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(54) **MAGNETIC ACTUATOR AND ELECTROMAGNETIC RELAY**

(57) The present invention relates to magnetic actuators for a three-state switching relay, and an electromagnetic relay using the same. The magnetic actuator comprises an armature and a magnetic system for causing the armature to rotate about its center region from a neutral position to any of a first operating position and a second operating position in response to an input control signal. The magnetic system comprises: an electromagnet to create a magnetic flux field based on an input con-

trol signal, a core member, at least two outer poles on an outer side of the electromagnet, and at least two permanent magnets, each permanent magnet arranged in a gap between a respective outer pole and the core. Each permanent magnet is magnetically polarized to form a path with the core member and the respective outer pole for the created magnetic flux. A double-loop magnetic path may be defined using magnetic bridges.

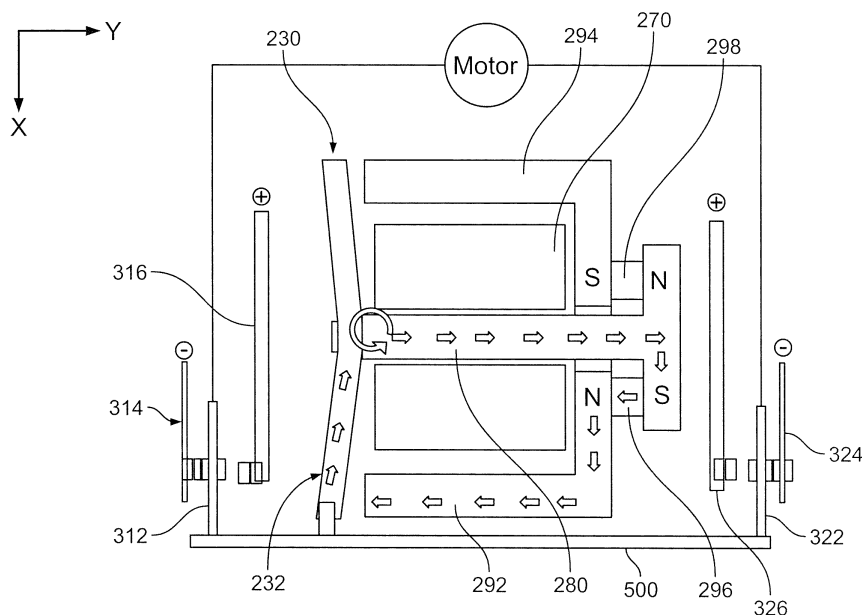


Fig. 8

Description

TECHNICAL FIELD OF THE INVENTION

5 **[0001]** The present invention relates to relays for general switching applications, and more particularly, to electromagnetic relays providing three switching states for automotive and/or appliances applications.

BACKGROUND OF THE INVENTION

10 **[0002]** Inductive circuit breakers, such as relays, are widely employed as switching devices in a variety of applications, such as automotive applications and electrical appliances. Single relays are conventionally used in applications that operate in only two states, for e.g. on and off states. Each relay state corresponds to a specific configuration of connections among the relay contacts, which can be changed or switched to another state or configuration in response to one or more control signals. Simple relays are generally operated by an inductive coil that actuates on a movable armature for switching on or off a contact with a terminal of a power source. Conventional change-over relays also provide two switching states by an arrangement of a change-over spring (CO terminal) and two stationary contact terminals, generally referred to as normally closed (NC) and normally open (NO), between which the CO terminal can be moved. The CO terminal is generally connected to a terminal of a motor or electrical appliance and is actuated by a magnetic system to switch contact to either the NO or NC terminals, which are respectively connected to the power source terminals. Both these type of relays can be operated with a single control line but are limited to only two relay states.

20 **[0003]** In order to increase the number of possible relay states, hereinafter also referred to as switching states, two or more single relays may be combined. Conventional relays based on a combination of two independent relays are capable of yielding four independent switching states (or three switching states if some mechanical coupling between two switching states is added) but typically use two magnetic systems driven by two independent coils that can have the same or independent activation signals. Each relay is still controlled by an individual control line and an individual driver for converting a digital input control signal into an analogue signal for activating or deactivating the relay. Thus, the conventional double relay arrangement requires two mandatory control lines to control each relay independently, which implies synchronization between control lines, leading to a more complex circuit design and programming effort.

25 **[0004]** Several motor and electrical appliance applications require relay designs capable of providing more than two relay states. Motor reverse requires at least three operating states for applying at the motor terminals one of: positive polarization (+/-) for motor motion in one direction, reversed polarization (-/+) for inverting the direction of motor motion, and halt/stop (-/- or +/+) for halting or stopping the motor. A double relay configuration based on two change-over relays is conventionally used in motor reverse applications, in which the motor rotates in a direction defined by the activated relay. When both relays are deactivated, both motor terminals are connected to the negative terminal of the power source (or ground potential), thereby stopping the motor motion and discharging the motor inductive system. However, the conventional double relay configuration also provides an additional fourth state that might not be necessary. In fact, the motor motion will also stop in the event that both relays are simultaneously activated, i.e. both motor terminals are connected to the same positive potential (+/+), however, in a slower manner since the inductive system will take more time to de-energize. Furthermore, as mentioned above, the double relay format has the drawback of requiring software handling and synchronization for switching the state of the individual relays simultaneously. This requires additional control lines for operating each relay, additional load as well as the necessary routing in comparison to single relay formats. More elements require more space and increase hardware and software complexity, as well as costs. These aspects are particularly important for motor applications, where relays are in general mounted in a PCB driver module or in a relay box.

40 **[0005]** An electromagnetic relay for motor reverse applications that provides three switching states is described in published European patent application No.16398001.4. This three-state relay design is based on two armatures that are actuated by an inductive coil for switching two spring arrangements coupled by a slider. The two spring arrangements may be switched among a neutral position corresponding to a brake or blocking state of the motor, a left position to apply power of a given polarity at the motor terminals and a right position for inverting the polarity of the applied power. However, this relay design might be not sufficiently compact for some applications and/or prone to mechanical vibrations due to the double-armature concept.

45 **[0006]** Other type of applications may also benefit from a three-state relay design, including applications which operate with three level power adjustment (e.g. off, minimum and maximum power), such as headlights, wipers or fans, and applications which require polarity reversal with in-between circuit energy drain.

50 **[0007]** Hence, there is still a need for simple and flexible relay designs capable of yielding three switching states with reduced costs and number of components and requiring less complexity in circuit design and programming.

SUMMARY OF THE INVENTION

5 [0008] The present invention has been made in view of the shortcomings and disadvantages of the prior art, and an object thereof is to provide a magnetic actuator for a three-state switching relay and an electromagnetic relay comprising same, which are capable of yielding three independent switching states with a compact and easy to control design, while providing improved robustness against vibrations.

[0009] This object is solved by the subject matter of the independent claims. Advantageous embodiments of the present invention are subject matter of the dependent claims.

10 [0010] The present invention provides a magnetic actuator for a three-state switching relay, comprising: an armature having two arms that extend laterally from a center region of the armature; and a magnetic system adapted to apply a magnetic force on at least one of the armature arms for causing the armature to rotate about its center region from a neutral position to any of a first operating position and a second operating position; wherein the magnetic system comprises: an electromagnet adapted to create a magnetic flux field based on an input control signal supplied by a control line, an end side of the electromagnet facing the armature; a core member extending longitudinally across an inner side of the electromagnet; at least two outer poles arranged on an outer side of the electromagnet, each outer pole extending adjacent to the electromagnet towards the end side facing the armature; and at least two permanent magnets, each permanent magnet being arranged in a separation gap between a respective outer pole and the core member and magnetically polarized with respect to the core member so that the core member, each outer pole and the respective permanent magnet form a respective path for the magnetic flux created by the electromagnet.

20 [0011] According to an embodiment, the permanent magnets have different polarizations to create a differential in magnetic resistance between the respective magnetic flux paths; and the magnetic pole of each permanent magnet faces the core member with a sign opposite to the sign of the other permanent magnet pole.

25 [0012] In a further embodiment, said magnetic resistance differential causes a differential between the magnetic forces applied by each outer pole on the respective armature arm that is adapted to rotate the armature towards the outer pole associated with the lower magnetic resistance path.

[0013] In a further embodiment, the armature is rotatively coupled to the core member through a hinge spring mounted through the center region of the armature; the hinge spring is adapted to maintain the armature in the neutral position when the electromagnet is de-energized.

30 [0014] In a further embodiment, the armature has a groove at said central region that is adapted to engage with a tip of the core member, wherein the groove and the tip are designed with complementary shapes such that the tip provides a fulcrum about which the armature rotates between the neutral position and any of the first and second operating positions and blocks a lateral displacement of the armature during rotation. In a further embodiment, each arm of the armature extends laterally away from the center region such that the cross-section of the armature has the shape of an angled double wing.

35 [0015] In a further embodiment, the core member is configured with a T-shape having a longitudinal limb and two transverse limbs, the longitudinal limb being adapted to be inserted along the longitudinal inner axis of the electromagnet and each transverse limb being adapted to extend outwards from an end side of the longitudinal limb; and each permanent magnet being arranged between a respective transverse limb and a respective outer pole.

40 [0016] In a further embodiment, each of the outer poles is designed with a L-shape including a longitudinal arm and a transverse arm that substantially form a right angle to each other, the outer poles being arranged outside the electromagnet with the respective longitudinal arms extending along the electromagnet longitudinal axis and the transverse arms extending inwards towards the core member; and each permanent magnet being arranged on the transverse arm of the respective outer pole and facing the core member.

45 [0017] In a further embodiment, the electromagnet is formed by a single coil wound in a same direction about the longitudinal inner axis such that the direction of the magnetic flux field created by the electromagnet is controlled by the sign of the input control signal; and/or each permanent magnet is a two-pole magnet.

50 [0018] In a further embodiment, each of the outer poles includes a transverse arm onto which the permanent magnets are respectively arranged and adapted to extend inwards towards a longitudinal limb of the core member without contacting the longitudinal limb, thereby defining a first magnetic path across the core member, the permanent magnet, and the transverse arm for the magnetic flux generated by the electromagnet; and a magnetic bridge element extending from the transverse arm towards the longitudinal limb such as to partially overlap, without contacting, the longitudinal limb from a lateral side of the core member, thereby defining a second magnetic path across the core member, the magnetic bridging element, and the transverse arm for the magnetic flux generated by the electromagnet.

55 [0019] In a further embodiment, the magnetic bridge element has a portion with a thinner cross-section, the thickness of the thinner cross-section being selected such that magnetic bridge element is magnetically saturated at a desired flux density to limit the magnetic flux that can be passed through the second magnetic path and to force an amount of magnetic flux exceeding the desired flux density to pass through the first magnetic path.

[0020] The invention further provides an electromagnetic relay, comprising: a magnetic actuator according to the

invention.

[0021] In a further embodiment, the electromagnetic relay further comprises a slidable coupler mechanically coupled to the armature of the magnetic actuator and adapted to perform a linear movement when the armature is rotated from the neutral position to any of the first and second operating positions; and a contact assembly adapted to switch among any of three switching states under the actuation of the slidable coupler.

[0022] In a further embodiment, the contact assembly comprises: a first arrangement of contacts comprising a movable contact element and at least one stationary contact element, the first arrangement of contacts being arranged on a first side of the magnetic actuator; wherein the slidable coupler includes a first pressure feature adapted to exert pressure on a side of the movable contact element during a linear movement of the slidable coupler from the neutral position towards a second side, opposed to the first side, after a first travelling distance, and a second pressure feature adapted to exert pressure on the opposed side of movable contact element during a linear movement of the slidable coupler from the neutral position towards the first side, after travelling a second travelling distance, and the second travelling distance is higher than the first travelling distance; and a second arrangement of contacts comprising a movable contact element and at least one stationary contact element, the second arrangement of contacts being arranged on the second side of the electromagnetic relay, opposite to the first arrangement of contacts; wherein the slidable coupler includes a third pressure feature adapted to exert pressure on the movable contact element of the second arrangement during the linear movement from the neutral position towards the second side, after travelling the second travelling distance, and a fourth pressure feature adapted to exert pressure on the movable contact element of the second arrangement during the linear movement from the neutral position towards the first side, after travelling the first travelling distance.

[0023] In a further embodiment, each of the first and second arrangements of contacts comprises first and second stationary contact elements, the first stationary contact elements corresponding to outer stationary contact elements and the second stationary contact elements corresponding to inner stationary contact elements with respect to the movable contact elements of the first and second arrangements of contacts.

[0024] In a further embodiment, the slidable coupler is adapted to make each movable contact element to come into contact with the respective first or second stationary contact depending on the movement direction of the slidable coupler, such that: a first switching state is achieved when the slidable coupler is moved, in a first movement direction, from the neutral position into a first position at which the slidable coupler presses each movable contact element against the respective stationary contact elements on the side defined by the slidable coupler movement direction; a second switching state is achieved when the slidable coupler is moved, in a second movement direction opposed to the first movement direction, from the neutral position into a second position, at which the slidable coupler presses each movable contact element against the respective stationary contact elements on the side defined by the second movement direction; and third switching state is achieved when the slidable coupler is in an intermediate position corresponding to the neutral position at which the slidable coupler exerts no pressure on each of the movable contact elements.

[0025] In a further embodiment, the movable contact element is a change-over terminal, and the first stationary contact elements are normally closed terminal and the second stationary contact elements are normally opened terminal.

[0026] In a further embodiment, the first and second stationary contact elements extend in a direction approximately transverse to the direction of the linear movement of the slidable coupler, and the movable contact element extends in a direction that makes a non-zero angle with the direction first and second stationary contact elements and such that an end part of the movable contact element rests in contact with an end part of the first stationary contact element when the slidable coupler is in the neutral position.

[0027] The accompanying drawings are incorporated into and form a part of the specification for the purpose of explaining the principles of the invention. The drawings are not to be construed as limiting the invention to only the illustrated and described examples of how the invention can be made and used.

