed bar element.

24. The magnetic circuit of claim 18, wherein the moveable bar element is moveably coupled to the fixed bar element by at least one bearing that is positioned between at least one first groove and at least one second groove.

25. The magnetic circuit of claim 24, wherein the at least one bearing is a cube.

26. The magnetic circuit of claim 24, wherein the at least one bearing includes a plurality of bearing gear elements that interact with at least one of a plurality of first gear elements or at least one of a plurality of second gear elements.

27. The magnetic circuit of claim 18, further comprising an additional moveable bar element separated from the moveable bar element by the fixed bar element wherein the additional moveable bar element is moveably coupled to the fixed element and includes at least a third hard magnet and a fourth hard magnet.

28. The magnetic circuit of claim 27, wherein the additional moveable bar element is moveably coupled to the fixed bar element by at least one bearing that is positioned between at least one third groove and at least one second groove.

29. The magnetic circuit of claim 18, wherein the moveable bar element further includes at least one mass adding element.

30. The magnetic circuit of claim 29, wherein the at least one mass adding element comprises tungsten.

31. The magnetic circuit of claim 29, wherein the at least one mass adding element is positioned between the first hard magnet and the second hard magnet.

32. A magnetic circuit, comprising:
a moveable body element including at least one first groove comprising a plurality of first gear elements;

at least one bearing including a plurality of bearing gear elements; and

5 a fixed body element including at least one second groove comprising a plurality of second gear elements;

wherein the moveable body element is moveably coupled to the fixed body element by at least one of the plurality of the bearing gear elements interacting with at least one of one of the plurality of first gear elements or one of the plurality of second gear elements.

33. The magnetic circuit of claim 32, wherein the at least one bearing is cylindrical.

34. The magnetic circuit of claim 32, wherein the magnetic circuit comprises a magnetic actuator.

35. The magnetic circuit of claim 32, wherein the moveable body element further comprises a first bar element that includes at least a first hard magnet and a second hard magnet and the fixed body element further comprises a second bar element that includes an electrical coil structure wound around the second bar element wherein a first section of the
5 electrical coil structure is wound in a first direction around a first area of the second bar

element and a second section of the electrical coil structure is wound in a second direction around a second area of the second bar element.

36. The magnetic circuit of claim 35, wherein the moveable body element further comprises at least one soft magnet that is separated from the fixed body element by at least one of the first hard magnet or the second hard magnet.

37. An actuator, comprising:

a fixed body element, including at least one first groove and at least one electrical coil;

5 a moveable body element, including at least one second groove and a first and second hard magnet; and

at least one cube bearing positioned between the at least one first groove and the at least one second groove that separates the at least one moveable body element from the fixed body element;

10 wherein the moveable body element is magnetically attracted toward the fixed body element and at least one of the at least one first groove or the at least one second groove is curved such that applying a lateral force to the moveable body element causes the at least one cube bearing to move the moveable body element laterally with respect to the fixed body element.

38. The actuator of claim 37, wherein ceasing to apply the lateral force causes the at least one cube bearing to move the moveable body element laterally with the fixed body element to return to an original position.

39. An actuator, comprising:

a fixed body element including a top structure, at least a first hard magnet and a second hard magnet, and at least a first side soft magnet coupled to the top structure and a second side soft magnet coupled to the top structure; and

5 a moveable body element that is moveably coupled to the fixed body element and including at least one electrical coil;

wherein the moveable body element moves to approach at least one of the first side soft magnet or the second side soft magnet in response to a lateral force exerted upon the moveable body element.

40. The actuator of claim 39, wherein the moveable body element magnetically attaches to at least one of the first side soft magnet or the second side soft magnet upon contact.

41. The actuator of claim 39, wherein applying the lateral force moves the moveable body element laterally to approach, contact, and magnetically attach to the first side soft magnet.

42. The actuator of claim 41, wherein the contact of the moveable body element and the first side soft magnet is utilized to produce a tactile output for a user.

43. The actuator of claim 42, wherein the tactile output is a tap.

44. The actuator of claim 41, wherein the moveable body element remains magnetically attached to the first side soft magnet after application of the lateral force.

45. The actuator of claim 44, wherein the moveable body element detaches from the first side soft magnet when at least one opposite lateral force is applied to the moveable body element.

46. The actuator of claim 45, wherein application of the at least one opposite lateral force moves the moveable body element toward the second side soft magnet.

47. The actuator of claim 46, wherein application of the opposite lateral force moves the moveable body element to contact the second side soft magnet.

48. The actuator of claim 39, wherein the top structure comprises at least one soft magnet.

49. An actuator, comprising:

a first magnetic attraction element;

a second magnetic attraction element; and

a moveable member that is moveably coupled to the first magnetic attraction element

5 and the second magnetic attraction element and that includes at least one first hard magnet, at least one second hard magnet, and at least one electrical coil positioned at least partially around the first hard magnet and the second hard magnet;

10 wherein the moveable member moves such that at least one of the first hard magnet approaches the first magnetic attraction element upon exertion of a force or the second hard magnet approaches the second magnetic attraction element upon exertion of the force.

50. The actuator of claim 49, wherein at least one of the first hard magnet magnetically attaches to the first magnetic attraction element upon contact or the second hard magnet magnetically attaches to the second magnetic attraction element upon contact.

51. The actuator of claim 49, wherein applying the force causes the moveable member to move such that the first hard magnet contacts and magnetically attaches to the first side soft magnet.

52. The actuator of claim 51, wherein the contact of the first hard magnet and the first magnetic attraction element is utilized to produce a tactile output for a user.

53. The actuator of claim 52, wherein the tactile output is a tap.

54. The actuator of claim 51, wherein the first hard magnet remains magnetically attached to the first magnetic attraction element after application of the force.

55. The actuator of claim 54, wherein the first hard magnet detaches from the first magnetic attraction element upon the application of an opposite force.

56. The actuator of claim 55, wherein application of the opposite force moves the moveable body element such that the second hard magnet approaches the second magnetic attraction element.

57. The actuator of claim 56, wherein application of the opposite force moves the moveable body element such that the second hard magnet contacts the second magnetic attraction element.

58. The actuator of claim 49, wherein the a first magnetic attraction element and the second magnetic attraction element comprise at least one of hard magnets of soft magnets.

59. The actuator of claim 49, wherein the moveable body element comprises at least one shaft that extends through a first aperture in the first magnetic attraction element and a second aperture in the second magnetic attraction element.

60. The actuator of claim 49, further comprising at least one housing that surrounds at least the at least one first hard magnet, the at least one second hard magnet, and the at least one electrical coil.

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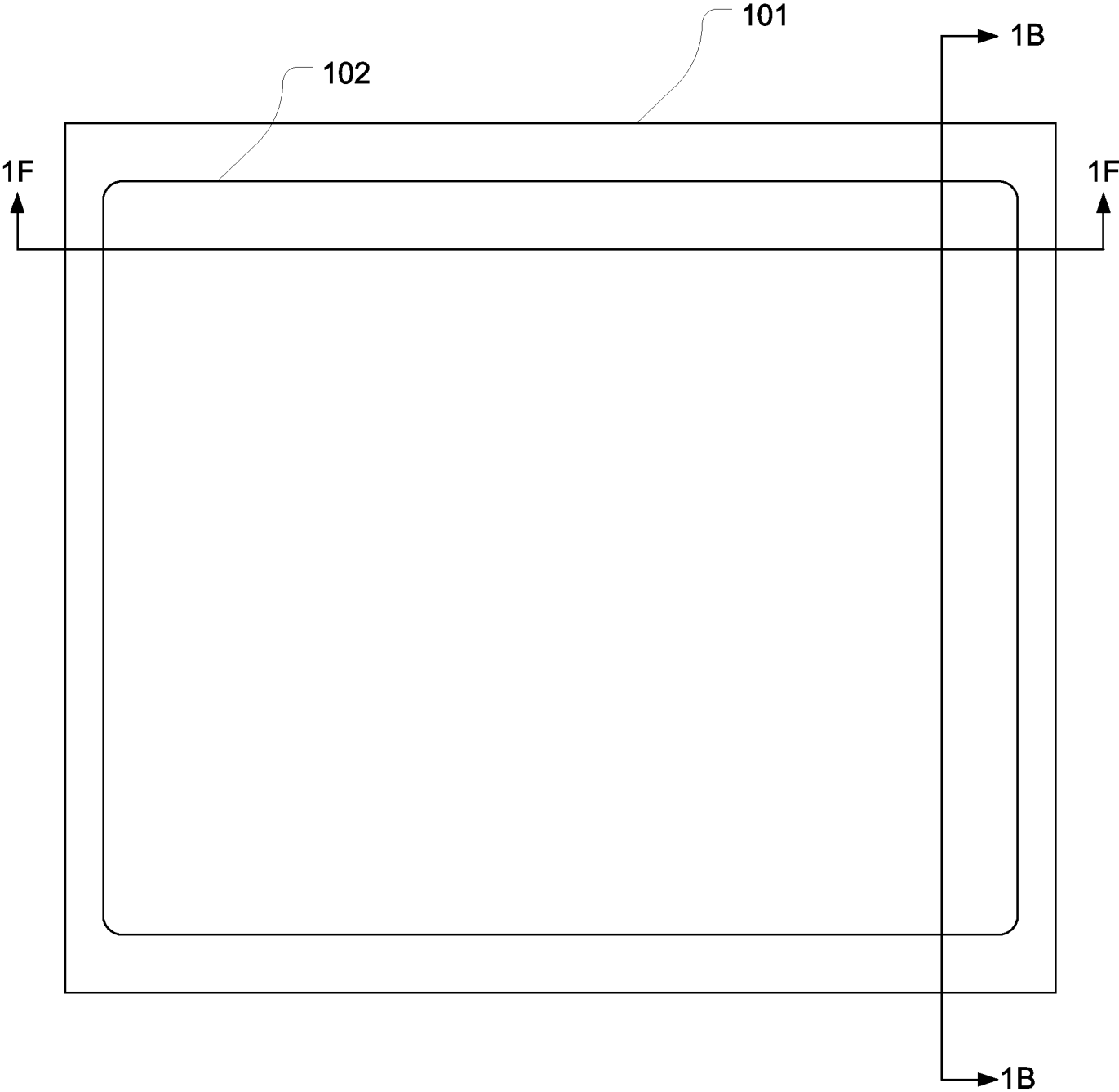


FIG. 1A

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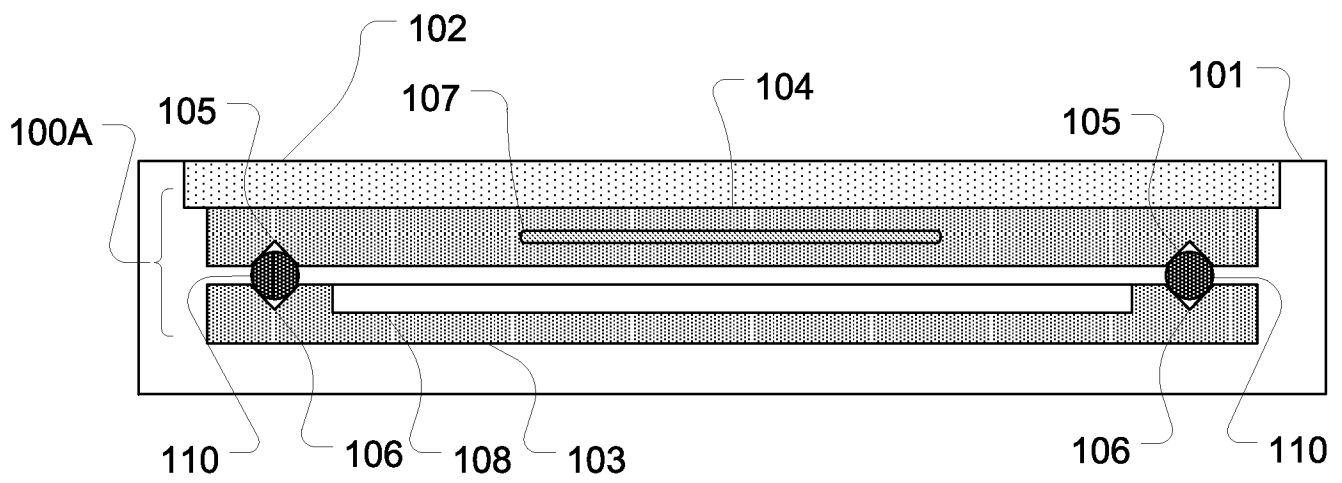