BRIEF DESCRIPTION OF THE FIGURES

[0028] Further features and advantages will become apparent from the following and more detailed description of the invention as illustrated in the accompanying drawings, in which:

Fig. 1 is an exploded perspective view of an electromagnetic relay according to an embodiment of the present invention;

Fig. 2 is a perspective view of the electromagnetic relay shown in Fig. 1 in an assembled condition;

Fig. 3 is a schematic perspective view of a magnetic actuator of the electromagnetic relay according to an embodiment;

Fig. 4 shows an exploded perspective view of an armature and hinge spring of the magnetic actuator shown in Fig. 3;

Fig. 5 is a schematic perspective view of a coil body of the magnetic actuator shown in Fig. 3;

Fig. 6 shows schematically a cross-section view across the plane XY of the magnetic actuator illustrated in Fig. 3 with the armature in a neutral position;

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Fig. 7 is a graphical representation of simulation results of the resultant magnetic force applied on the armature as a function of the air gap separation between an outer pole and the tip of the respective armature arm;

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Fig. 8 shows schematically a cross sectional view of an electromagnetic relay having a magnetic actuator coupled to a contact assembly according to an embodiment; and

Fig. 9 is a lateral view of a contact assembly having two arrangements of contacts and a slidable coupler in a neutral position;

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Fig. 10 is a lateral view of the contact assembly and slidable coupler in a first operating position;

Fig. 11 is a perspective view of a movable contact element according to an embodiment;

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Fig. 12 is a perspective view of a movable contact element according to an embodiment;

Fig. 13 illustrates schematically the slidable coupler in the neutral state with respect to the contact elements of the contact assembly;

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Fig. 14 illustrates schematically the slidable coupler and the contact elements of the contact assembly in an intermediate state between the neutral state and a first operating state (moving rightwards);

Fig. 15 illustrates schematically the slidable coupler and the contact elements of the contact assembly in the first operating state;

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Fig. 16 shows a circuit diagram of a motor reverse application using the electromagnetic relay of the present invention for switching between any of three switching states; and

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Fig. 17 shows a circuit diagram of a headlight or fan application using the electromagnetic relay of the present invention for switching between any of three switching states.

Fig. 18 shows schematically a cross-section view across a plane XY of a magnetic actuator according to a second embodiment;

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Fig. 19 shows schematically a perspective view of a magnetic actuator with a double-loop magnetic path according to a third embodiment, viewed from a front-side of the magnetic actuator;

Fig. 20 shows schematically another perspective view of the magnetic actuator illustrated in Fig. 19, viewed from a back-side of the magnetic actuator;

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Fig. 21 represents diagrammatically the distribution of magnetic flux lines between left and right branches of the magnetic actuator, where: (A) shows the flux distribution taking into account the effect of the permanent magnets and the magnetic flux produced by the electromagnet and (B) shows the flux distribution taking into account the magnetic flux produced by the electromagnet alone, both for the magnetic actuator illustrated in Fig. 6; (C) shows the flux distribution taking into account the effect of the permanent magnets and the magnetic flux produced by the electromagnet and (D) shows the flux distribution taking into account the magnetic flux produced by the electromagnet alone, both for the magnetic actuator shown in Figs. 19 - 20. The black arrows in Fig. 21 (A) to (C) represent the polarization of the permanent magnets;

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Fig. 22 shows a detail of the magnetic flux lines established in the region of the bridge elements illustrated in Fig. 21 (C) and (D).

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DETAILED DESCRIPTION OF THE INVENTION

5 [0029] The present invention will now be more fully described hereinafter with reference to the accompanying drawings, in which exemplary embodiments of the invention are shown. The present invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodi-
10 ments are provided so that the disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout.

[0030] It should be noted that the following description assumes that, in the figures, the longitudinal direction is the direction of the illustrated Y axis, a movement in the positive or negative direction of the Y axis being referred to as a longitudinal movement to the right or to the left, respectively. Further, the following description assumes that the vertical direction is a direction parallel to the direction of the Z axis in the figures, the upward direction corresponding to a +Z direction and the downward direction to a -Z direction. Furthermore, a plane parallel to the plane defined by the X and Y axes in the figures is referred to as an horizontal plane in the following description.

15 [0031] Fig. 1 shows an exploded perspective view of an electromagnetic relay 100 according to an embodiment. The electromagnetic relay 100 is a three-state relay capable of switching between any of three different states for providing three different levels of operating voltage at the relay output terminals 110 and 120 based on the contact configuration and one or more potential voltage applied at each of the relay input terminals 130, 140, 150, 160. Each of the three operating states of the relay 100 correspond to a specific configuration of connections between contacts of a contact assembly 300 and can be switched to another configuration under the actuation of a magnetic actuator 200, as it will be explained below.

20 [0032] The electromagnetic relay 100 may comprise a base 400 with features adapted to receive and fix the contact assembly 300 with the magnetic actuator 200 thereon, for e.g. by press-fit. The magnetic actuator 200 is designed with a shape and size suitable for fitting within the contact assembly 300. A perspective view of the electromagnetic relay 100 with the magnetic actuator 200, the contact assembly 300 and the base 400 in an assembled condition is shown in Fig. 2. In this case, the electromagnetic relay 100 may also include a cover (not shown) for covering and protecting the contact assembly 300 and the magnetic actuator 200 in harsh environments. The base 400 and/or the cover may be made of a plastic material, such as LCP GF 30. Alternatively, the magnetic actuator 200 and the contact assembly 300 may be directly mounted on a PCB or inside a box of the appliance to be operated. As shown in Fig. 2, the input control terminals 210, 220 of the magnetic actuator 200 and the relay terminals 110 - 140 (which coincide with contact terminals of the contact assembly 300) protrude from a same side of the base 400 so as to facilitate electrical connections with external circuitry (not shown) from a same side of the relay 100.

25 [0033] The magnetic actuator 200 is mechanically coupled to the contact assembly 300 for changing its contact configuration between any of three switching configurations via magnetic actuation in response to an input control signal applied at input terminals 210, 220 of the magnetic actuator 200. For instance, in case the input terminals 130, 140 are both connected to a same terminal of a power source (e.g. - terminal) and the input terminals 150, 160 are connected to the other terminal of the same power source (+ terminal), the contact assembly 300 provides a first operating state where the voltage input at the relay input terminals 130 and 160 is output with a given polarity, a second operating state where the voltage input at the relay input terminals 150 and 130 is output, i.e. with the inverse polarity of the first operating state, and a third operating state at which both terminals 110, 120 are at a same potential (neutral state). A three-state configuration corresponding to three different levels of voltage output at the relay terminals 110, 120 may be achieved In case the relay input terminals 130, 140, 150, 160 are each connected to one of three different voltage potentials. The structure and operation of the magnetic actuator 200 will now be described with reference to Figs. 3 - 6.

30 [0034] Referring to Fig. 3, the magnetic actuator 200 includes a rocking armature 230 that is pivotally supported on the magnetic actuator 200 at a center region 240 of the armature 230. The armature 230 can rotate in a clockwise and counter-clockwise direction about a rotation axis C that extends through the center region 240 under the actuation of a magnetic system 250 of the magnetic actuator 200, as it will be explained later. The armature 230 is preferably made of a single piece of rigid material and designed with two arms 232, 234 that extend in opposed directions on each side of the center region 240. As illustrated in more detail in Fig. 4, the armature arms 232, 234 may have a symmetric shape and extend from the center region 240 with an inclination angle such that the rocking armature 230 does not have a flat shape but rather an angled double-wing shape with respect to the center region 240. The center region 240 then acts as a fulcrum about which the armature 230 rotates in the clockwise or counter-clockwise direction about the rotation axis C. The angled double-wing shape also provides an air separation gap between the tips of the armature arms 232, 234 and outer poles of the magnetic system 250 when the armature 230 is in a neutral position, as it will be explained later. The armature 230 may be fixed to a coil body 260 of the magnetic system 250 by a hinge spring 236 that is mounted on the center region 240 of the armature 230 and fixed to receiving features 262 provided in the coil body 260. The hinge spring 236 functions as a torsional spring that ensures mechanical contact of the armature with a core member of the magnetic system 250.

35 [0035] The magnetic system 250 is designed to apply a magnetic force on at least one of the armature arms 232, 234

that causes the armature 230 to rotate about the rotation axis C from a neutral position to either a first operating position (for e.g. by rotating in a clockwise direction) or a second operating position (for e.g. by rotating in counter-clockwise direction). Referring to Fig. 6, the magnetic system 250 comprises an electromagnet 270 responsible for creating a magnetic flux field in response to an input control signal supplied at the input control terminals 210, 220 for and which is responsible for the magnetic forces to be applied on the armature 230. The electromagnet 270 may be provided as a bobbin or a single coil that is wound around the coil body 250. The electromagnet 270 is oriented with respect to the armature 230 such that one of its end sides faces the armature 230, approximately centered with the armature center region 240, and its inner longitudinal axis L is approximately aligned in a direction transverse to the rotation axis C and passing through the center of mass of the armature 230.

[0036] In addition, the magnetic system 260 includes a core member 280 that extends longitudinally across the inner side of the electromagnet 270 and at least two outer poles 292, 294 arranged on an outer side of the electromagnet 270. The core member 280 and the outer poles 292, 294 are made of soft magnetic materials so as to respectively concentrate the magnetic flux created by the electromagnet 270 along the magnetic flux paths defined by the core member 280 and the outer poles 292, 294 in the inner and outer sides of the electromagnet 270, respectively.

[0037] Each of the outer pole 292, 294 extends adjacently along the electromagnet 270, preferably between the end facing the armature 230 and the opposed end of electromagnet 270.

[0038] The outer poles 292, 294 and the core member 270 are provided as separate parts so as to provide two alternative magnetic paths for applying a resultant magnetic force on one arm or the other arm of the armature 230 depending on the direction of the magnetic flux field created by the electromagnet 270, as it will be explained later. In order to magnetically couple the core member to the outer pole 292, 294 on either adjacent side of the electromagnet, the magnetic actuator 200 further includes at least two permanent magnets 296, 298. Each permanent magnet 296, 298 is arranged in a separation gap between a respective outer pole 292, 294 and the core member 270 and are provided with a magnetic polarization suitable for increasing or decreasing the magnetic resistance along the magnetic circuit branch formed by the core member 280, the permanent magnet 296 (or 298) and the respective outer pole 292 (or 294) depending on the direction of the magnetic flux created by the electromagnet 270. Moreover, on one branch of the magnet flux circuit, for e.g. along the outer pole 292 and core member 280, the permanent magnet 296 is arranged with a magnetic polarization that is the inverse of the magnetic polarization of the permanent magnet 298 arranged on the other branch of the magnetic circuit, i.e. along outer pole 294 and the core member 280, so that the magnetic path through which the magnetic force is primarily applied to the armature 230 becomes automatically selected by the magnetic circuit branch that offers the lowest magnetic resistance to the direction of the magnetic flux created by the electromagnet 270, and therefore, by the sign of the input control signal supplied to the input terminals 210, 220. Accordingly, the two permanent magnets 296, 298 produce sensitivity of the magnetic system 250 to the polarity of the electromagnet 270, so that when the electromagnet 270 is energized with a specific polarity, the different poles 292, 294 will exert attractive magnetic forces of different intensity on the armature arms 232, 234, respectively. As a consequence, a binary force is produced on the center hinge 250 of the armature 230 due to the differential between the magnetic forces exerted by the top ends of each outer pole 292, 294 on the respective armature arms 232, 234. The design of the magnetic circuit 250 can be optimized by providing a core member 280 with a T-shape that includes a longitudinal limb 282 adapted to be inserted along the longitudinal inner axis L of the electromagnet 270 and two transverse limbs 284, 286 that protrude from an end side of the longitudinal limb 282 and the electromagnet 270 on a side opposed to the armature 230. In addition, each outer pole 292, 294 may be designed so as to almost form a yoke with a U-shape when arranged around the electromagnet 270, but which are provided as separate elements so as to decouple the magnetic flux paths flowing through the outer poles 292, 294 from each other. Accordingly, each outer pole 292, 294 may be provided with similar L-shapes having a longitudinal arm and a transverse arm that substantially form a right angle with each other, the length of the longitudinal arm being suitable for extending at least along the entire longitudinal length of the electromagnet 270. The transverse arms are oriented towards the core member 280 and partially overlap the end side of the electromagnetic 270 opposed to the armature 230. Each permanent magnet 296, 298 is then arranged on the transverse arm of the respective outer pole 292, 294 and facing the core member 280.

[0039] When the electromagnet 270 is de-energized, the resultant magnetic force applied to the armature arms 232, 234 by the respective outer poles 292, 294 is null or negligible. In this state, the armature 230 is maintained in the neutral position, i.e. with similar air gap separation between the tips of the armature 232, 234 and the respective outer poles 292, 294, through the action of the hinge spring 250.

[0040] Fig. 7 is a graphical representation of simulation results for the resultant magnetic force applied on the armature as a function of the air gap separation between an outer pole and the tip of the respective armature arm. The maximum intensity of the actuating force is reached at null separation distance between the outer pole and the armature arm (full contact between armature arm and outer pole) and progressively decreases with the increase on the separation distance, which is minimal when the armature reaches the neutral position.

[0041] The operation of switching the contact assembly 300 of the electromagnetic relay 100 among any of three switching states under the actuation of the magnetic actuator 200 will now be described with reference to Fig. 8. As

shown in Fig. 8, one arm 232 of the armature 230 is mechanically coupled to a slidable coupler 500 positioned on a lateral side of the magnetic system 250. Under mechanical actuation from the armature 230, the slidable coupler 500 performs a linear movement along the longitudinal direction of the magnetic system 250, for e.g. rightwards (positive direction of Y-axis in Fig. 8) when the armature rotates counter-clockwise from the neutral position towards the outer pole 292 of the magnetic system 250 due to the magnetic force applied via the respective magnetic circuit branch exceeding the magnetic force applied by the outer pole 294 of the opposed branch. The rotation of the armature 230 from the neutral position in the clockwise direction results in the slidable coupler 500 being moved to the opposed side, i.e. leftwards (negative direction of Y-axis in Fig. 8).

[0042] As shown in Fig. 2, the slidable coupler 500 has a main body 510 with an elongated form along the longitudinal direction (Y-axis) and a pair of legs 520, 522 provided at an intermediate position that extend transversely from each side of the longitudinal direction of the main body 510. The pair of legs 520, 522 include coupling features 530, 532 at each extremity for mechanically coupling with corresponding mating features 236, 238 provided in the armature arm 232. As a result of this mechanical coupling, a rotation movement of the armature 230 about the rotation axis C is transformed into a linear movement of the slidable coupler 500 in the longitudinal direction.

[0043] On the other hand, the slidable coupler 500 is mechanically coupled to the contact assembly 300 such as to switch configuration of contacts during its longitudinal movement.

[0044] Fig. 9 shows a lateral view of the contact assembly 300 with two arrangements of contacts and the slidable coupler 500 in a neutral position. The contact assembly 300 includes a first arrangement of contacts 310 comprising a movable contact element 312 and two contact elements 314, 316 positioned on each side of the movable contact element 312. The contact elements 314, 316 are preferably stationary contacts that maintain their relative position with respect to the electromagnetic relay 100 in the assembled state, whereas the movable contact element 312 can be moved or switched between the contact elements 314, 316. In the illustrated configuration, the movable contact element 312 corresponds to a change-over (CO) terminal, and the stationary contact elements 314, 316 correspond to normally closed (NC) and normally opened (NO) terminals, respectively.