FIG. 1B

3/25

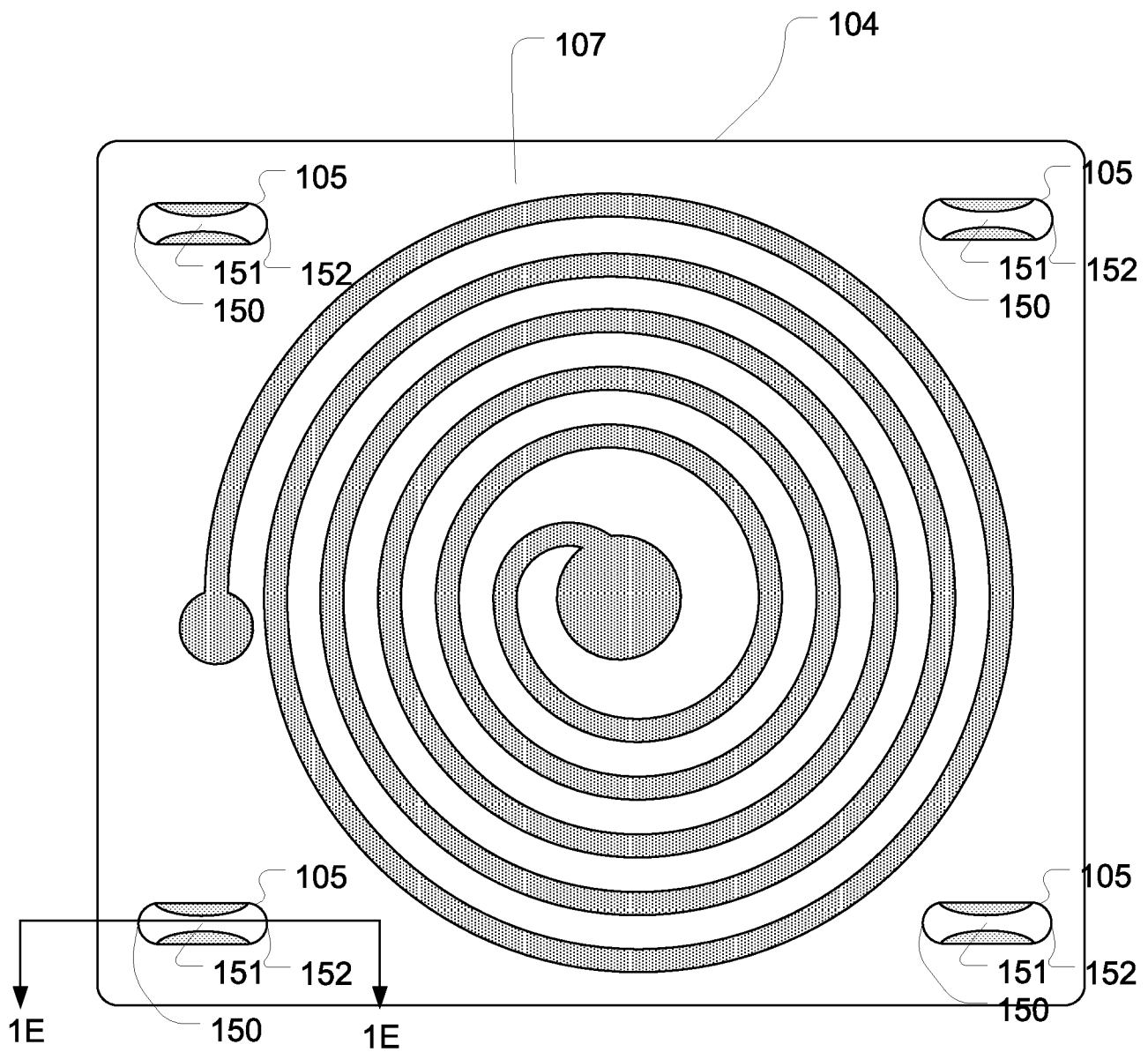


FIG. 1C

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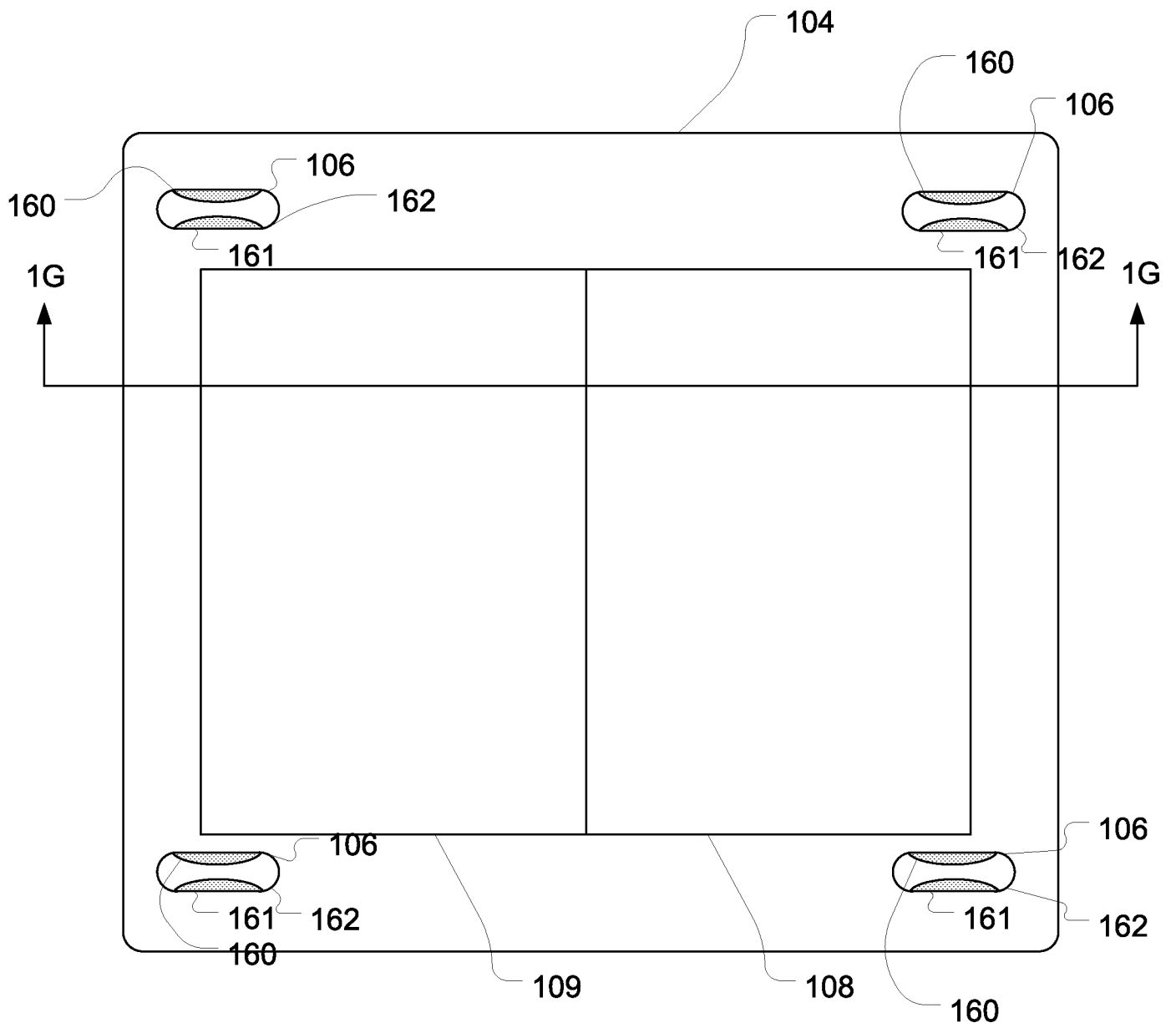


FIG. 1D

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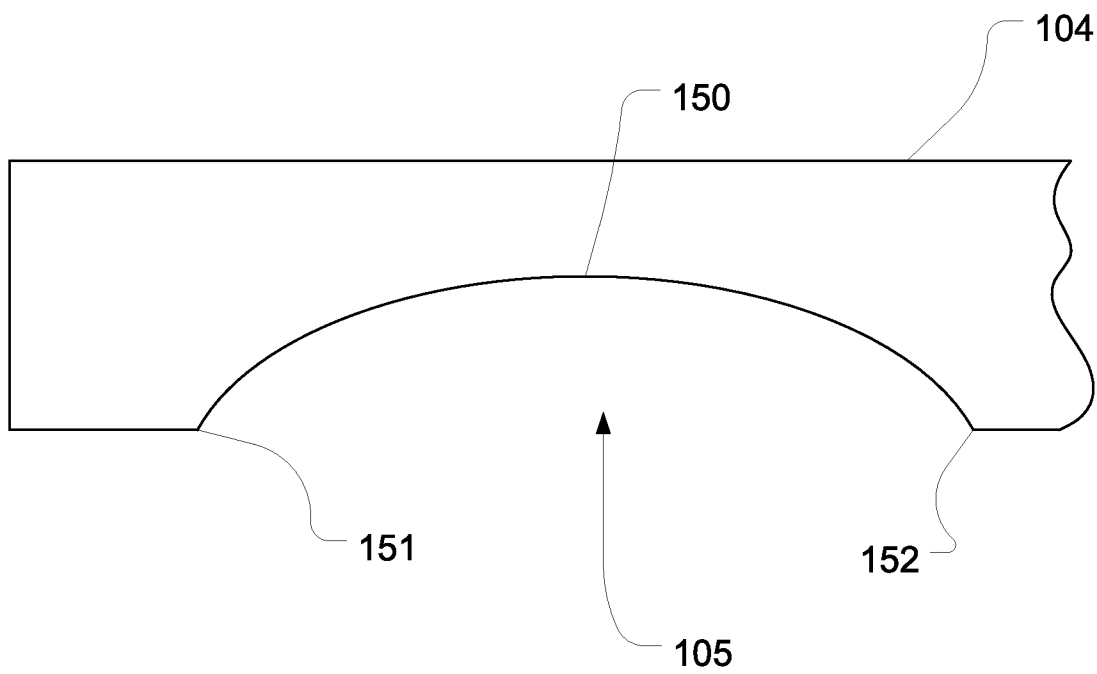


FIG. 1E

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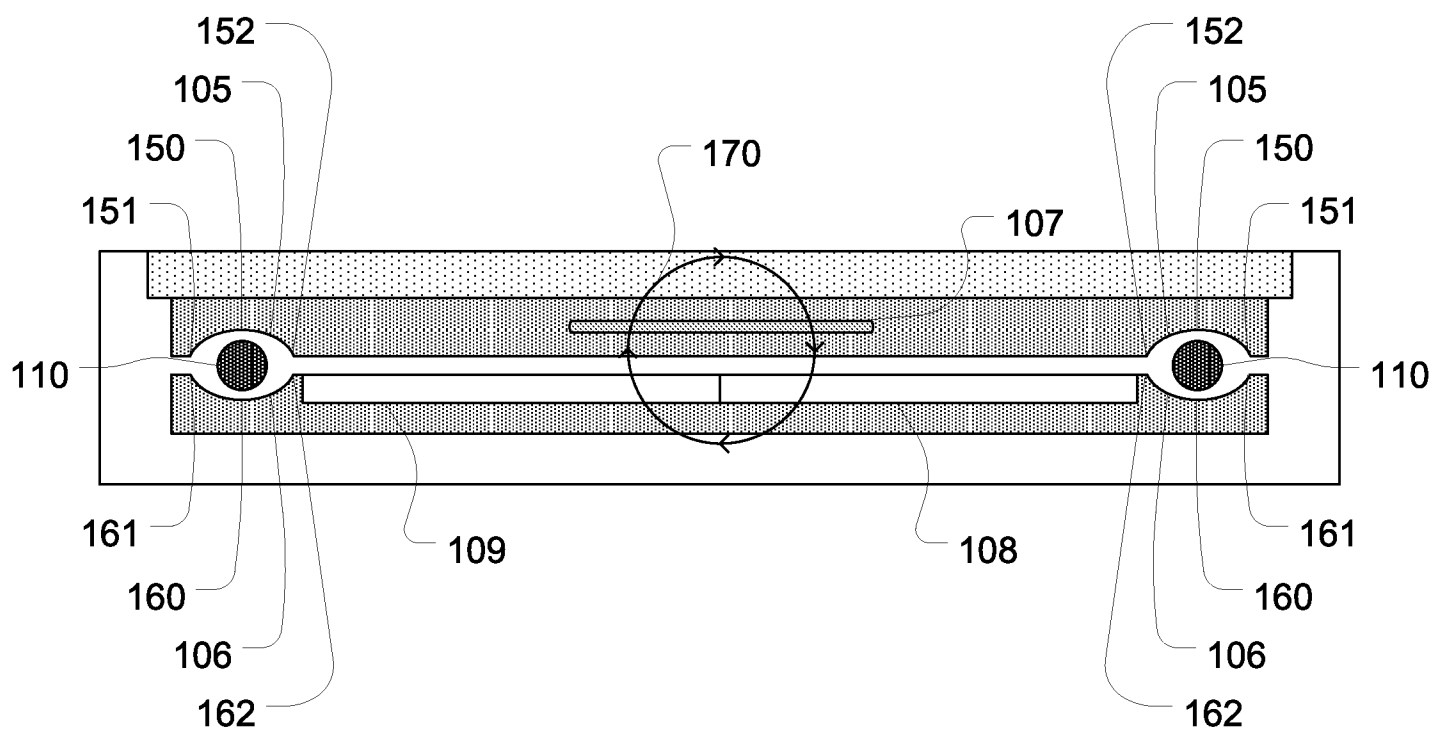


FIG. 1F

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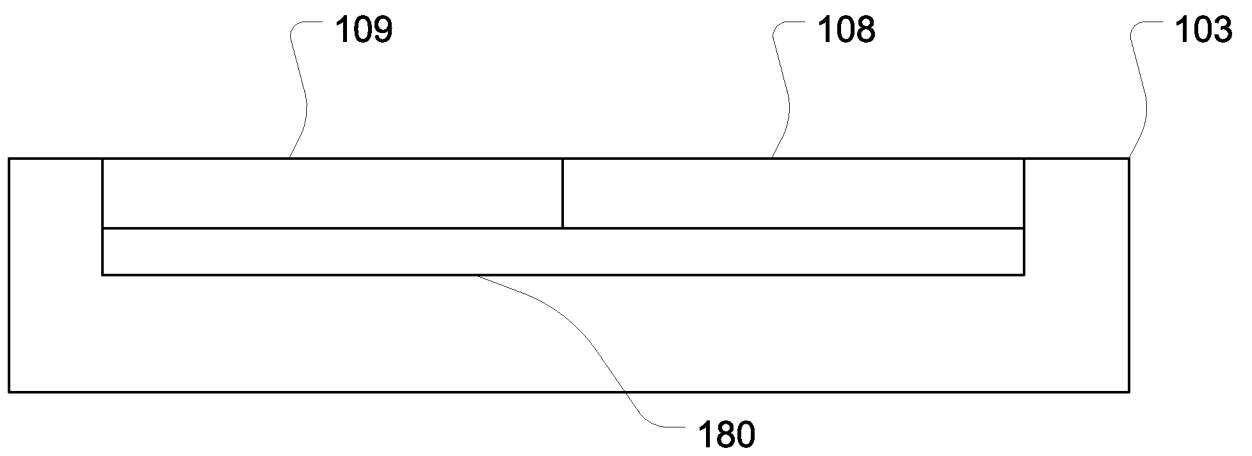


FIG. 1G

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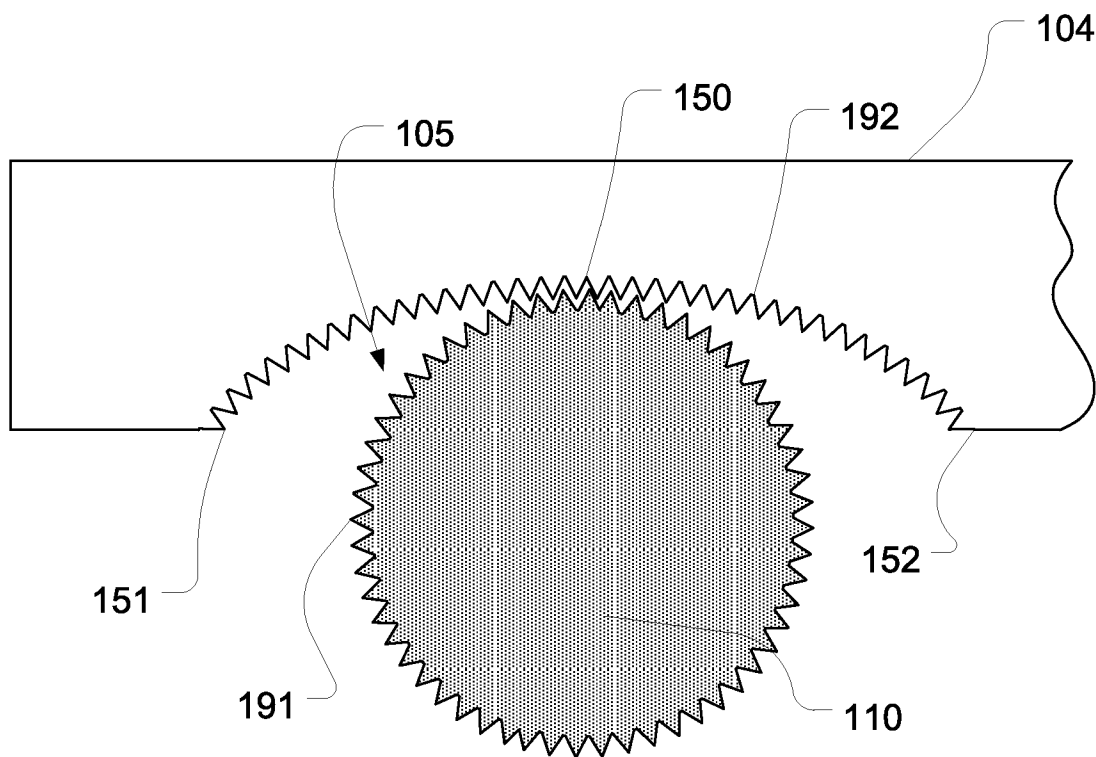


FIG. 1H

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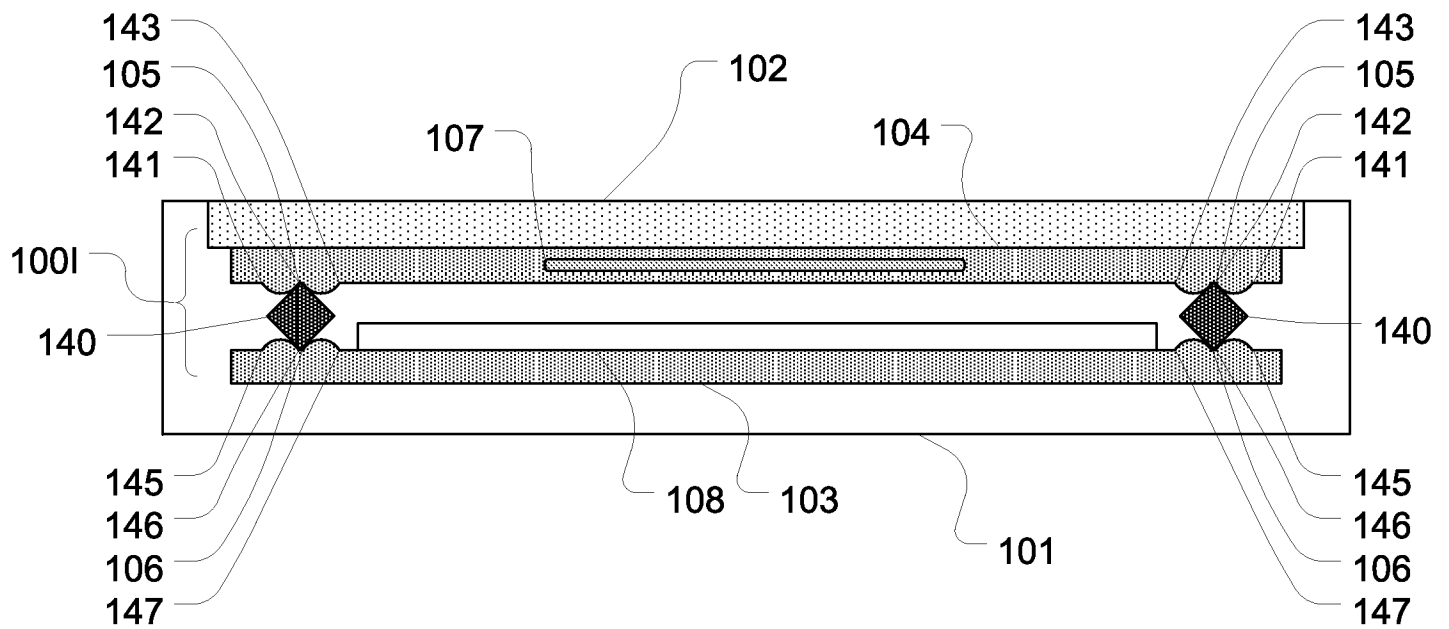


FIG. 11

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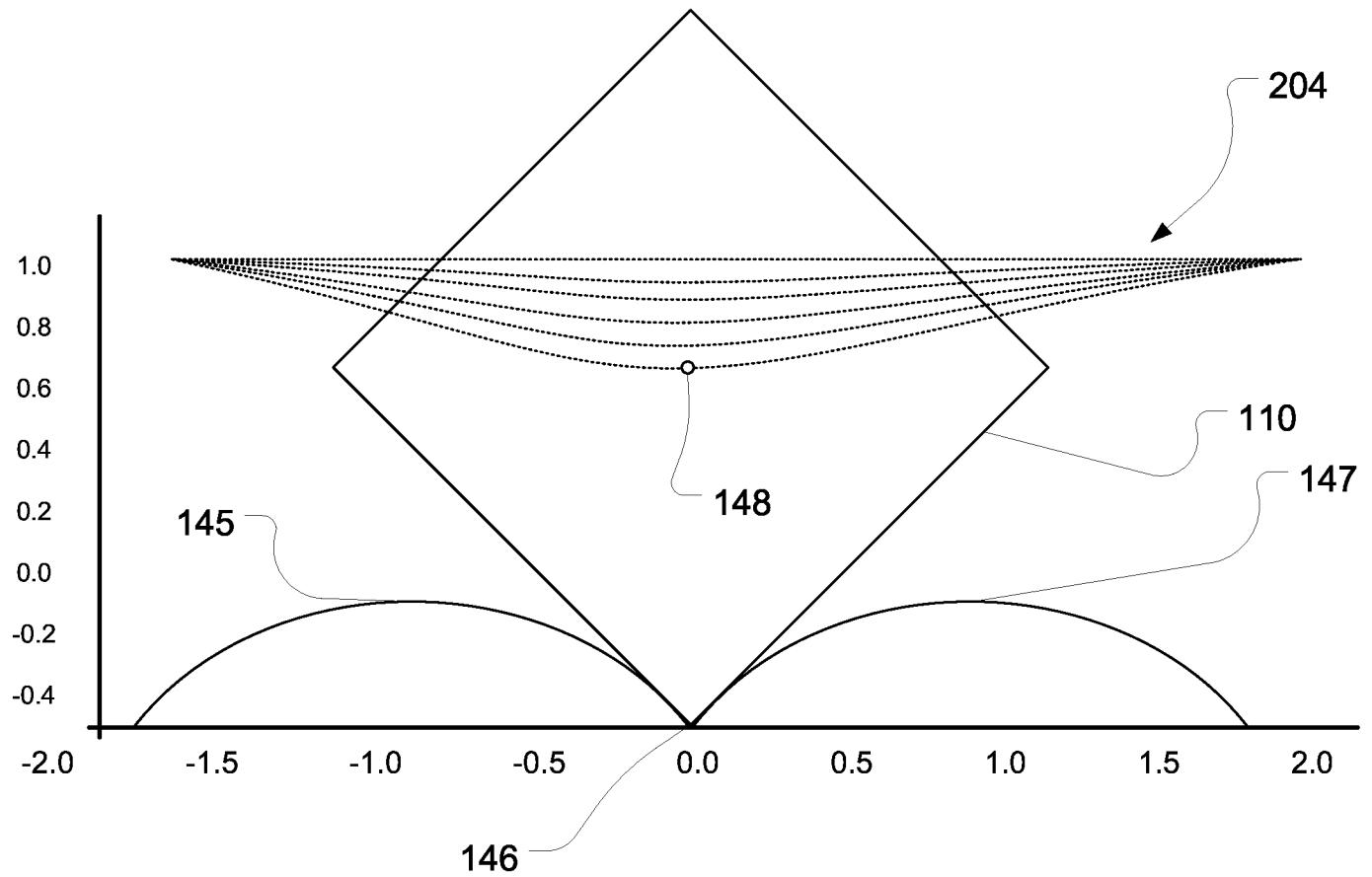