[0045] In addition, the contact assembly 300 includes a second arrangement of contacts 320 that is located on a side of the magnetic actuator 200, opposite to side where the first arrangement of contacts 310 is placed when the electromagnetic relay 100 is assembled. The second arrangement of contacts 320 comprises a movable contact element 322 arranged between stationary contact elements 324, 326. Similarly to the first arrangements of contacts 310, the stationary contact elements 324, 326 correspond to normally closed and normally opened terminals and the movable contact element 322 to a change-over terminal adapted to come into electrical contact with either one of the stationary contact elements 324, 326.

[0046] The movable and stationary contact elements are positioned with respect to each other within the respective contact arrangements 310, 320 and coupled by the slidable coupler 500 so as to obtain three different switching states of the contact assembly 300 as explained in the following with reference to Figs. 9 to 10.

[0047] Fig. 9 illustrates a case where the slidable coupler 500 is in the intermediate, neutral position and both movable contact elements 312, 322 are in a resting position, i.e. each of the movable contact elements 312, 322 is in electrical contact with the outer stationary contact element of the respective contact arrangement, i.e. with the stationary contact elements 314 and 324. In the intermediate position, the slidable coupler 500 exerts no contact pressure on the movable contact elements 312, 322. This switching state corresponds to the armature 230 being in the neutral position, such as illustrated in Fig. 6.

[0048] The contact assembly 300 may be made to switch from the neutral state to one of the first and second operating states of the electromagnetic relay 100 under the actuation of the armature 230 via the slidable coupler 500. Depending on movement direction of the slidable coupler 500, one of the movable contact elements 312, 322 is made to change from its resting position, where it is in contact with one of the stationary contact elements of respective contact arrangement 310, 320, into a contact with the opposed stationary contact element, i.e. the stationary contact element positioned in the movement direction of the slidable coupler 500, while the other of movable contact elements 312, 322 remains in its resting position.

[0049] Fig. 10 illustrates a case where a first switching state of the contact assembly 300 is achieved by displacing the slidable coupler 500 in a first movement direction (rightwards in Fig. 10) into a first position, thereby displacing the movable contact element 312 on the left side of the contact assembly 300 in the movement direction, from its resting, contact position with the outer stationary contact element 314 into a contact position with the inner stationary contact element 316. At the same time, the movable contact element 322 located on the right side of the contact assembly 300, i.e. in the movement direction of the slidable coupler 500, remains in its resting position though being now pressed against the outer stationary contact element 324 by the slidable coupler 500. Similarly, a second switching state is achieved when the slidable coupler 500 is moved in a movement direction opposed to the first movement direction, for e.g. leftwards, under the actuation of the armature 230 into a second position, at which the slidable coupler 500 presses each movable contact element 312, 322 against the respective stationary contact elements 314, 326 positioned leftwards from the movable contact elements 312, 322 (i.e. in the direction of movement of the slidable coupler 500).

[0050] The stationary contact elements 314, 316, 324, 326 may be provided as rigid contact terminals extending in a direction approximately transverse to the direction of the linear movement of the slidable coupler 500. Contact pads may be added at the respective end parts for improving contact with movable contact elements 312, 322.

[0051] The movable contact elements 312, 322 may be provided with a resilient body or connected by a spring to a support of the contact assembly 300 or the base 400 in order to reduce resistance against the movement induced by the slidable coupler 500. Fig. 11 shows a configuration of the movable contact element 322 (or 312) having a flat base 330 for attaching or inserting to a support of the contact assembly 300 or the base 400 of the electromagnetic relay 100, and a resilient body 340 that extends almost vertically from the flat base 330 with an inclination angle α larger than 90° . The inclination angle α , of the movable contact elements 312, 322 ensures that the movable contact elements 312, 322 are in stable electrical contact with the respective outer stationary contact elements 314, 326 when the relay is in the neutral state and the magnetic actuator 200 is not energized. However, other contact configurations may be envisaged in which both the movable and the stationary contact elements extend in parallel to each other.

[0052] The resistance against movement applied by the movable contact elements 312, 322 on the slidable coupler 500 may be reduced by decoupling the stages when the slidable coupler 500 applies mechanical force on the movable contact elements 312 and 322, as explained below with reference to Figs. 13 - 15. For simplicity, only the contact pads of the stationary contact elements 314, 316, 324, and 326 are represented in Figs. 13 - 15.

[0053] Fig. 13 illustrates schematically the slidable coupler 500 in the neutral state with respect to the contact elements of the contact assembly 300. First and second pressure elements 540, 550 are provided on the left and right sides of the slidable coupler 500 for pushing the respective movable contact elements 312 or 322 from their respective neutral positions when the coupler 500 is moved rightwards or leftwards, respectively. The first and second pressure elements 540, 550 are positioned with respect to the respective movable contact elements 312 or 322 so as to leave an initial gap 560 between them when the slidable coupler 500 is in the neutral position. As a consequence, the slidable coupler 500 does not exert mechanical force on the movable contact element 312 or 322 in the neutral position.

[0054] During the linear movement of the slidable coupler 500, the respective first or second pressure element 540 or 550 will enter into contact with the respective movable contact element 312 or 322 only after the slidable coupler 500 is linearly displaced from the neutral position by a first traveling distance that approximately corresponds to the value of the initial gap 560. As illustrated in Fig. 14, the first pressure feature 540 on the left side of the slidable coupler 500 contacts and starts exerting pressure on the left side of the movable contact element 312 only after the slidable coupler 500 has been displaced rightwards by a distance equal to the initial gap 560. At this intermediate stage, the slidable coupler 500 is still not applying mechanical force on the movable contact element 322 on the left side of the contact assembly 300.

[0055] The slidable coupler 500 also includes additional third and fourth pressure elements 542, 552 provided on the inner left and right sides of the slidable coupler 500. In the neutral position the pressure elements 542, 552 have a separation from the respective movable contact elements 312, 322 that corresponds to an overtravel distance 570 by which the slidable coupler 500 has to be additionally displaced for bringing the movable contact element 312 or 322 into contact with the opposed, inner stationary contact element 316 or 326. Fig. 15 illustrates the case where the movable contact element 312 is brought into contact with the inner stationary contact element 316 after the slidable coupler 500 has been further displaced rightwards by the overtravel distance 570. At this time, the pressure element 552 on the right side of the slidable coupler 500 exerts pressure onto the movable contact element 322, which helps to maintain the movable contact element 322 in electrical contact with the outer stationary contact element 324, and therefore improves resistance of the electrical connection against vibrations. As a result, for switching the movable contact element 312 or 322 from the neutral operating position into a contact configuration corresponding to either the first or second operating states, the slidable coupler 500 is first linearly displaced by a distance corresponding to the initial gap 560 with reduced resistance from only one of the movable contact elements 312 or 322, and then by an overtravel distance 570 in the same movement direction for bringing the movable contact element 312 or 322 into contact with the opposed stationary contact element. The overall displacement of the slidable coupler 500 when switching from the neutral state to one of the first and second operating states corresponds to an overall distance approximately equal to equal to the initial gap 550 and the overtravel 570. Preferably, the overtravel distance 570 is higher than the initial gap 550 for improving stability of the contacts in the three switching states.

[0056] Fig. 16 shows a circuit diagram of a motor reverse application using a three-state relay 600 according to principles of the present invention for switching between any of a neutral state for stopping/halting the motor, a first state for driving the motor in given direction and a second state for reverting the direction of the motor movement. In the illustrated configuration, the three-state relay 600 has NO terminals 610 and NC terminals 620 that are respectively coupled to the positive and negative terminals of a power source, such as a battery. The movable CO terminals 630 are electrically coupled to the terminals of the motor 640 and remain in the resting position, i.e. in contact with the NC terminals, when the relay coil 650 is not energized, which corresponds to the contact configuration for stopping or halting the motor (neutral state). The three-state relay 600 can be switched from the neutral state to any of two operating states for operating the motor 640 with direct or reverse rotation by supplying a single input signal from a signal source 660

and which is converted by a single driver 672 into an analogue signal with suitable polarity and intensity for causing a rotation of the relay armature in the direction associated with the desired motor rotation.

5 [0057] Fig. 17 shows a circuit diagram of a headlight or fan application using the three-state relay 600 shown in Fig. 16. In this application, the NO terminals 610 of the three-state relay 600 are not connected to the same positive terminal of a power source as in Fig. 16 but rather to respective potential voltages V1 and V2 so that two different power levels for driving the appliance can be achieved depending on whether one or the other of the CO terminals 630 is made to contact one or the other of the NO terminal 610. Similarly to the operation shown in Fig. 16, the neutral state is achieved when the CO terminals 630 are both switched to connect to the NC terminals 620.

10 [0058] Fig. 18 shows a cross-sectional view of a magnetic actuator 700 according to a second embodiment, which differs from the configuration described above with reference to Fig. 6 in the shape of the rocking armature 730 and of the extremity of the core member 280 by which the rocking armature 730 is supported. Referring to Fig. 18, the armature 730 is designed with a recess or groove 740 at a centre region and which extends along the armature rotation axis C. The recess or groove 740 is designed with an inverted-V shape suitable to engage with the extremity 750 of the core member 280 in a pivoting manner.

15 [0059] Two armature arms 732, 734 extend in opposed directions from each side of the groove 740 and are preferably symmetric in shape. The armature arms 732, 734 also make a non-zero angle with respect to a plane transverse to the rotation axis C such that the extremities of the armature arms 732, 734 do not physically contact the ends of the outer poles 292, 294 of the magnetic system 250, respectively, when the armature 730 is in a neutral position.

20 [0060] The extremity 750 of the core member 280 onto which the rocking armature 730 is supported is provided with V-shape suitable to engage with the armature groove 740 and to provide a pivot point or fulcrum 750 around which the armature 730 can rotate in a clockwise/counter-clockwise manner. For instance, as shown in Fig. 18, the V-inverted shape of the groove 740 has an overture angle larger than the angle of the V-shaped tip of the core member 280 such as to allow the armature 730 to pivot between the neutral and the first/second operating positions, while blocking lateral movements along the Y-direction. Thus, the inverted-V shape of the groove 740 improves stability of the armature movement by preventing lateral displacements of the armature 730 towards the left or right sides of the rotation axis C when the armature 730 is magnetically actuated to switch from the neutral position to the first or second operating positions. The principles and details of operation of the magnetic actuator 700 are the same as those described above with reference to the magnetic actuator 200, namely, the magnetic actuation produced by the magnetic system 250 onto the armature 730 for rotating it from the neutral position to either the first operating position (for e.g. where the armature arm 734 is rotated in the clockwise direction to contact the outer pole 294) or a second operating position (for e.g. where the armature arm 732 is rotated in the counter-clockwise direction to contact the outer pole 292), and therefore, these will not be repeated here.

25 [0061] The armature 730 is preferably made of a single piece of rigid material and may be fixed to the coil body 260 of the magnetic system 250 by a hinge spring 736 mounted on the centre region 740 of the armature 730 and fixed to receiving features (not shown) in the coil body 260. Similarly to the hinge spring 236 described above, the hinge spring 736 may also function as a torsional spring that improves the mechanical contact of the armature 730 with the end 750 of core member 280. The groove 740 and fulcrum 750 may be designed with shapes different from the inverted V-shape and V-shape described above, as long as these provide sufficient degree of freedom for the pivoting movement of the armature 730 while constraining any lateral displacements of the armature 730 during rotation.

30 [0062] A configuration of a magnetic actuator 800 according to a further embodiment is illustrated in Figs. 19 - 20. The magnetic actuator 800 differs from the magnetic actuator 200 described above with reference to Fig. 6 in comprising one or more magnetic bridging elements for defining a double-loop magnetic path for the magnetic flux generated by the electromagnet 270.

35 [0063] Similarly to the magnetic actuator 200 described above, the magnetic actuator 800 in the present example includes at least two permanent magnets 296, 298 that are respectively arranged with opposed polarizations in the respective separation gap between the transverse arms 292', 294' of the outer poles 292, 294 and the left and right limbs 286, 284 of core member 280 to provide two magnetic paths of different magnetic resistance for the magnetic flux generated by the electromagnet 270. Thus, although the magnetic flux generated by the coil of the electromagnet 270 is symmetric with respect to the coil longitudinal axis L, and therefore, it would be distributed equally, in the absence of the permanent magnets 296, 298, between the magnetic circuit branch formed by the core member 280, the armature 230, and the outer pole 292 on one side of the electromagnet 270 and the magnetic circuit branch formed by the core member 280, the armature 230 and the outer pole 294 on the opposed side as illustrated in Fig. 21 (B), the presence of the permanent magnets 296, 298 with anti-parallel polarizations between the transverse arms 292', 294' of the outer poles 292, 294 and the core member limbs 286, 284, leads to the density of magnetic flux being increased in the branch that offers less magnetic resistance to the passage of the magnetic flux, i.e. when the magnetic flux generated by the electromagnet 270 is aligned with the polarization of the permanent magnet 296 in the the gap between the outer pole and core limb (for e.g. across left-hand side branch in Fig. 21 (B), where solid arrows indicate the path with higher magnetic flux density), while offering a higher magnetic resistance when the polarity of the energizing current is inverted.

As a consequence, as one of the magnetic path branches is more favourable for the passage of the magnetic flux produced by the electromagnet 270 in detriment of the other branch depending on the polarity of the current energizing the electromagnet 270, a differential on the attraction forces exerted by the outer poles 292, 294 onto the armature arms 232, 234 is generated, causing the armature 730 to rotate to one or to the other side, depending on the polarity of the electromagnet current.

[0064] The sensitivity of this magnetic actuation principle to the energizing current polarity may be further improved by adding magnetic bridging elements 810, 820 to each transverse arm 292', 294' of the outer poles 292, 294, respectively. For example, referring to the transverse element 294' shown in Fig. 20, the magnetic bridge element 820 is arranged at an end of the transverse arm 294' and extends transversely towards the longitudinal limb 282 of the core member 280 such as to partially overlap the longitudinal limb 282, without contacting it, from a lateral side of the core member 280. The dimensions of the magnetic bridge element 820 and distance from the longitudinal core limb 282 are selected such as to establish a second magnetic path through the core member 280, the magnetic bridging element 820, and the transverse arm 294' for the magnetic flux generated by the electromagnet 270. This second magnetic path provides a shortcut for the passage of a fraction of the magnetic flux produced by the electromagnet, independent on the polarity of the energizing current, which allows to improve stability of the overall magnetic actuation principle. In particular, the magnetic bridge element 820 has a thinner portion with a thickness that is selected such as to ensure that the magnetic bridging element 820 is magnetically saturated at a desired flux density. This allows to limit the magnetic flux that can be passed through the second magnetic path to a desired level of flux density and therefore, force a main fraction of the resultant magnetic flux to pass through the main, first magnetic path defined through the core member limb - permanent magnet - transverse arm of the branch that offers less magnetic resistance at a given polarity of energizing current. The predetermined level is preferably selected so as to correspond to a magnetic flux density at which the magnetic bridge elements 810, 820 are magnetically saturated by magnetic flux density produced by the electromagnet 270 alone at a desired energizing current, i.e. without taking into account the effect of the permanent magnets 296, 298, such as illustrated in Fig. 21 (D). In this case, only a fraction of the magnetic flux generated by the electromagnet 270 passes across the saturated bridge elements 810, 820 (where the flux passing through the bridges 810, 820 is represented as white arrows in Fig. 21 (D)) while the remaining fraction is distributed equally between the left path through the core limb 286 and the outer pole 292 and the right flux path through the core limb 284 and out pole 294.