FIG. 1J

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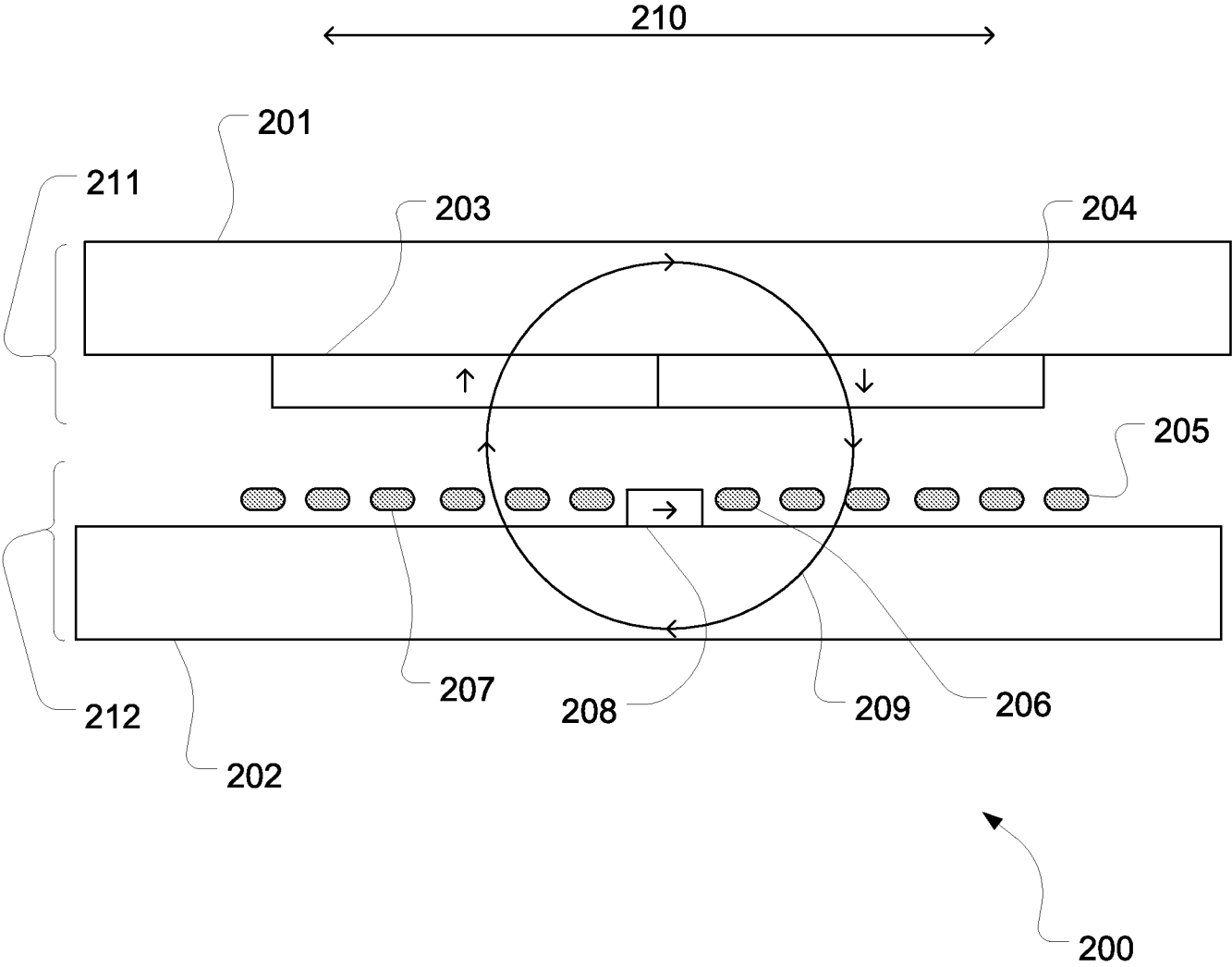


FIG. 2A

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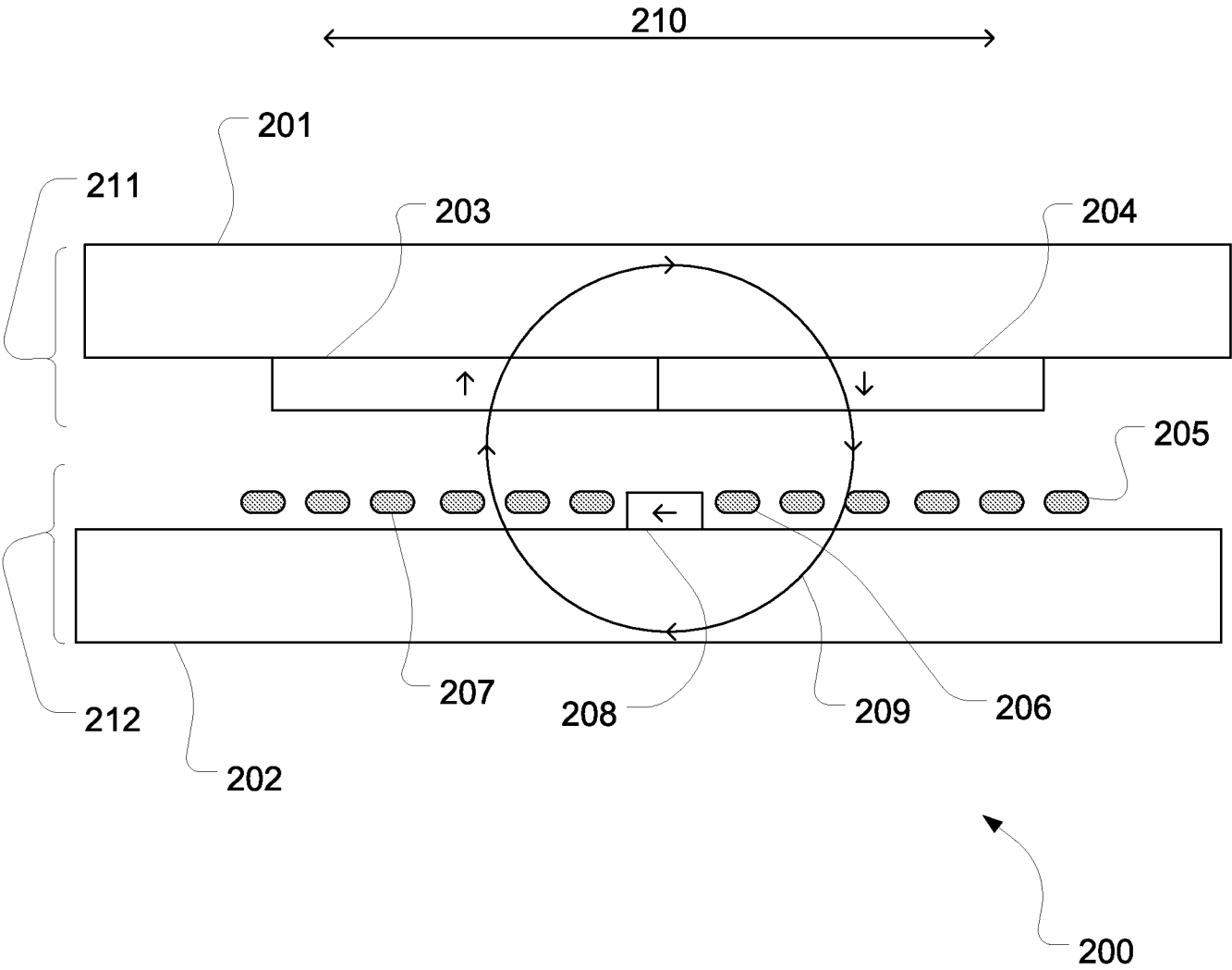


FIG. 2B

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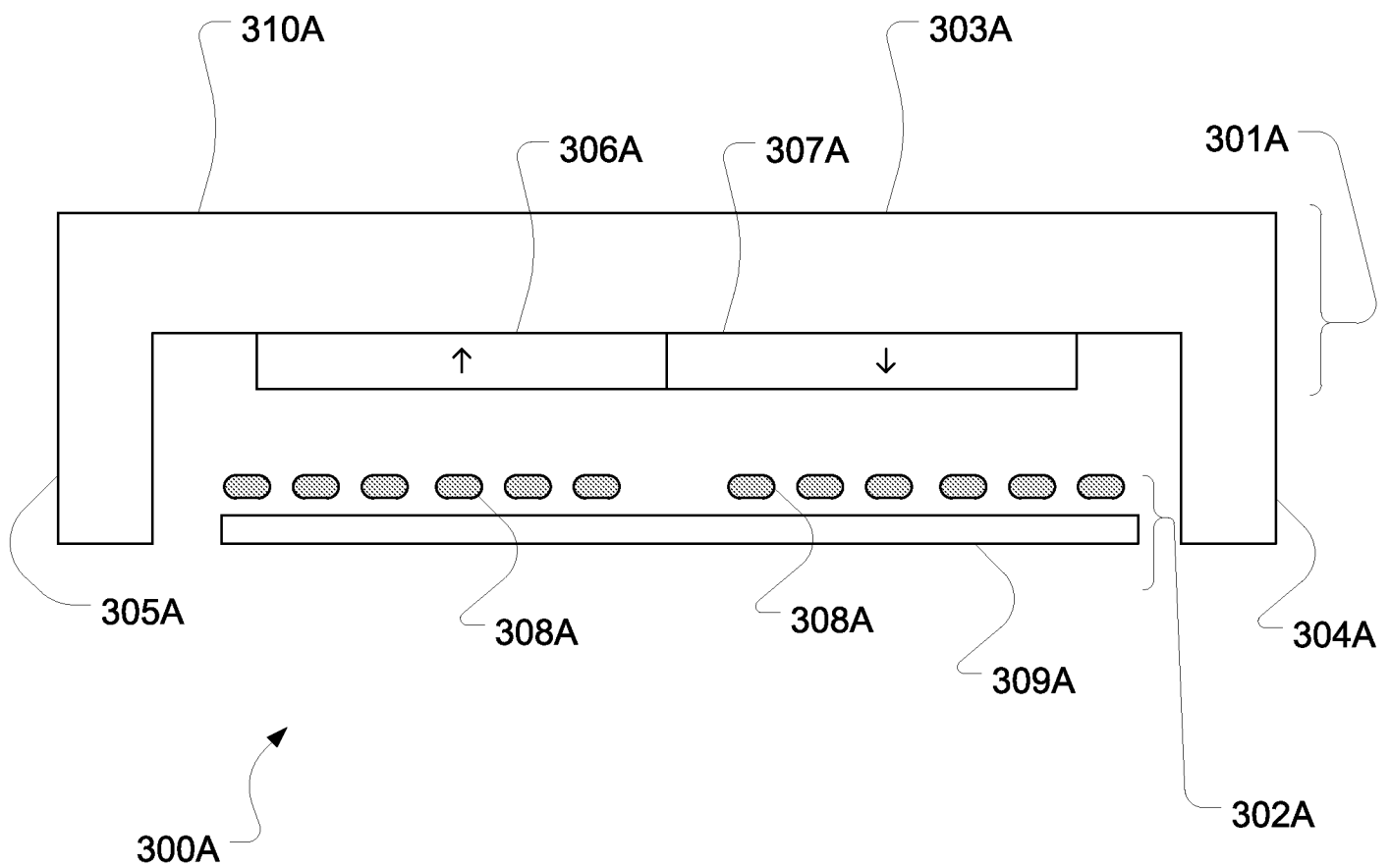


FIG. 3A

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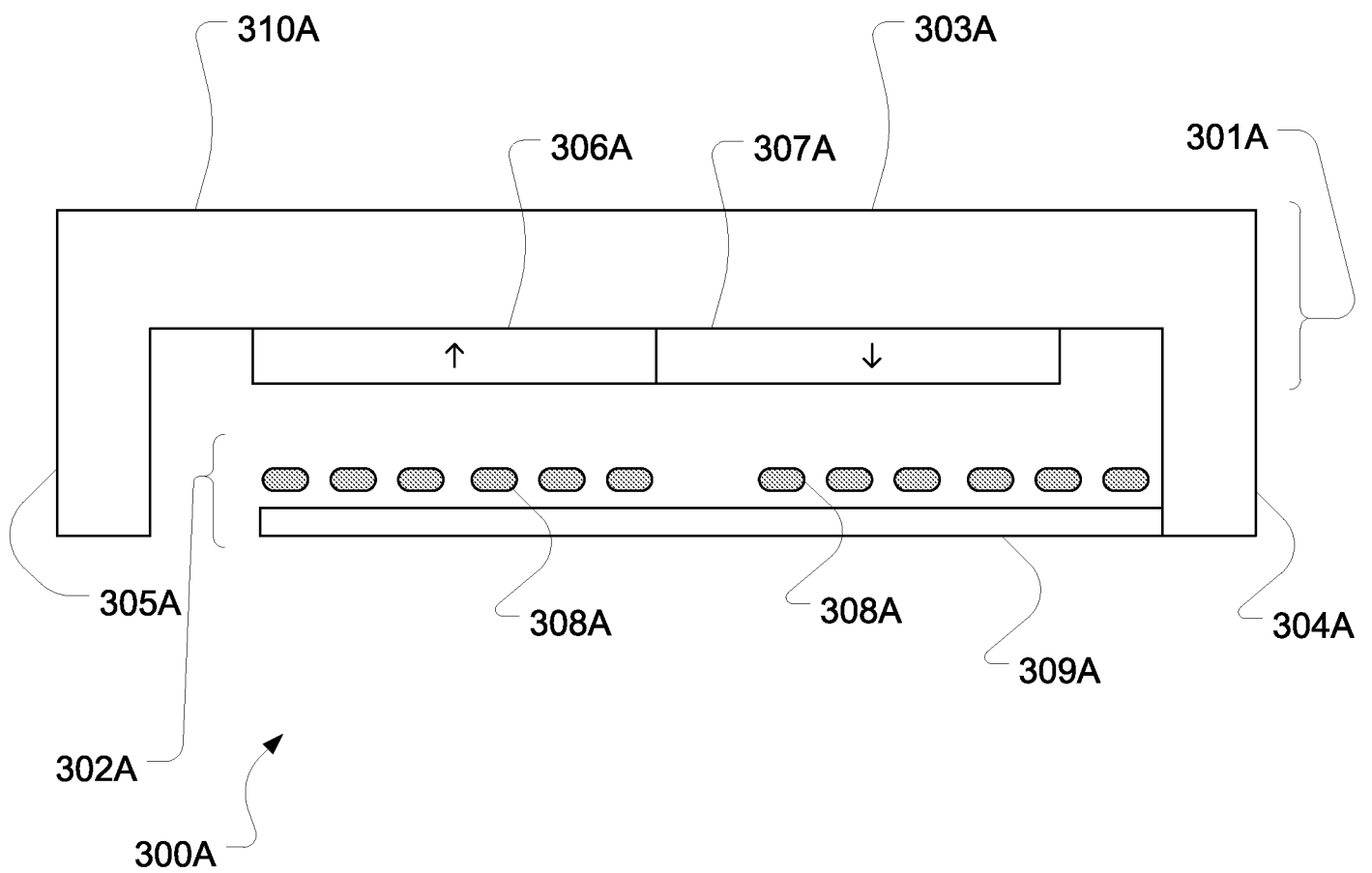


FIG. 3B

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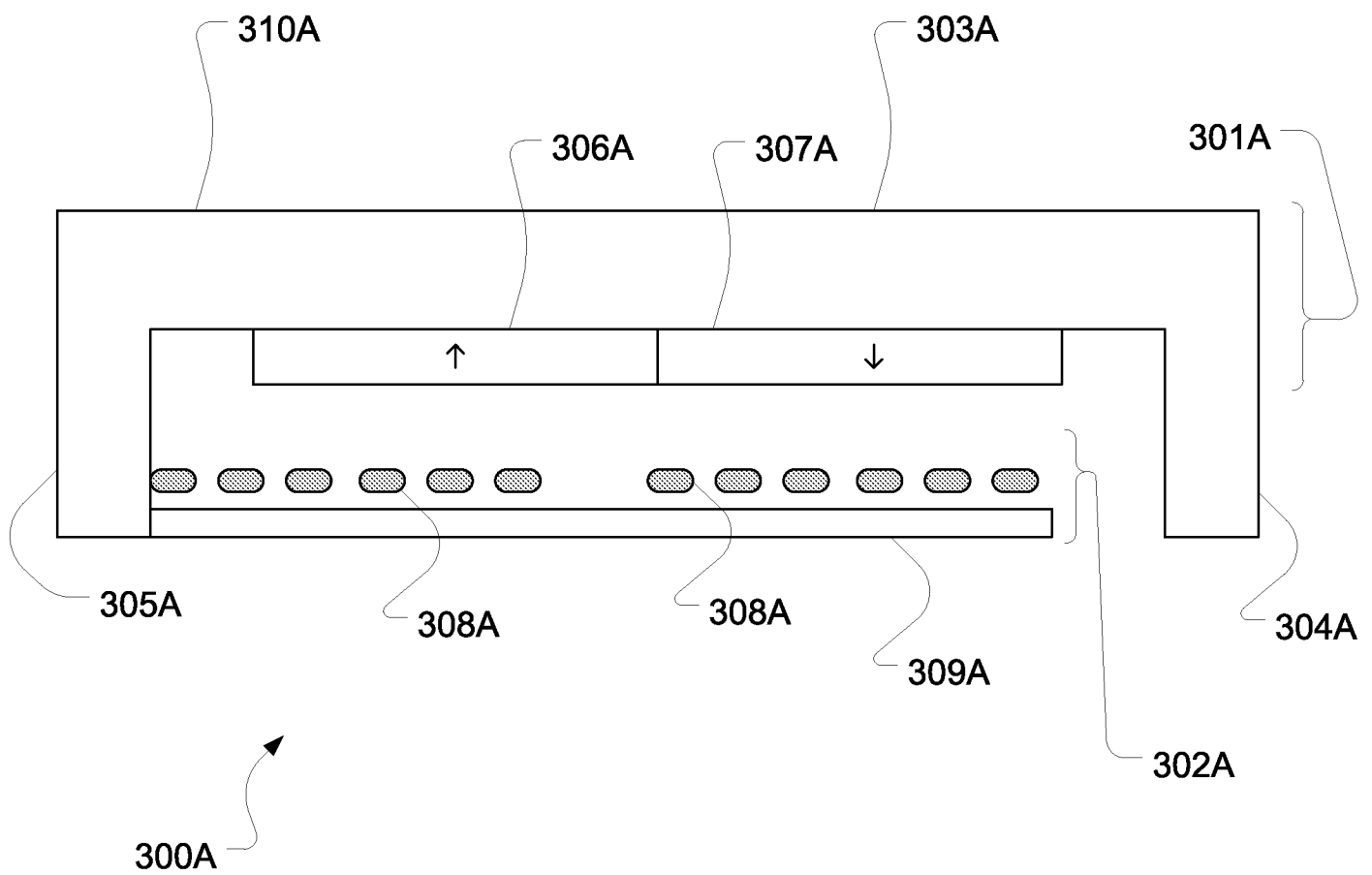


FIG. 3C

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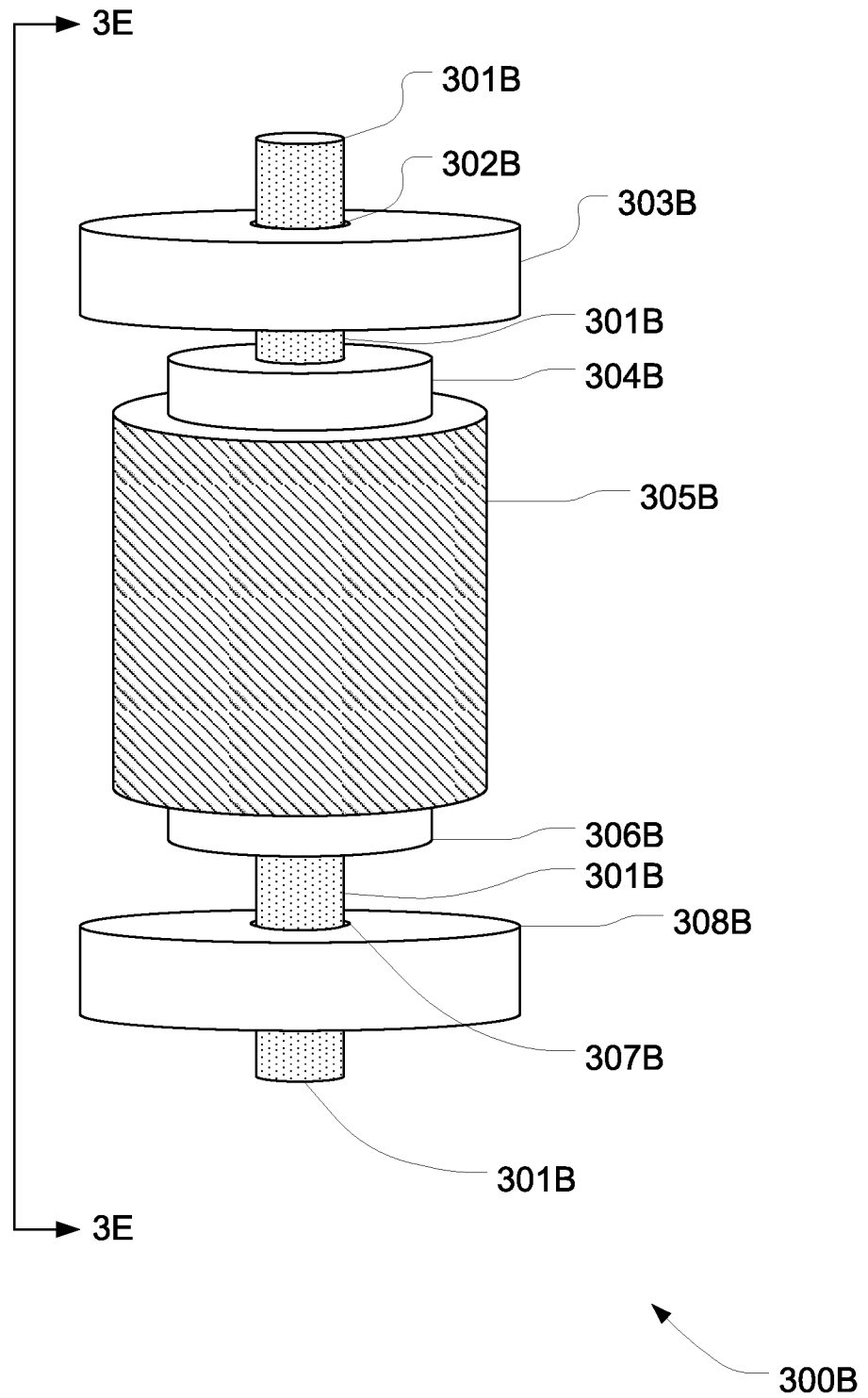