[0065] Fig. 21 (C) illustrated the distribution of the resultant magnetic flux when taking into account the effect of the permanent magnets 296, 298 (where the polarization of the permanent magnets is represented with black arrows) and the magnetic saturation of the bridge elements 810, 820. In this case, a fraction of the magnetic flux produced by the electromagnet 270 passes across the bridge element 810 on the left side of the actuator, and the remaining flux is directed towards the core limb 286 and the permanent magnet 296 due to the saturation of the bridge element 810, so that a double-loop magnetic path is established on the left branch of the magnetic actuator. On the right side, the bridge element 820 is also saturated by the magnetic flux generated by the electromagnet 270, which has the same direction inside the bridge element 820 as the magnetic flux introduced by the permanent magnet 298. As a result, the magnetic flux introduced by the permanent magnet 298 cannot be shortcut by the bridge element 820, and no double-loop magnetic path is formed. As a result, the subtraction effect from the permanent magnet 298 on the right-side onto the flux generated by the electromagnet 270 is maintained, thereby creating a differential of attractive forces that cause the armature 230 to rotate towards the left-side. When the polarity of the electromagnet energizing is inverted, situation described above is also invert and the double-loop magnetic path is established at the right side of the magnetic actuator. The magnetic bridge elements 810, 820 are made of a magnetic material, such as iron. As shown in Figs. 19 - 20, one of the magnetic bridge elements 810, 820 is provided on one side of the magnetic actuator 800 (for e.g. element 810 at the actuator front-side in Fig. 19) while the other magnetic bridge element is provided at the opposed side of the magnetic actuator 800 (for e.g. element 820 at the actuator back-side in Fig. 20), instead of on a same side of the magnetic actuator 800, for avoiding magnetic interference between the bridge elements 810, 820 and magnetic short-circuit between the transverse arms 292', 294' of the outer poles 292, 294.

[0066] The armature 730 described above with reference to Fig. 18 is also applicable to the magnetic actuator 800 of the present embodiment.

[0067] In conclusion, in contrast to double-armature and/or double magnetic systems of conventional relays, the concepts described above allows yielding a three-state relay which can be switched under actuation of a single armature operable with a single inductive coil by simply reversing the sign of the input control signal fed to the single inductive coil. Moreover, the contact configurations corresponding to the neutral configuration (off state) are achieved by deenergizing the single coil, and therefore, do not require additional excitation coils for reverting the armature to its neutral position. As a result, three switching states may be achieved with a single relay format that can be easily operated with a single control line, without requiring synchronization between multiple operation lines and complex circuitry. Furthermore, by replacing the usage of two armatures for one, the present invention provides magnetic actuators and electromagnetic relays with a compacter design and of simple operation. In addition, the magnets and other components of the magnetic actuators can be assembled by simple insertion or press fitting, and thereof, the assembly of the electro-

magnetic relay requires no welding or riveting.

[0068] Although certain features of the above exemplary embodiments may have been eventually described using terms such as "top", "bottom", and "upper", "left" or "right", these terms are used for the purpose of facilitating the description of the respective features and their relative orientation within the electromagnetic relay only and should not be construed as limiting the claimed invention or any of its components to a particular spatial orientation.

Reference Signs

[0069]

10	100	electromagnetic relay
	110, 120	relay output terminals
	130, 140, 150, 160	relay input terminals
	200	magnetic actuator
15	210, 220	input terminals of magnetic actuator
	230	rocking armature
	232, 234	armature arms
	236, 238	mating features
	240	center region
20	C	rotation axis
	L	inner longitudinal axis of electromagnet
	250	magnetic system
	260	coil body
	262	receiving features
25	270	electromagnet
	280	core member
	282	longitudinal limb
	284, 286	transverse limbs
	292, 294	outer poles
30	292', 294'	transverse branches of outer poles
	296, 298	permanent magnets
	300	contact assembly
	310	1 st arrangement of contacts
35	312	movable contact element
	314, 316	stationary contact elements
	320	2 nd arrangement of contacts
	322	movable contact element
	324, 326	stationary contact elements
40	330	flat base of movable contact element
	340	resilient body of movable contacts element
	350	contact pad of movable contact element
	α	inclination angle of movable contact element
	400	base
45	500	slidable coupler
	510	main body of slidable coupler
	520, 522	coupling legs
	530, 532	coupling features
	540, 542	pressure features on left side
50	550, 552	pressure features on right-side
	560	initial gap
	570	overtravel
	600	three-state relay
55	610	NO terminals
	620	NC terminals
	630	CO terminals
	640	motor

650 inductive coil
 660 signal source
 670 driver

5 700 magnetic actuator
 730 rocking armature
 732, 734 armature arms
 736 hinge spring
 740 groove in armature center region
 10 750 V-shaped tip of core member

800 magnetic actuator with double-loop magnetic path
 810, 820 magnetic bridge elements

15

Claims

1. A magnetic actuator for a three-state switching relay, comprising:

20 an armature having two arms that extend laterally from a center region of the armature; and
 a magnetic system adapted to apply a magnetic force on at least one of the armature arms for causing the
 armature to rotate about its center region from a neutral position to any of a first operating position and a second
 operating position;
 wherein the magnetic system comprises:

25 an electromagnet adapted to create a magnetic flux field based on an input control signal supplied by a
 control line, an end side of the electromagnet facing the armature;
 a core member extending longitudinally across an inner side of the electromagnet;
 at least two outer poles arranged on an outer side of the electromagnet, each outer pole extending adjacent
 30 to the electromagnet towards the end side facing the armature; and
 at least two permanent magnets, each permanent magnet being arranged in a separation gap between a
 respective outer pole and the core member and magnetically polarized with respect to the core member
 so that the core member, each outer pole and the respective permanent magnet form a respective path for
 the magnetic flux created by the electromagnet.

35 2. A magnetic actuator according to claim 1, wherein
 the permanent magnets have different polarizations to create a differential in magnetic resistance between the
 respective magnetic flux paths;
 the magnetic pole of each permanent magnet faces the core member with a sign opposite to the sign of the other
 40 permanent magnet pole.

3. A magnetic actuator according to claim 2, wherein said magnetic resistance differential causes a differential between
 the magnetic forces applied by each outer pole on the respective armature arm that is adapted to rotate the armature
 towards the outer pole associated with the lower magnetic resistance path.

45 4. A magnetic actuator according to any one of claims 1 to 3, wherein
 the armature is rotatively coupled to the core member through a hinge spring mounted through the center region of
 the armature;
 the hinge spring is adapted to maintain the armature in the neutral position when the electromagnet is de-energized.

50 5. A magnetic actuator according to any one of claims 1 to 4, wherein
 the armature (730) has a groove (740) at said central region that is adapted to engage with a tip (780) of the core
 member (280), wherein the groove (740) and the tip (780) are designed with complementary shapes such that the
 tip (780) provides a fulcrum about which the armature (730) rotates between the neutral position and any of the first
 55 and second operating positions and blocks a lateral displacement of the armature during rotation; and/or
 each arm of the armature extends laterally away from the center region such that the cross-section of the armature
 has the shape of an angled double wing.

- 5 6. A magnetic actuator according to any one of claims 1 to 5, wherein the core member is configured with a T-shape having a longitudinal limb and two transverse limbs, the longitudinal limb being adapted to be inserted along the longitudinal inner axis of the electromagnet and each transverse limb being adapted to extend outwards from an end side of the longitudinal limb; and
each permanent magnet being arranged between a respective transverse limb and a respective outer pole.
- 10 7. A magnetic actuator according to any one of claims 1 to 6, wherein each of the outer poles is designed with a L-shape including a longitudinal arm and a transverse arm that substantially form a right angle to each other, the outer poles being arranged outside the electromagnet with the respective longitudinal arms extending along the electromagnet longitudinal axis and the transverse arms extending inwards towards the core member; and
each permanent magnet being arranged on the transverse arm of the respective outer pole and facing the core member.
- 15 8. A magnetic actuator according to any one of claims 1 to 7, wherein the electromagnet is formed by a single coil wound in a same direction about the longitudinal inner axis such that the direction of the magnetic flux field created by the electromagnet is controlled by the sign of the input control signal; and/or
each permanent magnet is a two-pole magnet.
- 20 9. A magnetic actuator according to any one of claims 1 to 8, wherein each of the outer poles (292, 294) includes:

a transverse arm (292', 294') onto which the permanent magnets are respectively arranged and adapted to extend inwards towards a longitudinal limb (282) of the core member (280) without contacting the longitudinal limb (282), thereby defining a first magnetic path across the core member (280), the permanent magnet, and the transverse arm for the magnetic flux generated by the electromagnet (270); and
a magnetic bridge element extending from the transverse arm (292', 294') towards the longitudinal limb (282) such as to partially overlap, without contacting, the longitudinal limb (282) from a lateral side of the core member (280), thereby defining a second magnetic path across the core member (280), the magnetic bridging element, and the transverse arm for the magnetic flux generated by the electromagnet (270).
- 30 10. A magnetic actuator according to claim 9, wherein the magnetic bridge element has a portion with a thinner cross-section, the thickness of the thinner cross-section being selected such that magnetic bridge element is magnetically saturated at a desired flux density to limit the magnetic flux that can be passed through the second magnetic path and to force an amount of magnetic flux exceeding the desired flux density to pass through the first magnetic path.
- 35 11. An electromagnetic relay, comprising:
a magnetic actuator according to any one of claims 1 to 10.
- 40 12. An electromagnetic relay, further comprising:

a slidable coupler mechanically coupled to the armature of the magnetic actuator and adapted to perform a linear movement when the armature is rotated from the neutral position to any of the first and second operating positions; and
a contact assembly adapted to switch among any of three switching states under the actuation of the slidable coupler.
- 45 13. An electromagnetic relay according to claim 11, wherein the contact assembly comprises:

a first arrangement of contacts comprising a movable contact element and at least one stationary contact element, the first arrangement of contacts being arranged on a first side of the magnetic actuator; wherein the slidable coupler includes a first pressure feature adapted to exert pressure on a side of the movable contact element during a linear movement of the slidable coupler from the neutral position towards a second side, opposed to the first side, after a first travelling distance, and a second pressure feature adapted to exert pressure on the opposed side of movable contact element during a linear movement of the slidable coupler from the neutral position towards the first side, after travelling a second travelling distance, and the second travelling distance is higher than the first travelling distance; and
- 50
55

a second arrangement of contacts comprising a movable contact element and at least one stationary contact element, the second arrangement of contacts being arranged on the second side of the electromagnetic relay, opposite to the first arrangement of contacts; wherein
5 the slidable coupler includes a third pressure feature adapted to exert pressure on the movable contact element of the second arrangement during the linear movement from the neutral position towards the second side, after travelling the second travelling distance, and a fourth pressure feature adapted to exert pressure on the movable contact element of the second arrangement during the linear movement from the neutral position towards the first side, after travelling the first travelling distance.

10 **14.** An electromagnetic relay according to claim 13, wherein each of the first and second arrangements of contacts comprises first and second stationary contact elements, the first stationary contact elements corresponding to outer stationary contact elements and the second stationary contact elements corresponding to inner stationary contact elements with respect to the movable contact elements of the first and second arrangements of contacts.

15 **15.** An electromagnetic relay according to claim 14, wherein:
the slidable coupler is adapted to make each movable contact element to come into contact with the respective first or second stationary contact depending on the movement direction of the slidable, such that:

20 a first switching state is achieved when the slidable coupler is moved, in a first movement direction, from the neutral position into a first position at which the slidable coupler presses each movable contact element against the respective stationary contact elements on the side defined by the slidable coupler movement direction;
a second switching state is achieved when the slidable coupler is moved, in a second movement direction opposed to the first movement direction, from the neutral position into a second position, at which the slidable
25 coupler presses each movable contact element against the respective stationary contact elements on the side defined by the second movement direction; and
a third switching state is achieved when the slidable coupler is in an intermediate position corresponding to the neutral position at which the slidable coupler exerts no pressure on each of the movable contact elements.

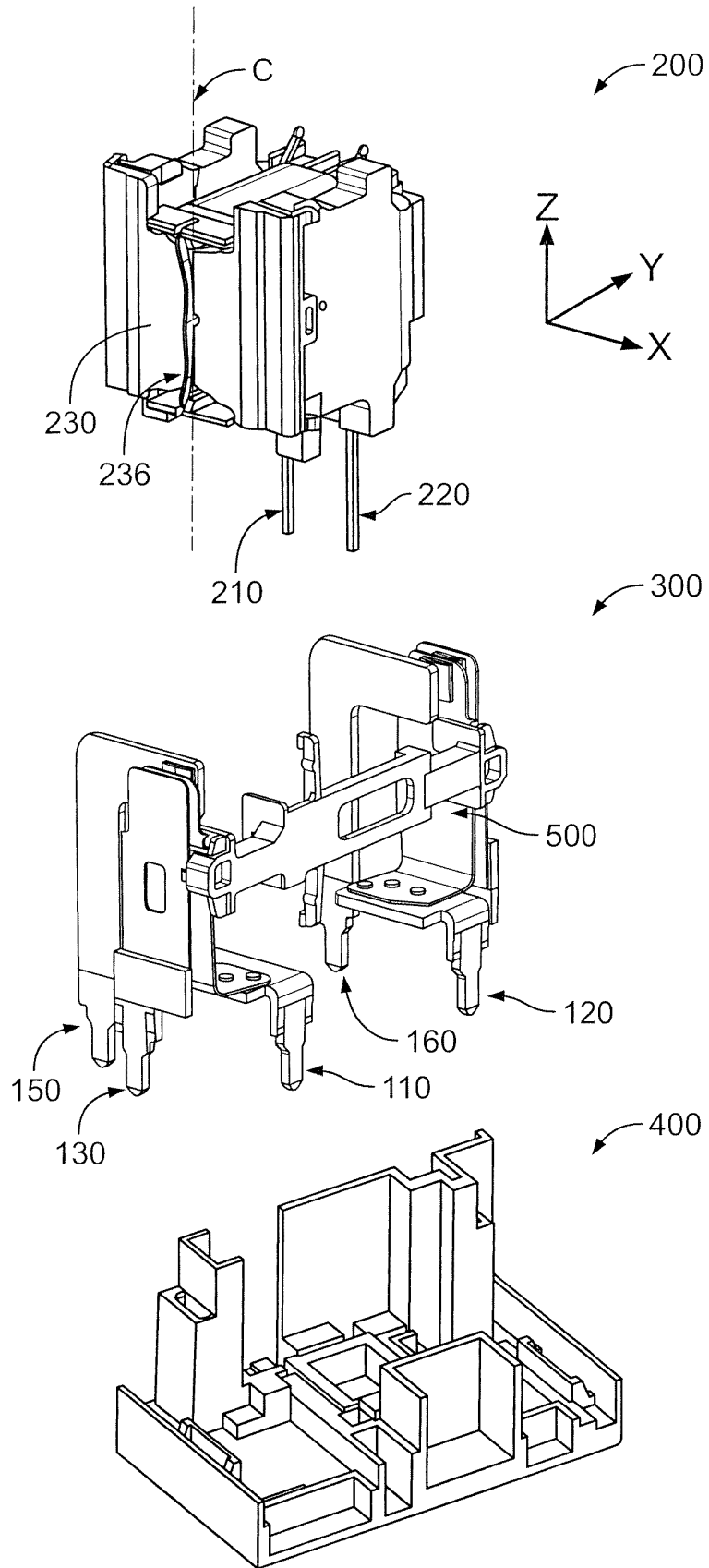


Fig. 1

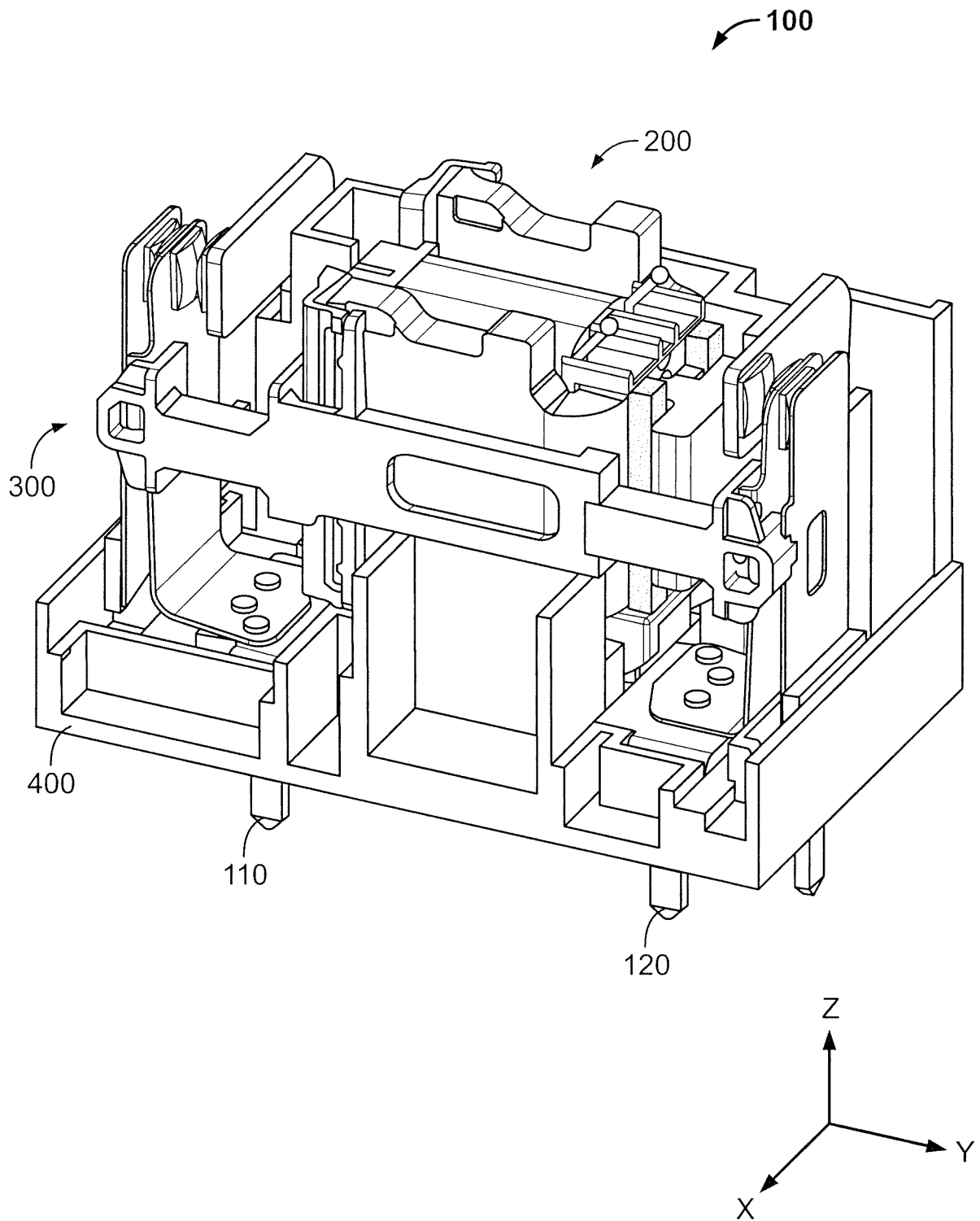


Fig. 2

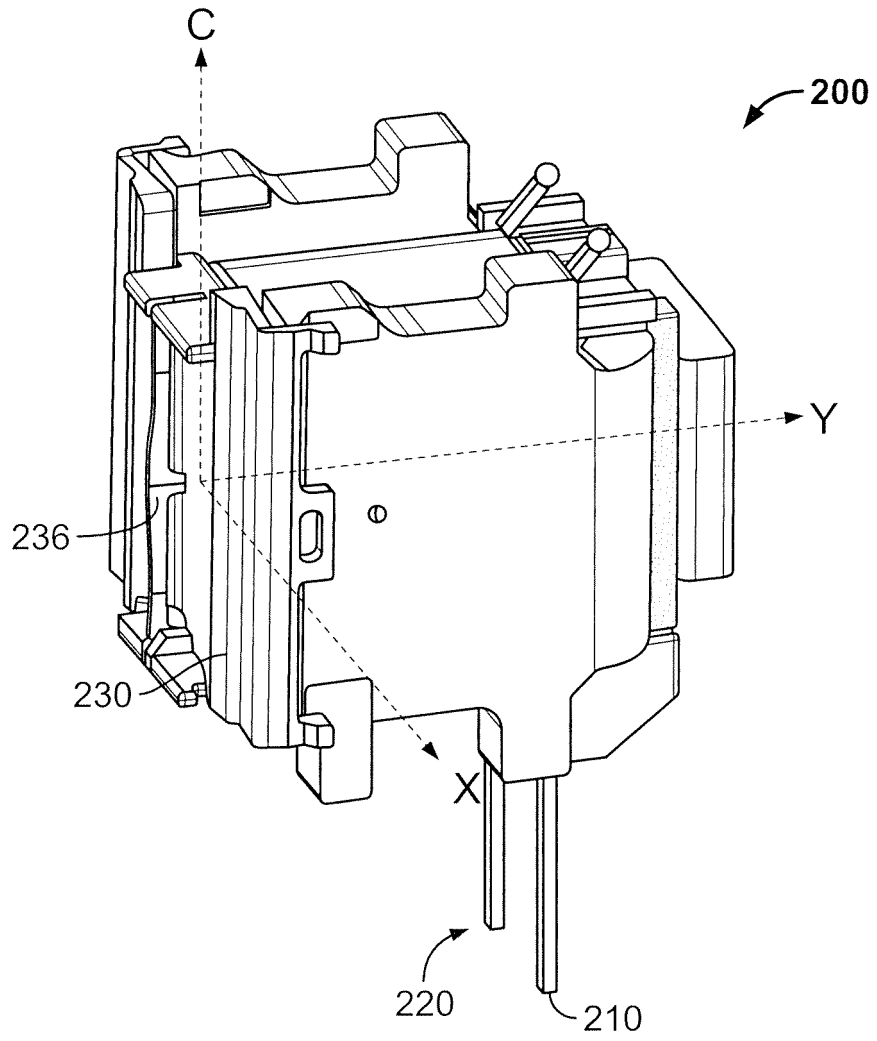


Fig. 3

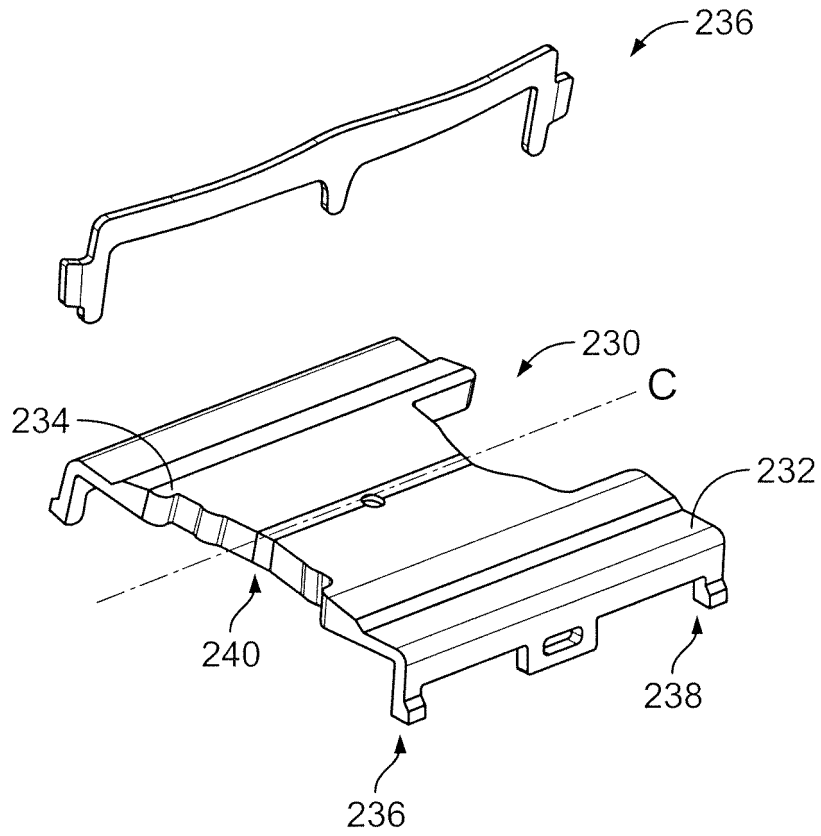


Fig. 4

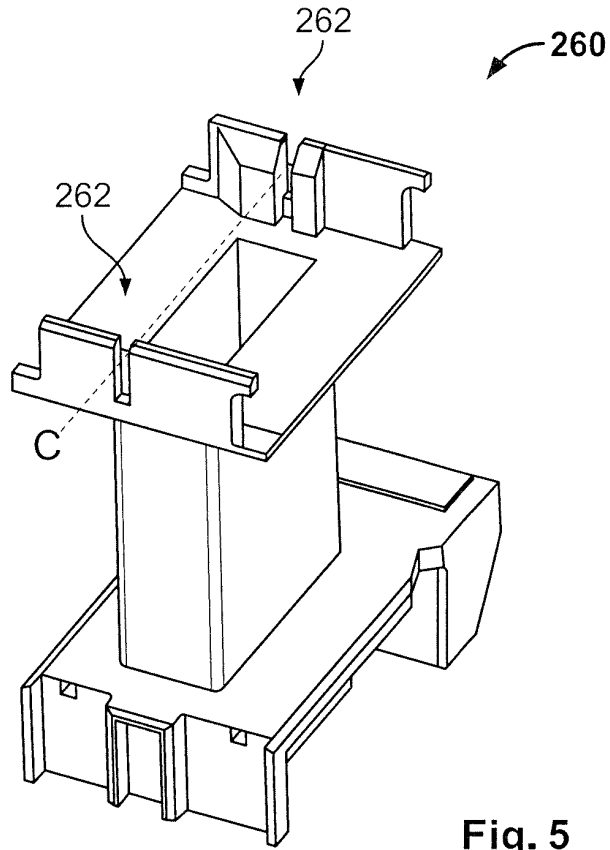


Fig. 5