FIG. 3D

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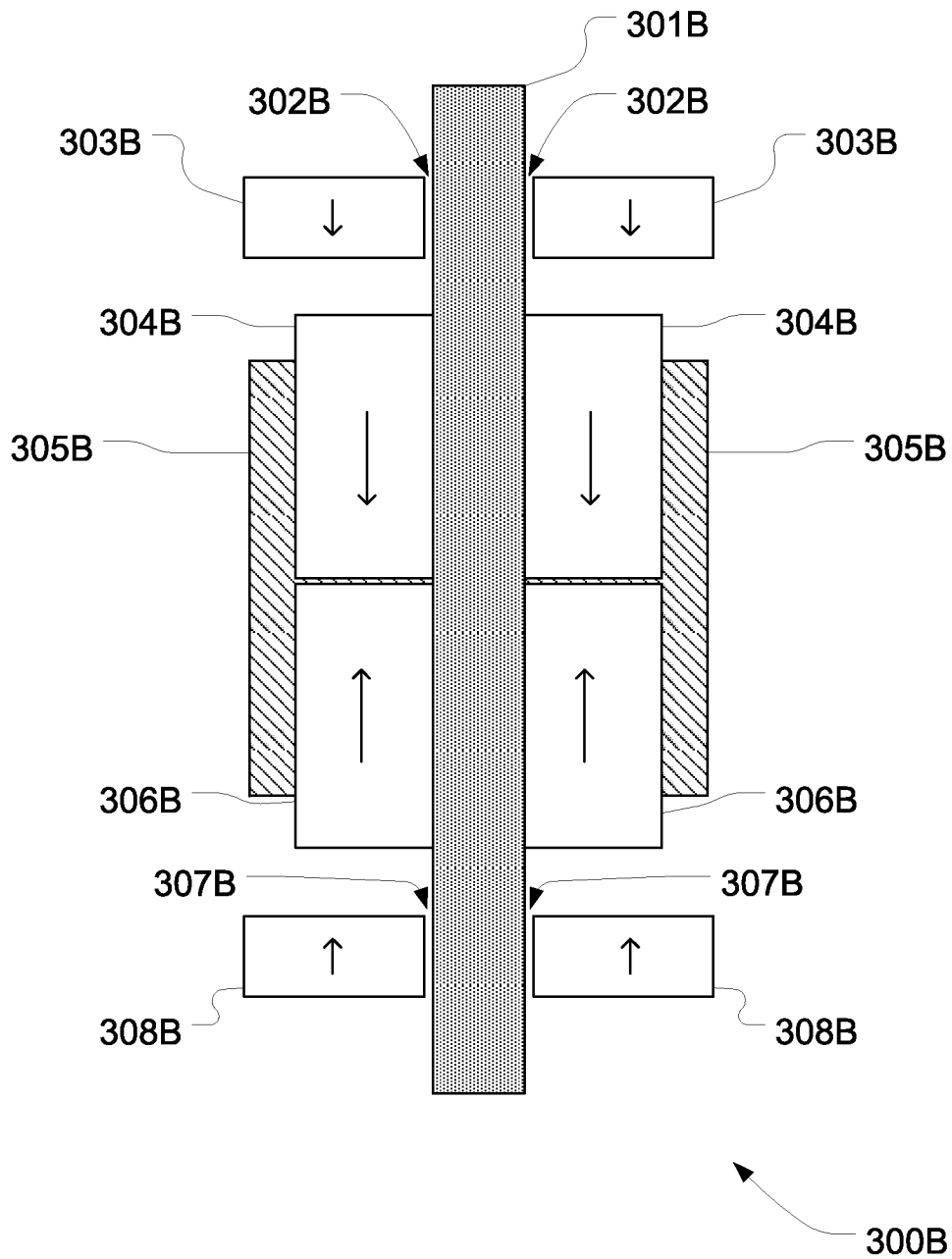


FIG. 3E

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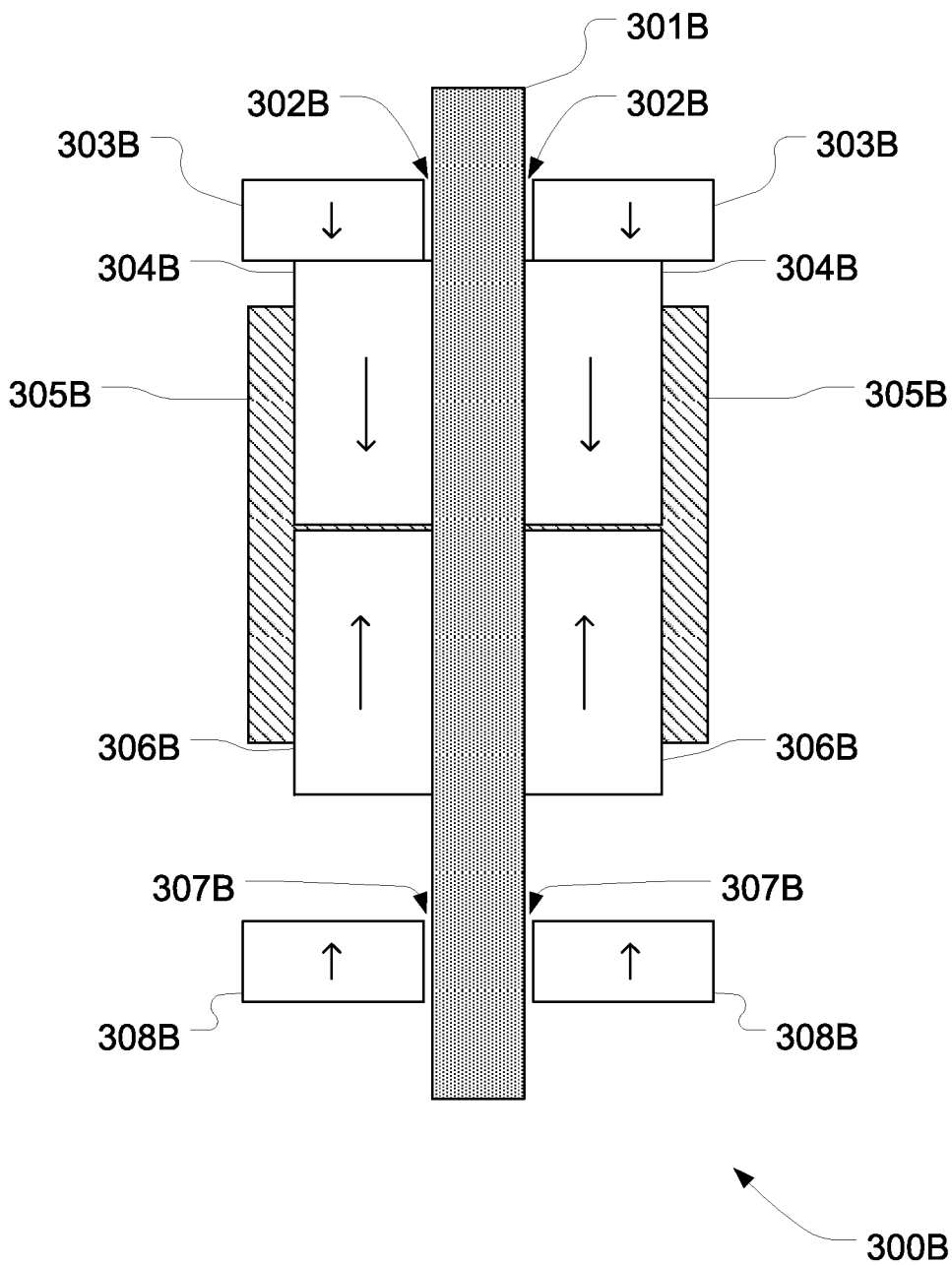


FIG. 3F

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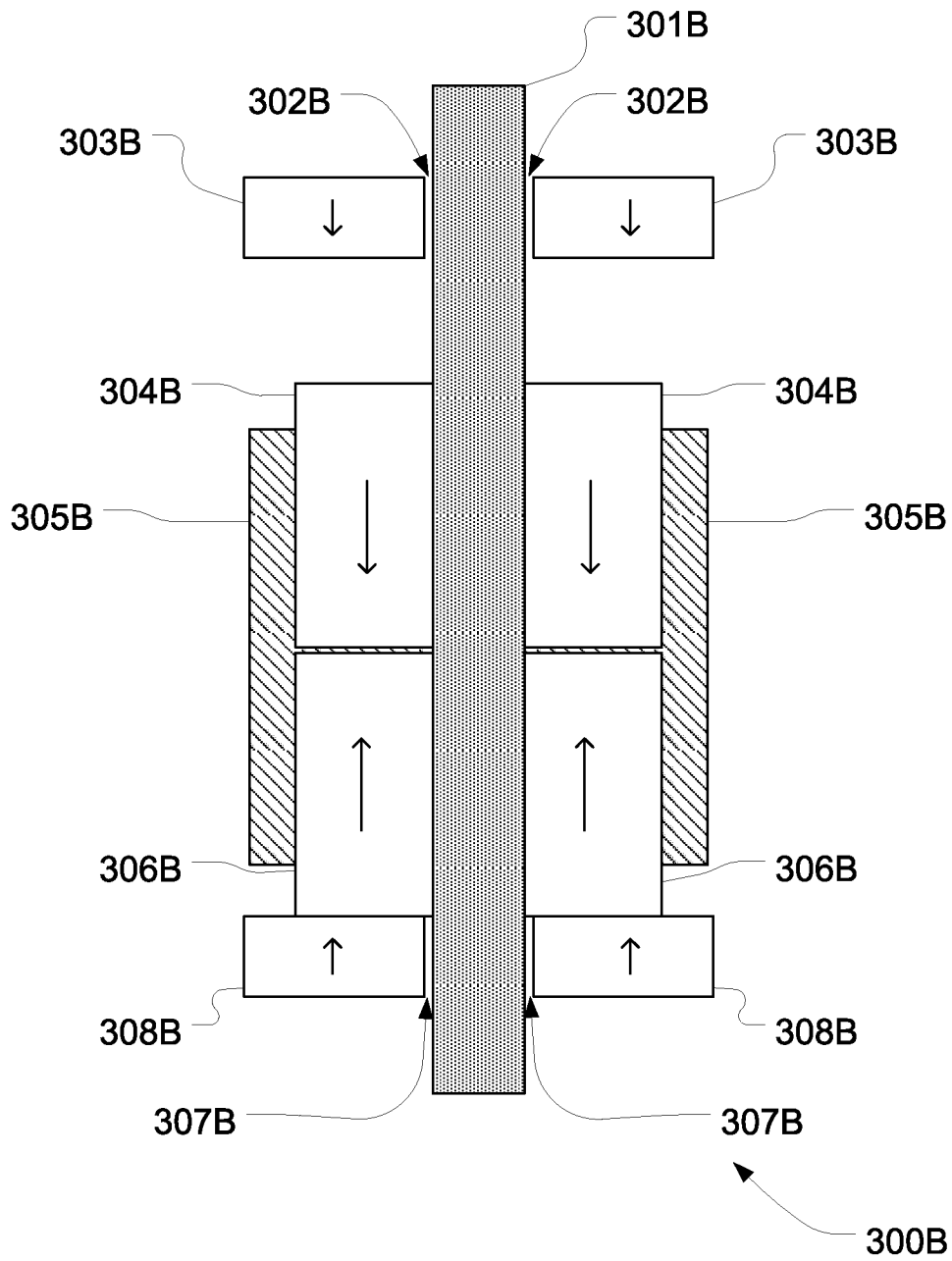