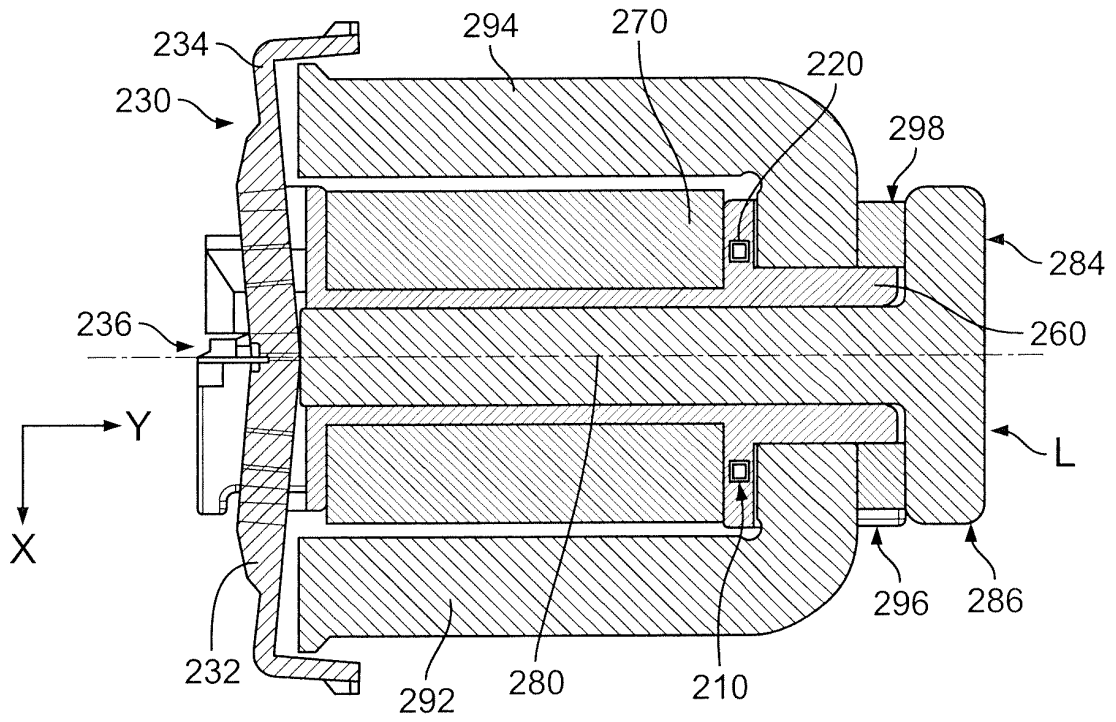


Fig. 6

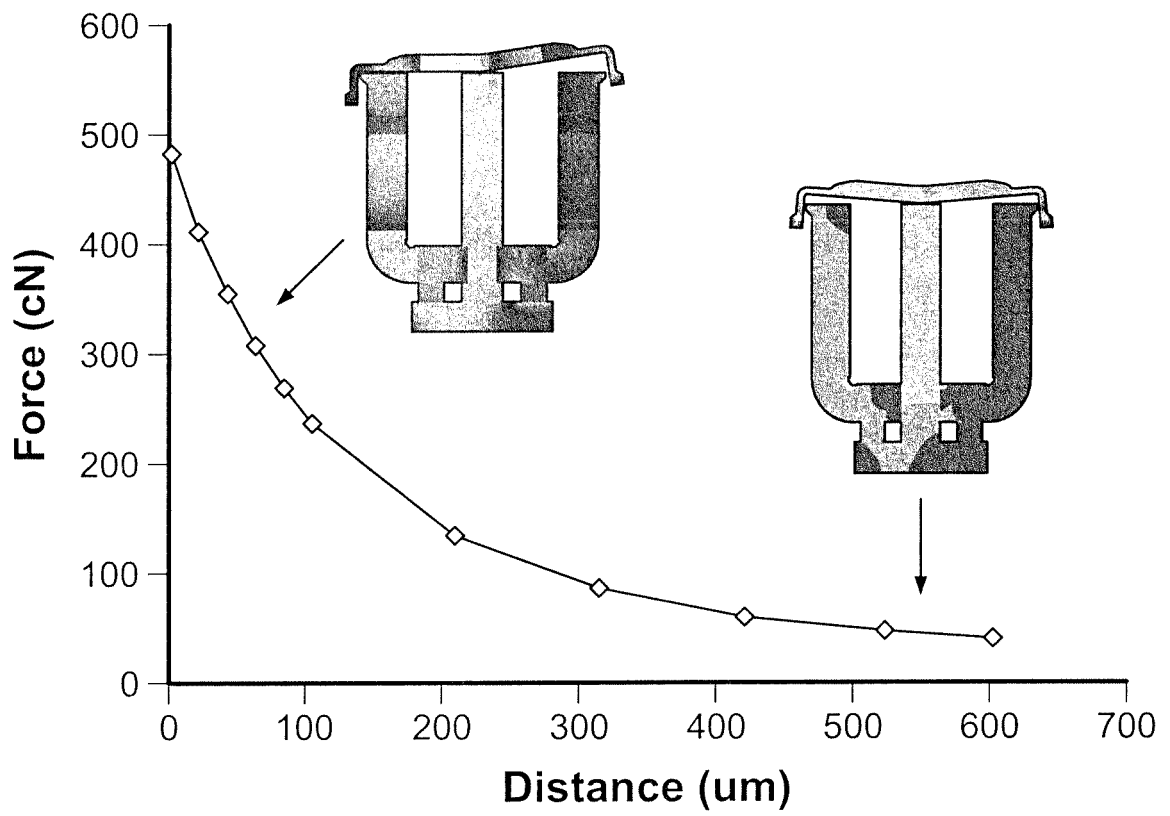


Fig. 7

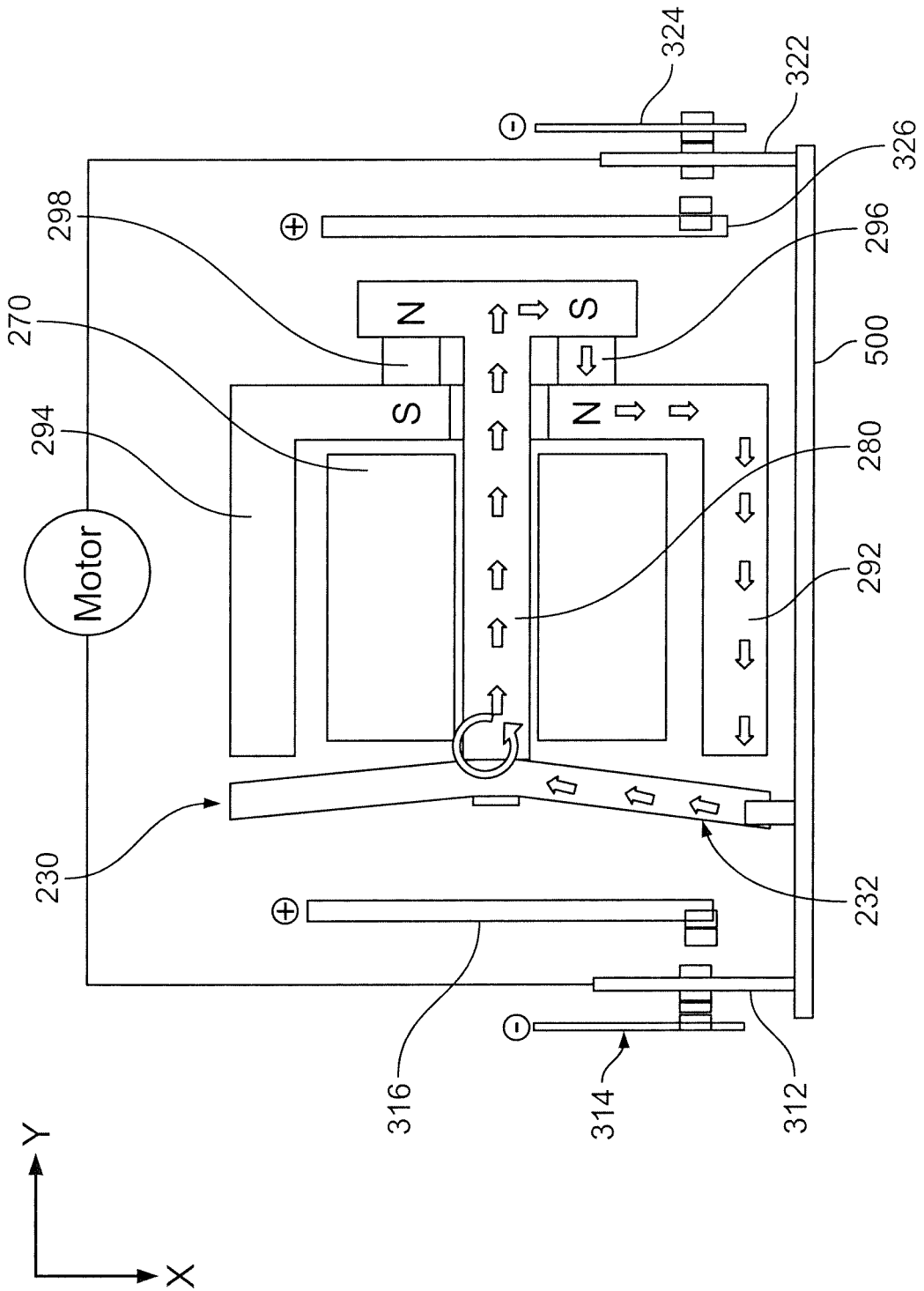


Fig. 8

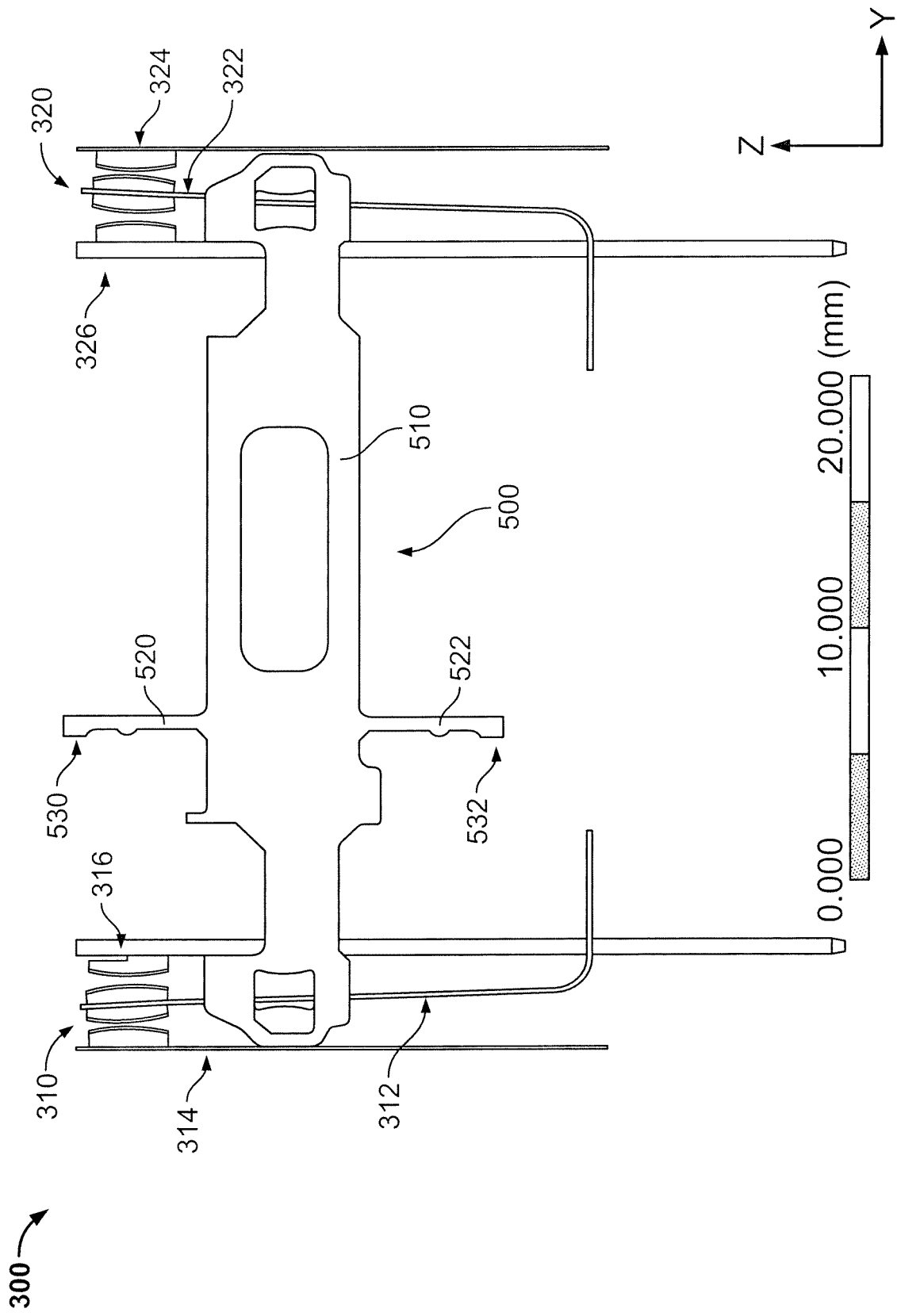


Fig. 9

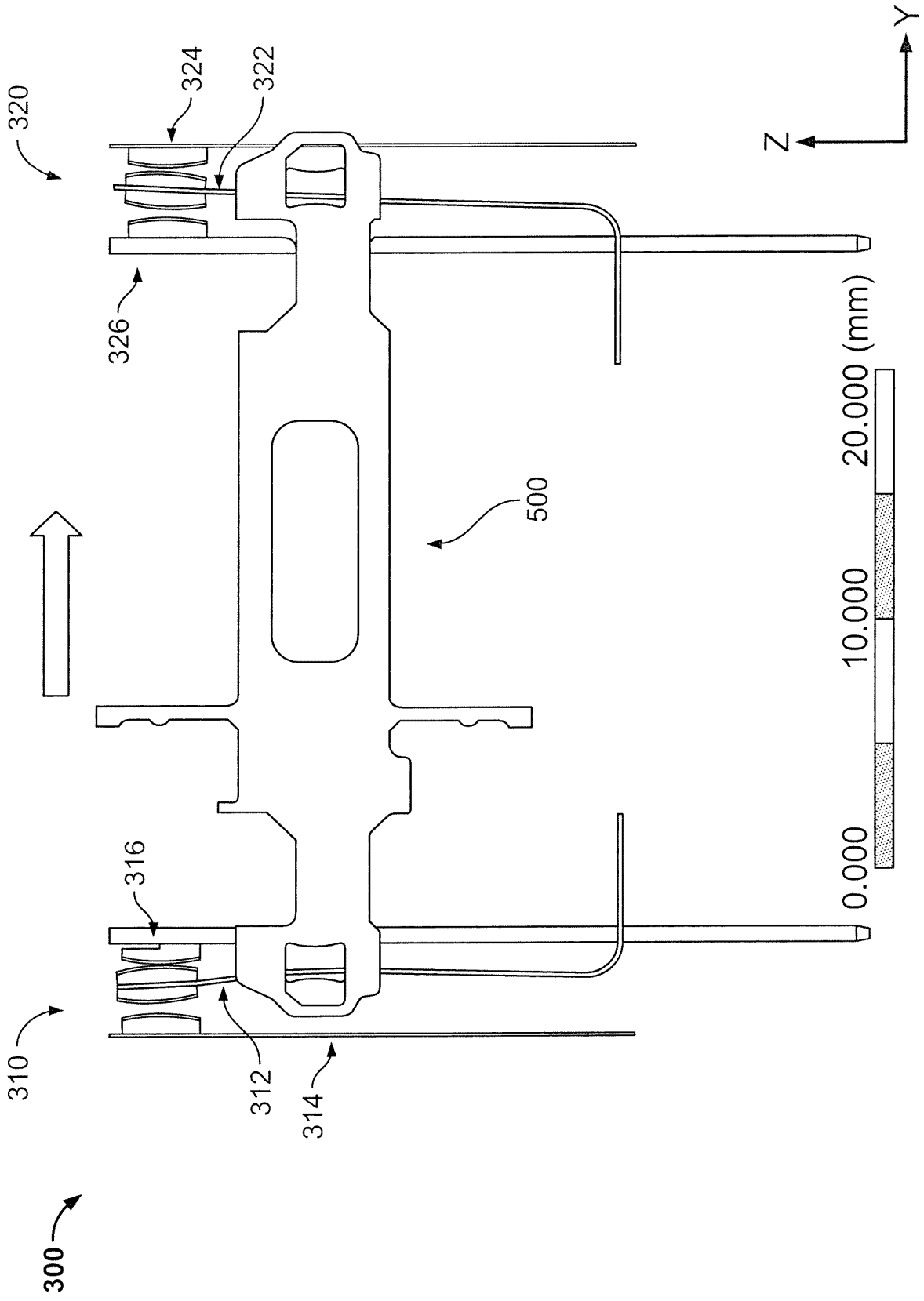


Fig. 10