FIG. 3G

20/25

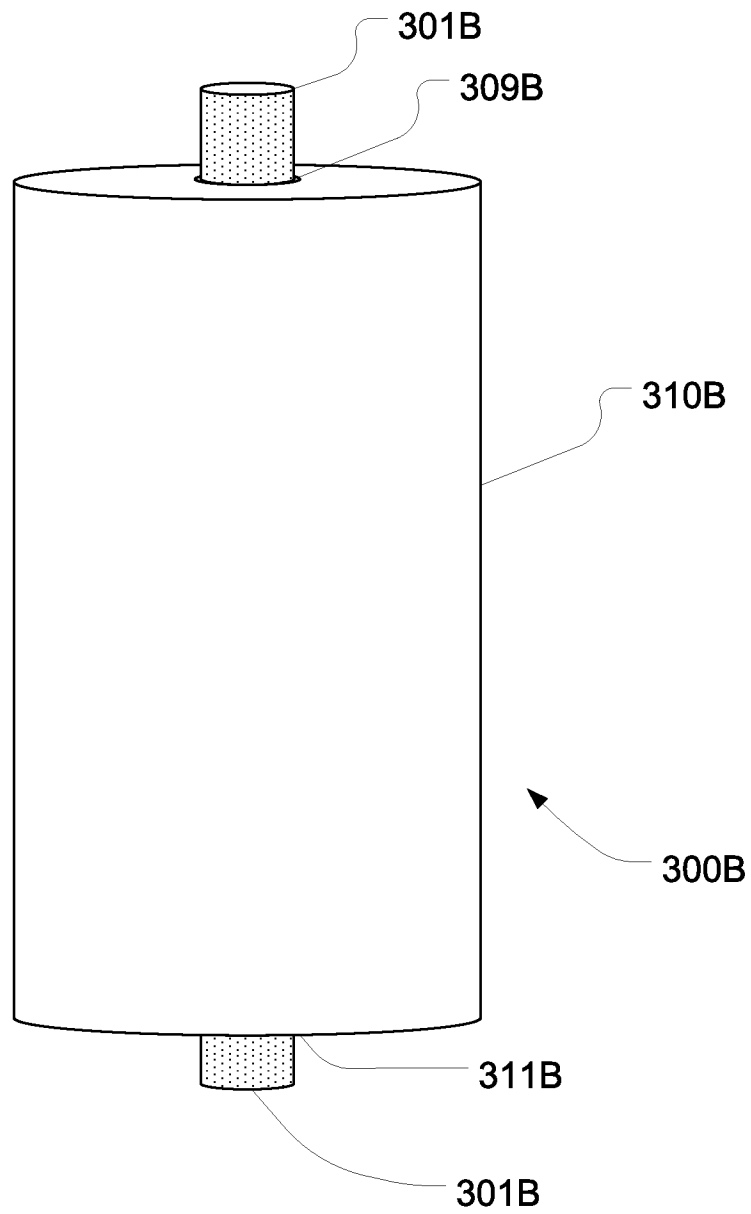


FIG. 3H

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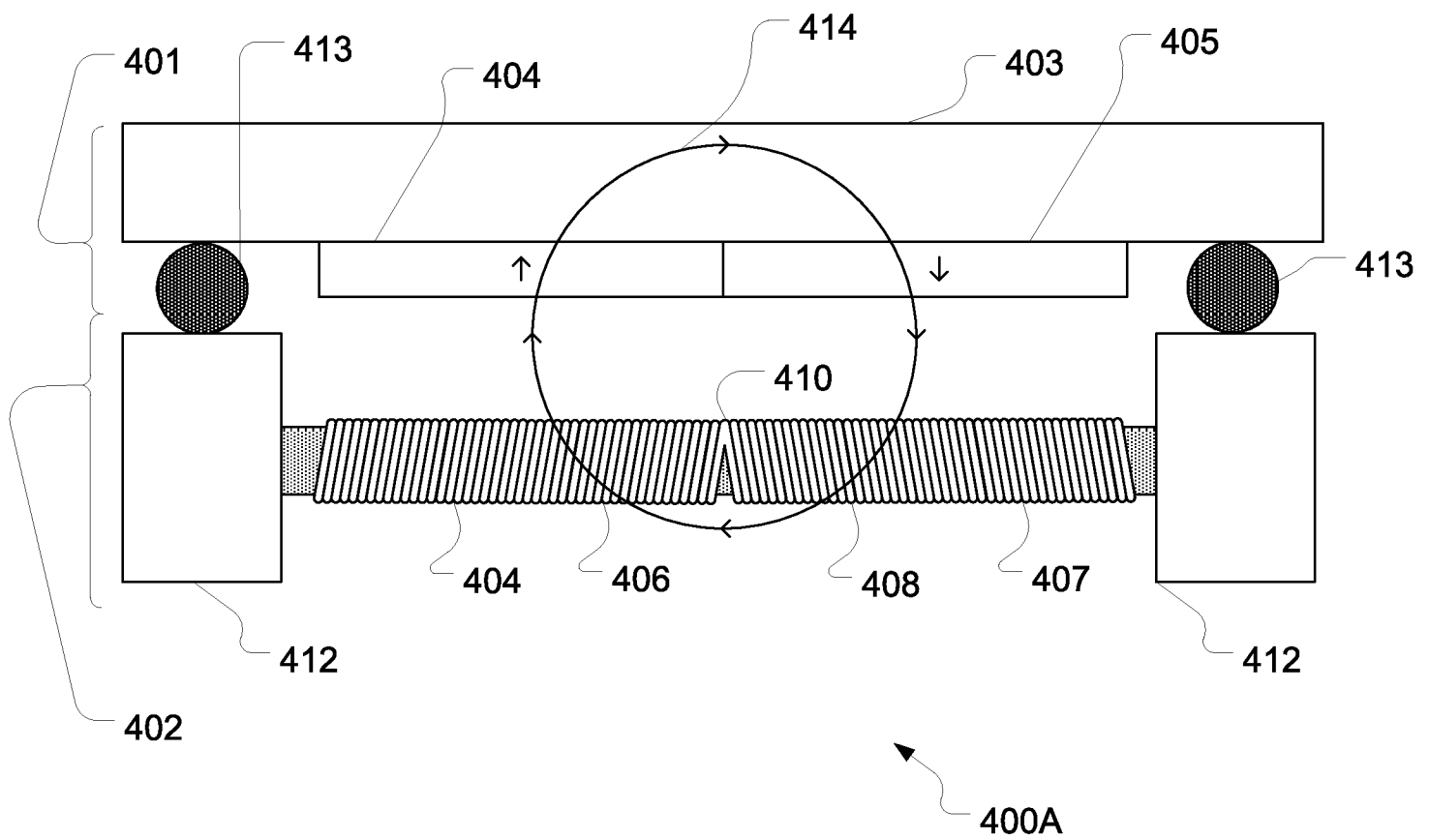


FIG. 4A

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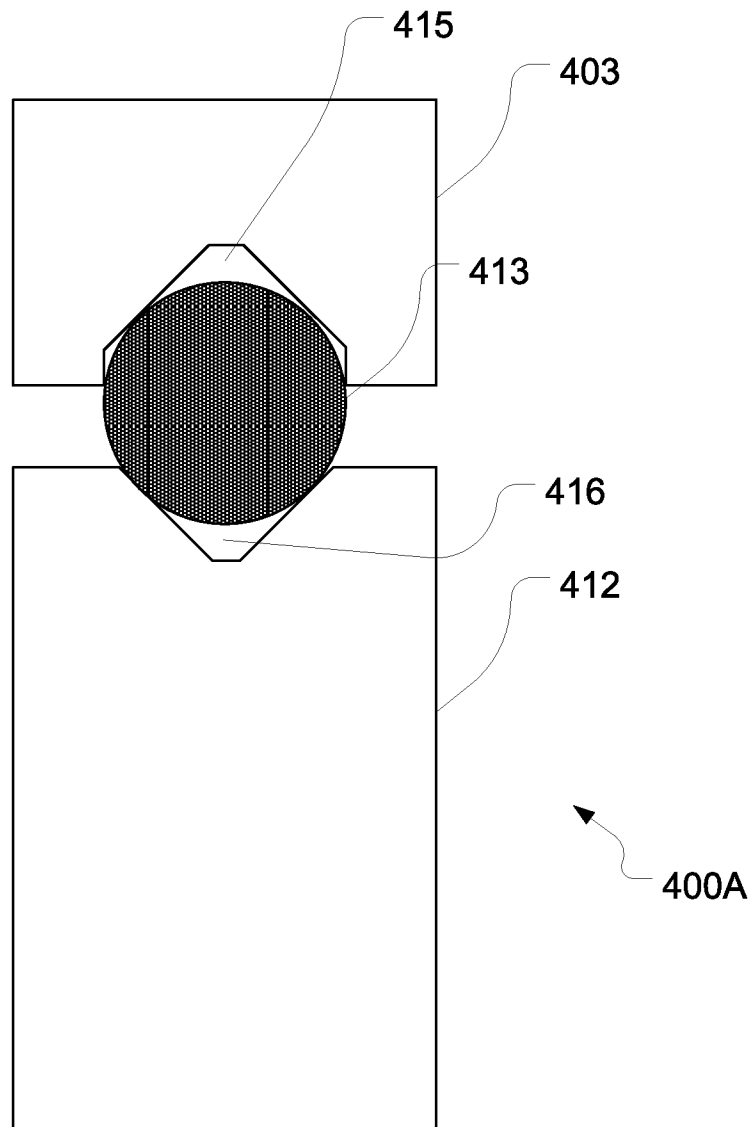


FIG. 4B

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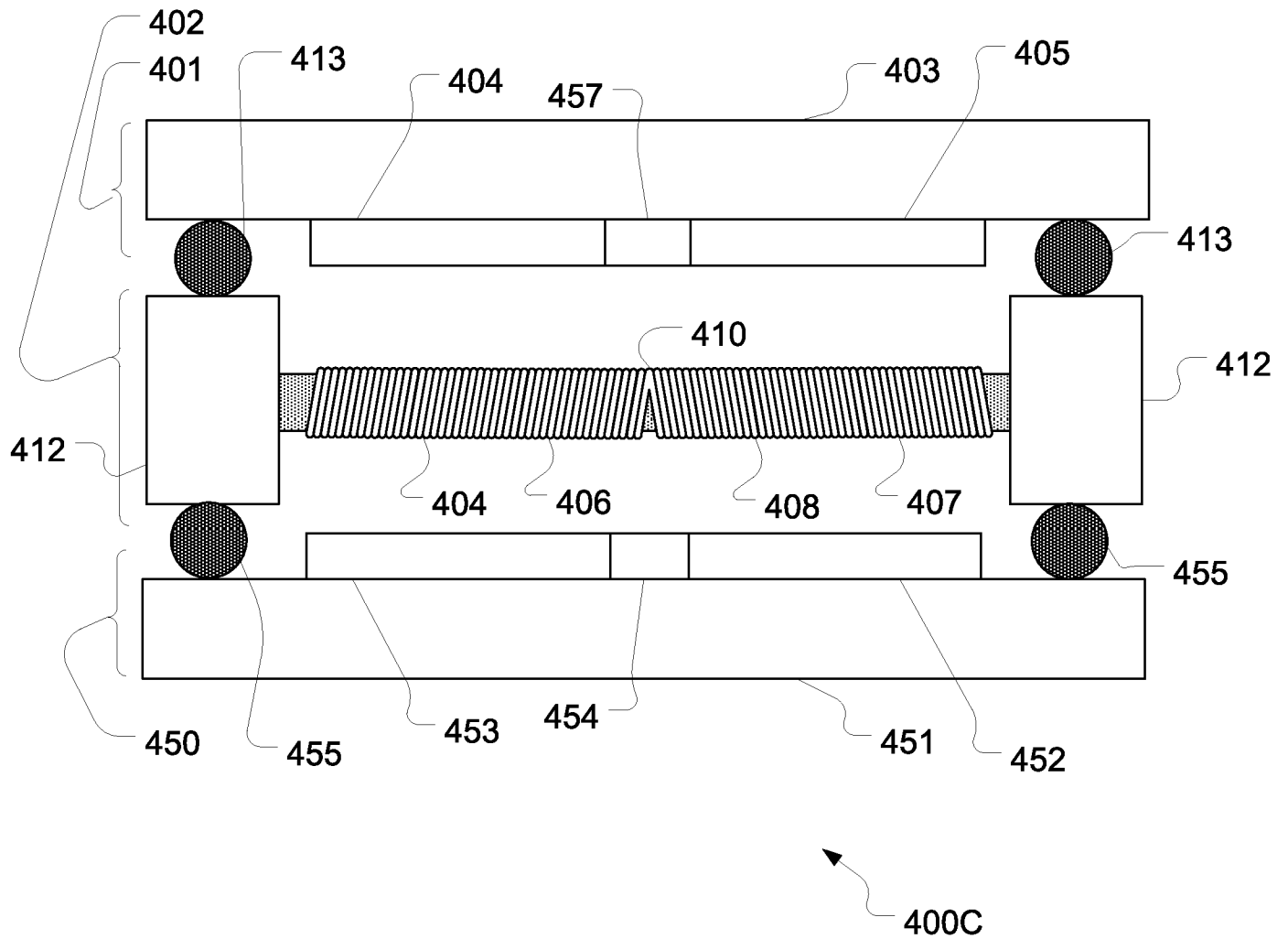