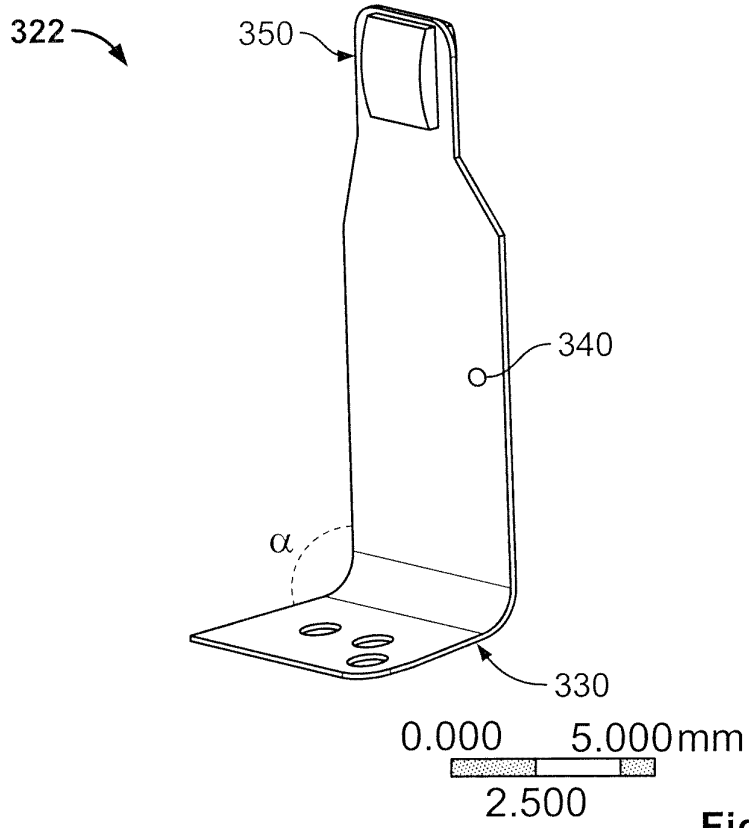


Fig. 11

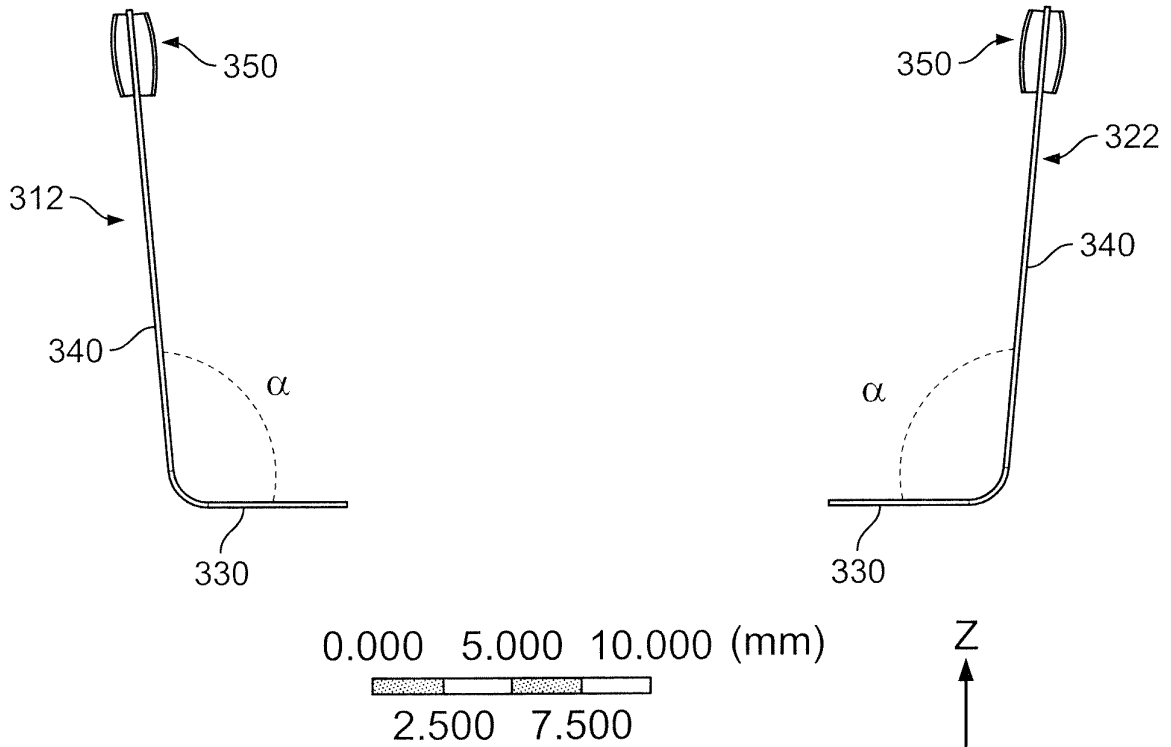


Fig. 12

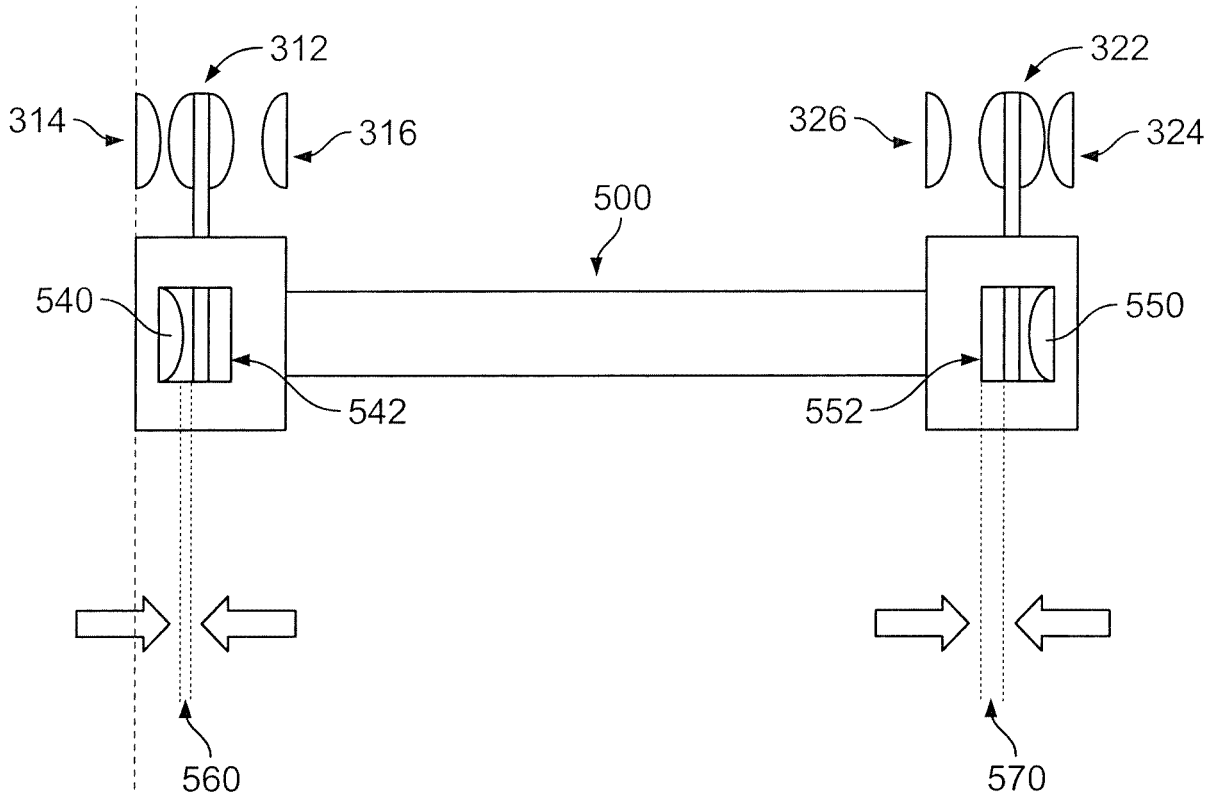


Fig. 13

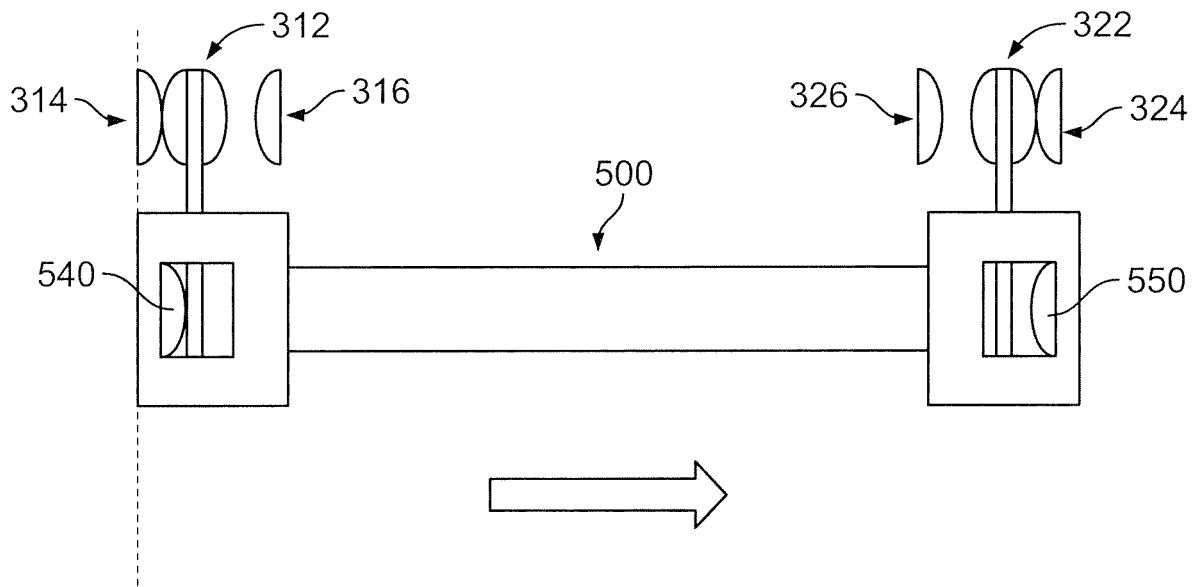
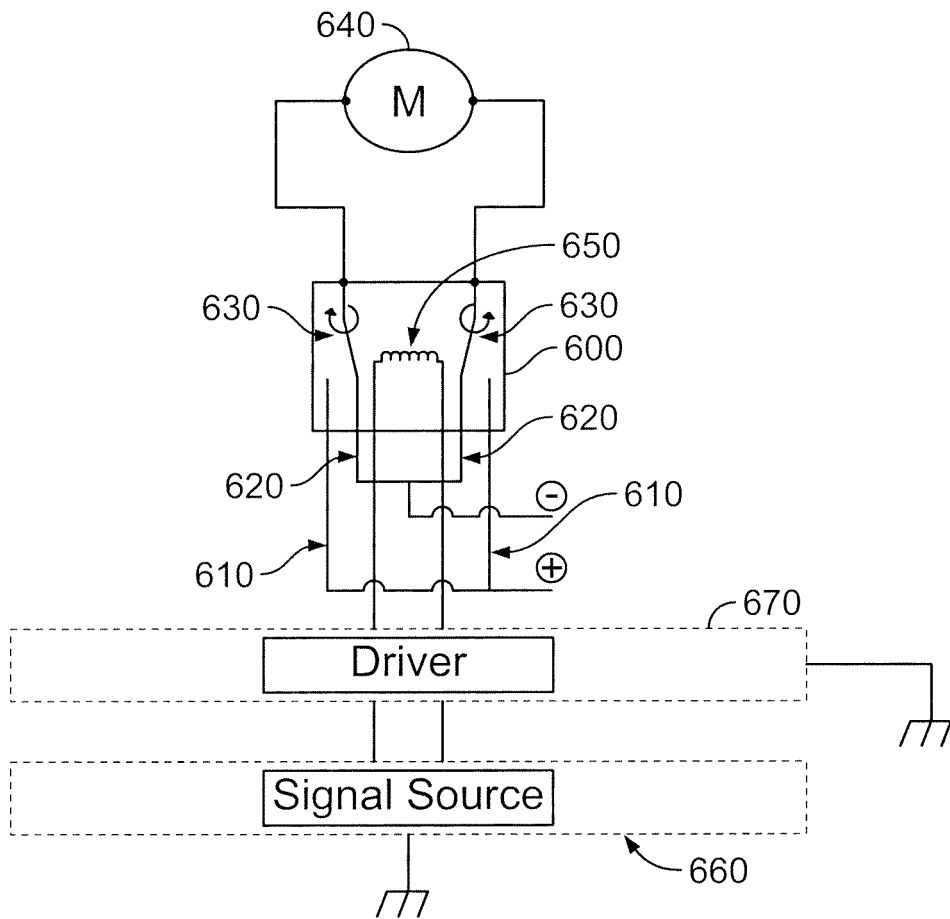
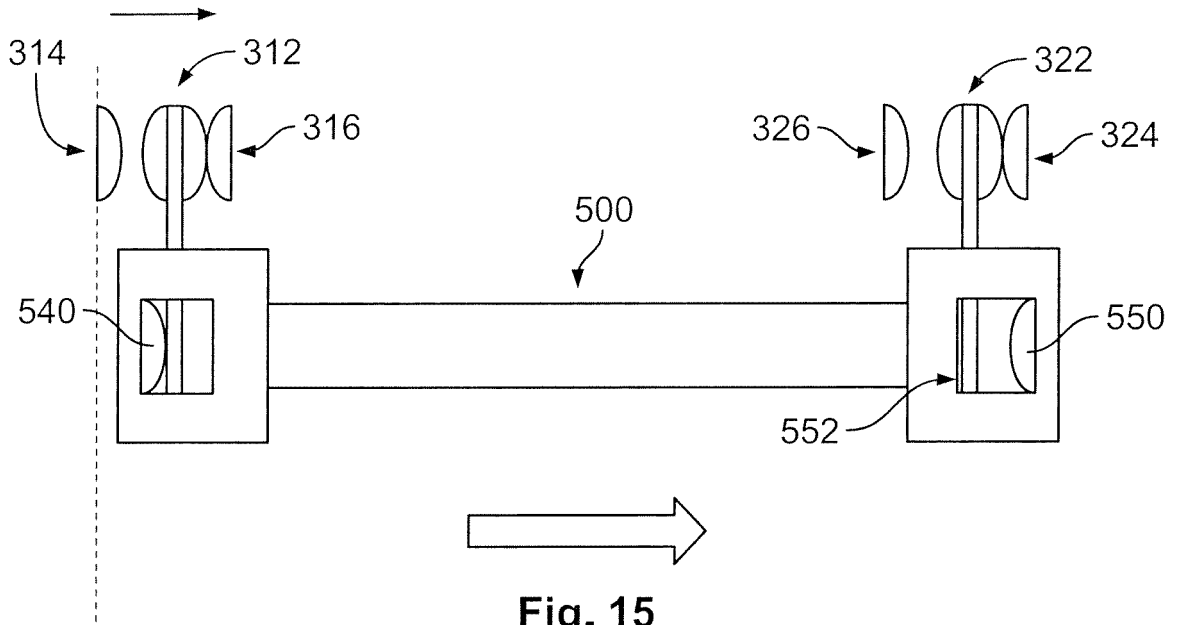