FIG. 4C

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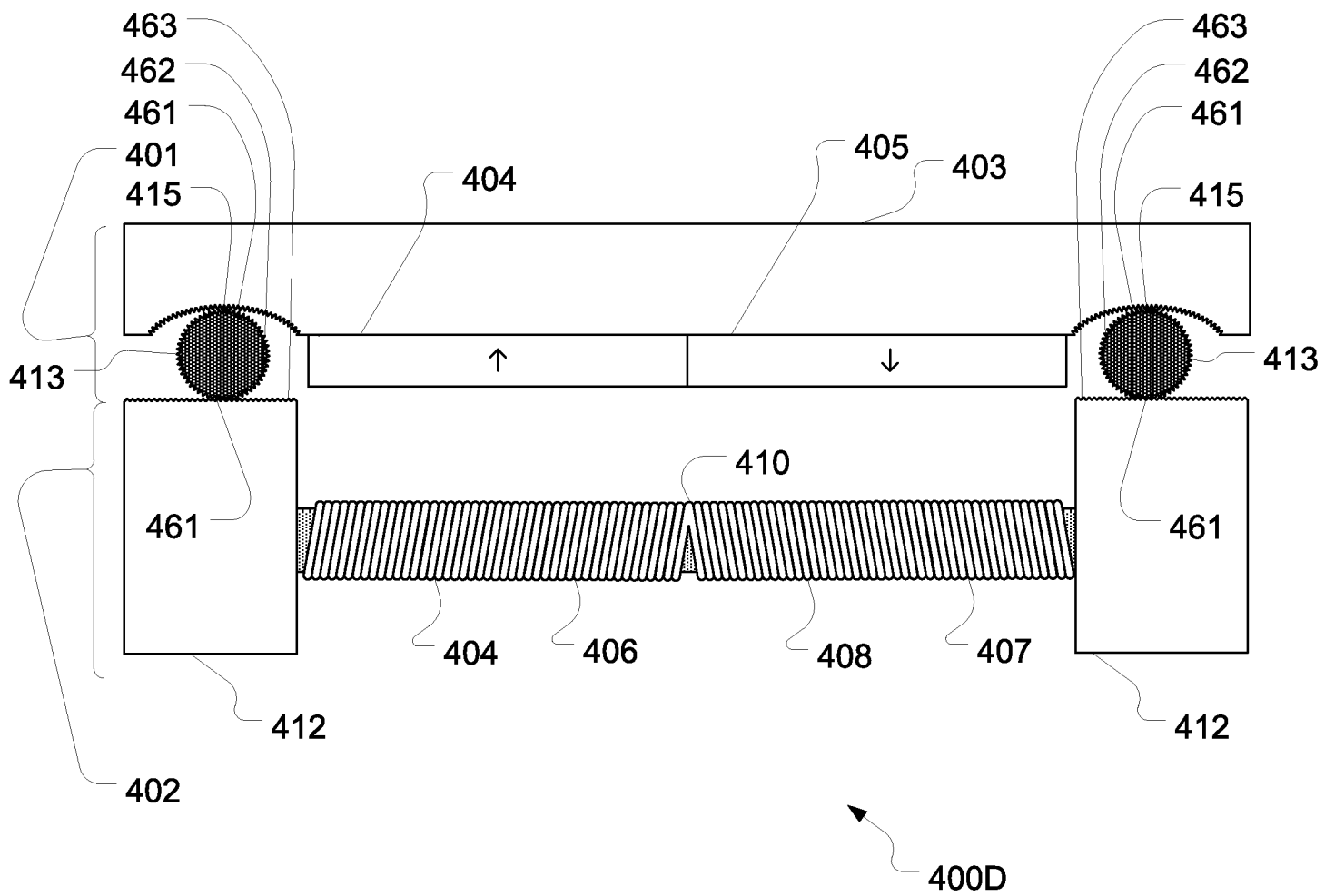


FIG. 4D

25/25

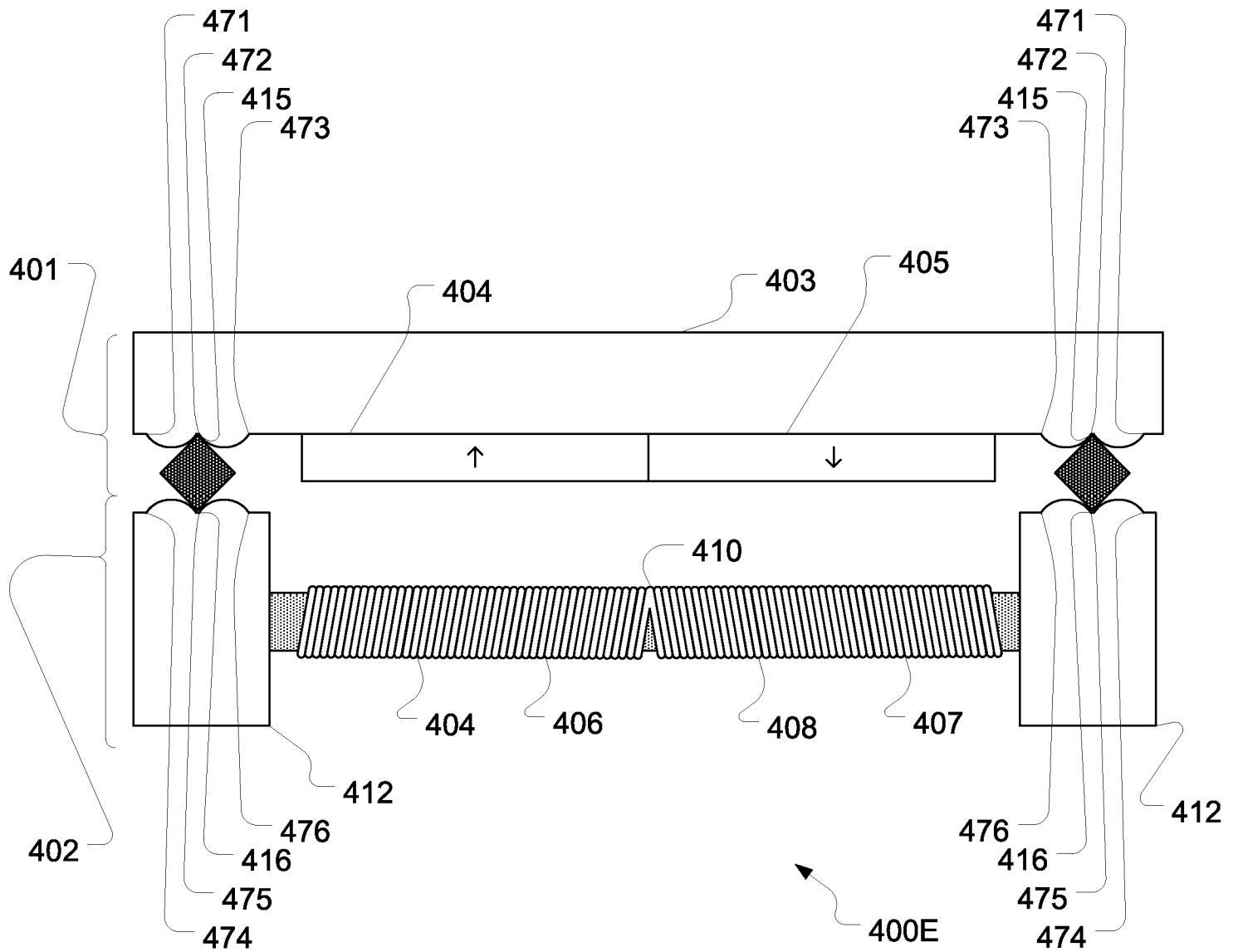


FIG. 4E

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/062556

A. CLASSIFICATION OF SUBJECT MATTER INV. G06F3/01 ADD.		
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) G06F		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2009/201608 A1 (ARGUMEDO ARMANDO JESUS [US] ET AL) 13 August 2009 (2009-08-13) abstract paragraph [0067]; figures 3a,3b,6a-6d -----	1-11,37,38
A	US 6 809 727 B2 (PIOT JULIEN [CH] ET AL) 26 October 2004 (2004-10-26) column 4, line 8 - column 5, line 8; figures 6A-8B -----	1-11,37,38
A	US 2006/221052 A1 (HARADA KEITA [JP] ET AL) 5 October 2006 (2006-10-05) paragraph [0067]; figure 16 -----	1-11,37,38
<input style="width: 20px; height: 20px; margin-right: 5px;" type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" style="width: 20px; height: 20px; margin-right: 5px;" type="checkbox"/> 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 another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 19 March 2014	Date of mailing of the international search report 18/06/2014	
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Thibaudeau, Jean	

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/062556

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.:
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:

see additional sheet

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 fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-11, 37, 38

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.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-11, 37, 38

Actuator comprising a fixed body element including a first groove and an electrical coil and a moveable body element including a second groove and a first and second hard magnets, wherein a bearing is positioned between the first groove and the second groove that separates the fixed body element from the moveable body element.

2. claims: 12-17

Actuator comprising a first body element including a first hard magnet and a second hard magnet and a moveable body element including an electrical coil and at least one center hard magnet positioned in a center of the at least one electrical coil.

3. claims: 18-31

Magnetic circuit comprising a moveable bar element including a first hard magnet and a second hard magnet and a fixed bar element including an electrical coil structure wound around the fixed bar element wherein a first section of the electrical coil structure is wound in a first direction around a first area of the fixed bar element and a second section of the electrical coil structure is wound in a second direction around a second area of the fixed bar element.

4. claims: 32-36

Magnetic circuit comprising a moveable body element including a first groove comprising a plurality of first gear elements, at least one bearing including a plurality of bearing gear elements and a fixed body element including a second groove comprising a plurality of second gear elements.

5. claims: 39-48

Actuator comprising a fixed body element including a top structure, a first hard magnet and a second hard magnet, and a first side soft magnet and a second side soft magnet, the side soft magnets being coupled to the top structure; and a moveable body element including at least one electrical coil.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

6. claims: 49-60

Actuator comprising a first magnetic attraction element, a second magnetic attraction element and a moveable member that is moveably coupled to the first magnetic attraction element and the second magnetic attraction element and that includes a first hard magnet, a second hard magnet and at least one electrical coil positioned at least partially around the first hard magnet and the second hard magnet.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2013/062556

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2009201608	A1	13-08-2009	TW 200951944 A 16-12-2009
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