Fig. 14



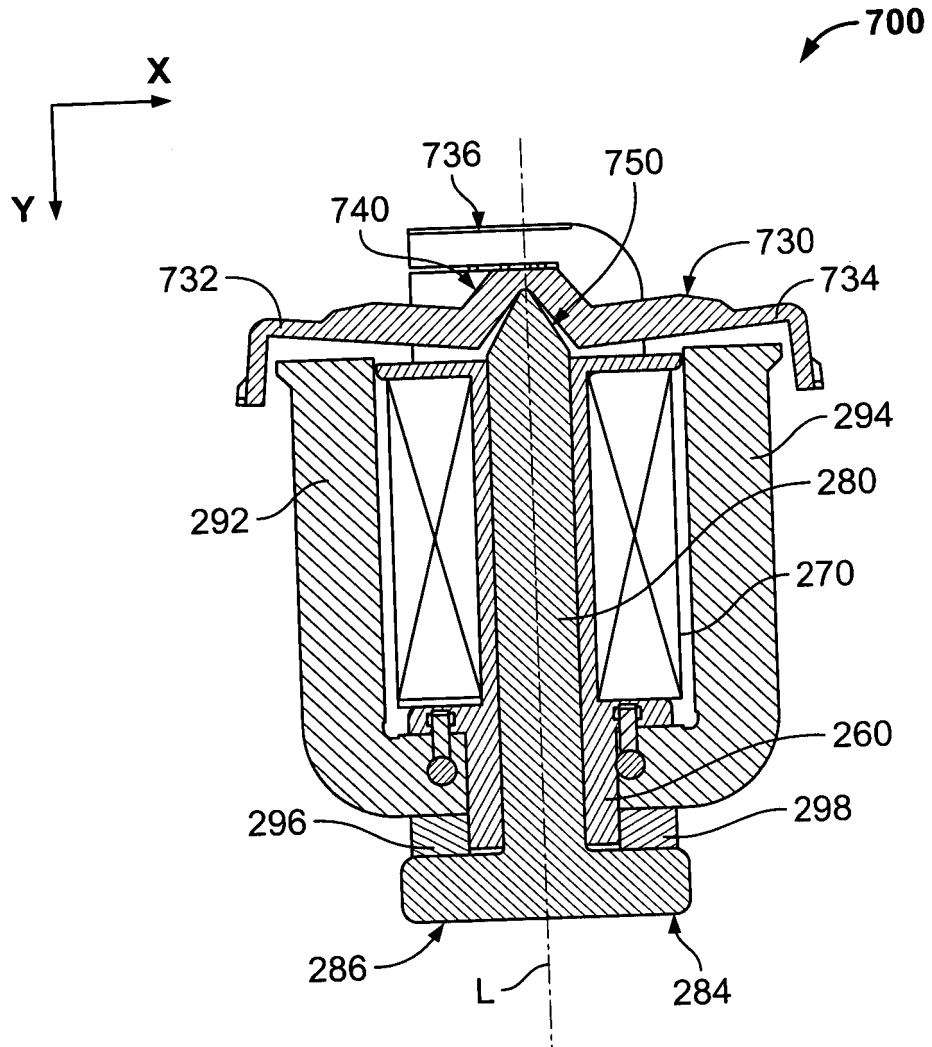


FIG. 18

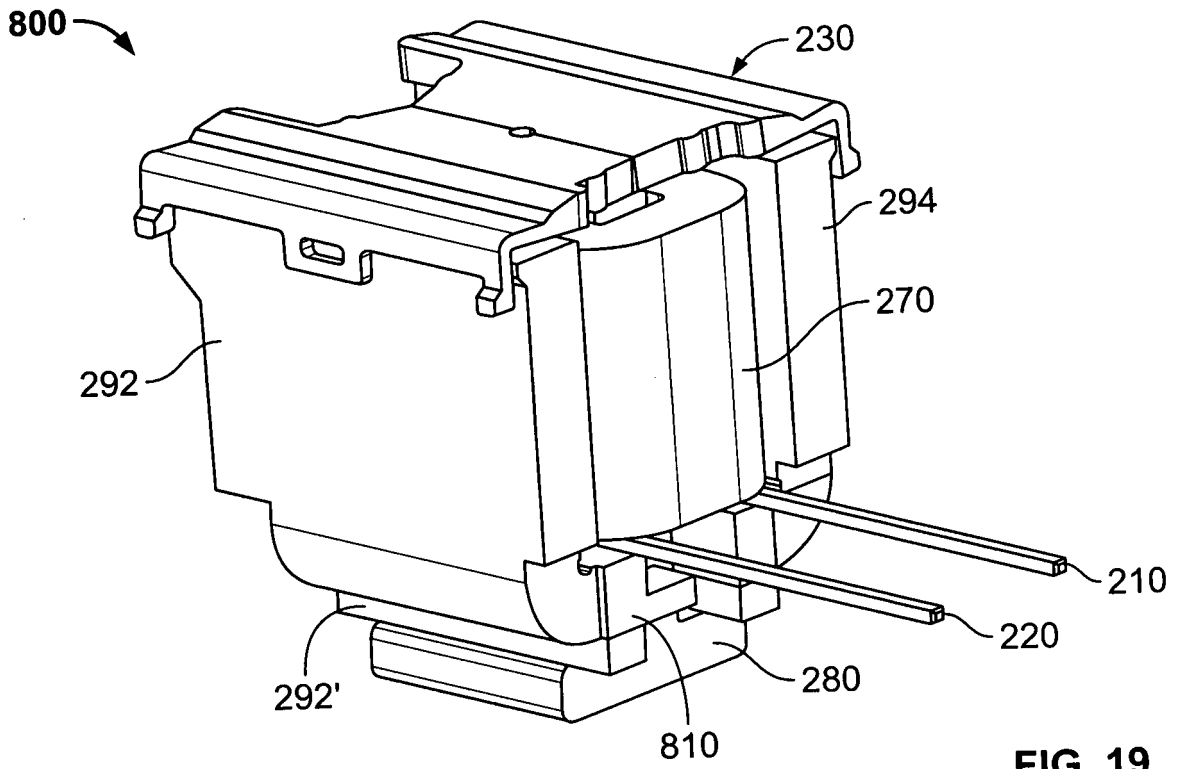


FIG. 19

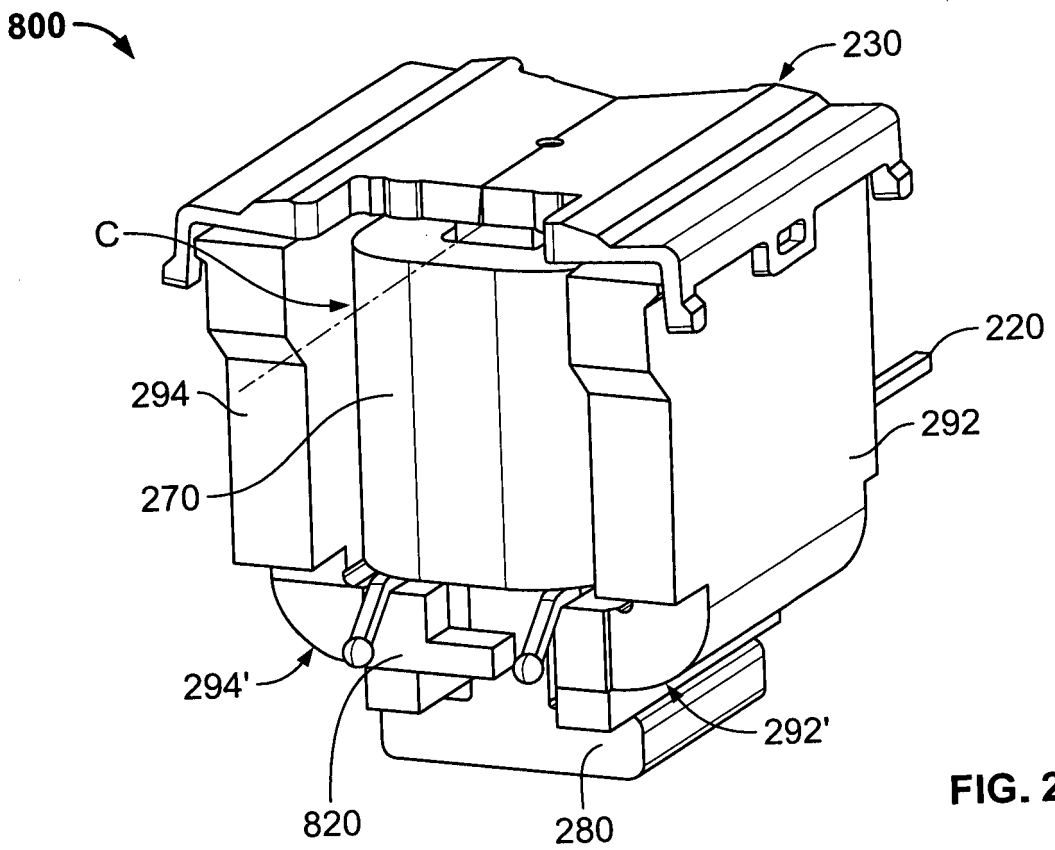


FIG. 20

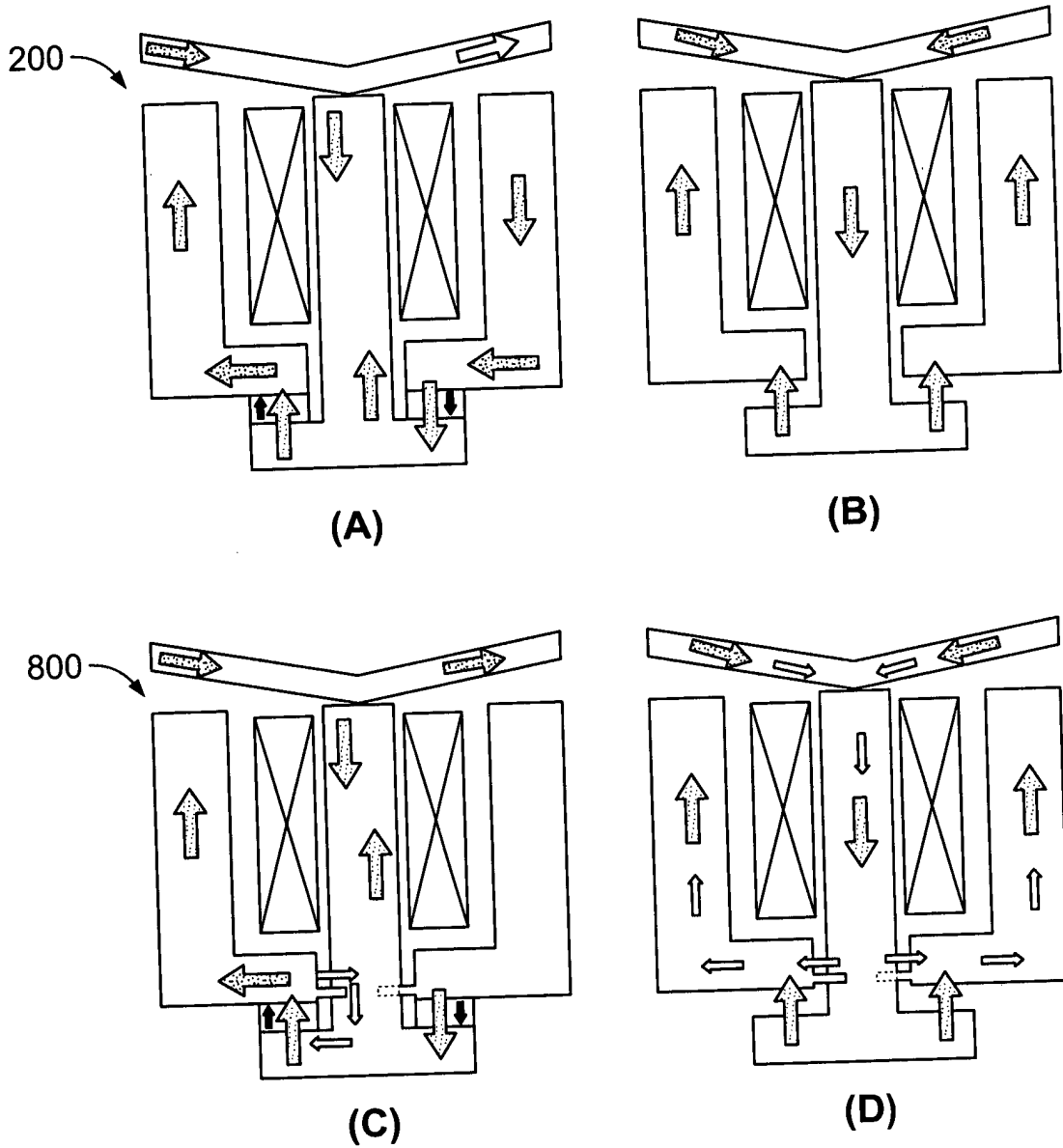


FIG. 21

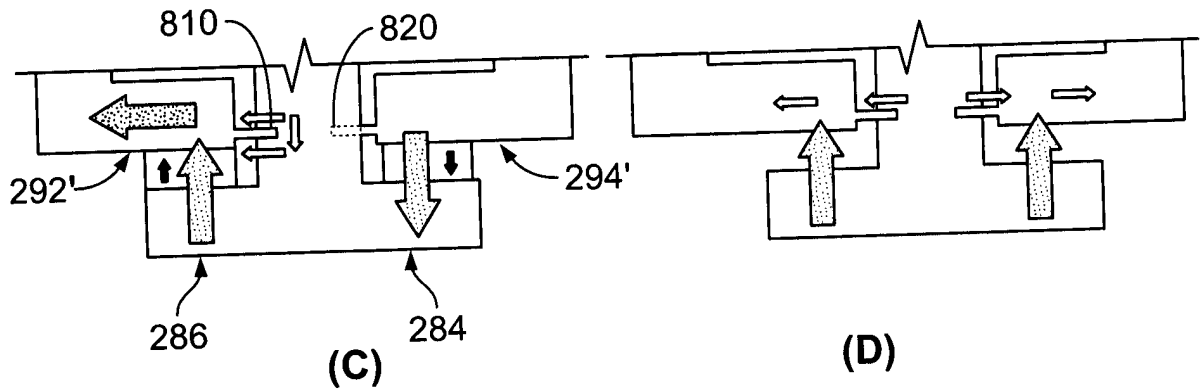


FIG. 22



EUROPEAN SEARCH REPORT

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