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(54) **Title:** HIGH-VOLTAGE FAULT BREAK CONTACTOR WITH A PERMANENT DISCONNECT FEATURE

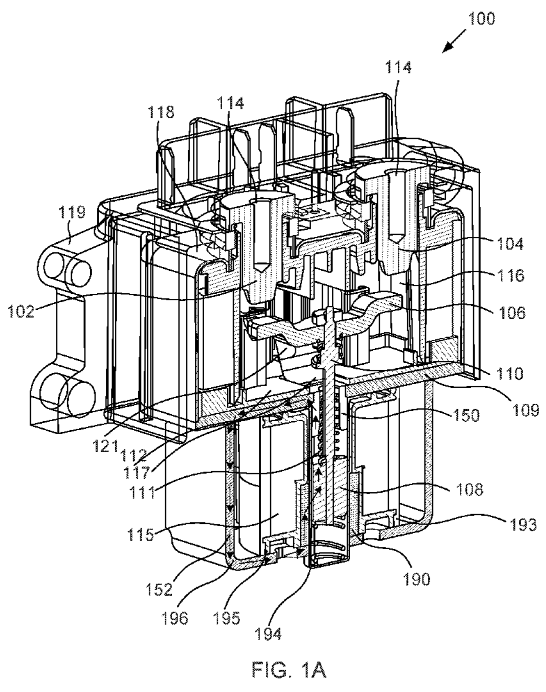

FIG. 1A

(57) **Abstract:** Contactors, apparatuses, assemblies, and devices with a permanent disconnect feature and methods of operating a contactor with a permanent disconnect feature are disclosed. In a particular embodiment, a contactor assembly with a permanent disconnect feature is disclosed that includes a moveable contact configured to engage and disengage stationary contacts. The contactor assembly also includes an actuator assembly for driving the moveable contact and a two-stage restrike prevention mechanism configured to prevent restrike at a first current level and provide permanent disconnect at a second current level.

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HIGH-VOLTAGE FAULT BREAK CONTACTOR WITH A PERMANENT DISCONNECT FEATURE

BACKGROUND

[0001] Electromechanical switching devices, such as contactors and relays, are designed to carry a certain amount of electrical current for certain periods of time. Such devices are particularly important in electric vehicles. Typically, electric vehicles include one or more high voltage batteries connected, via a direct current (DC) contactor, to a vehicle power distribution system for powering an electric motor. The DC contactor is typically an electromechanical switch that opens or closes high current paths between the battery packs and the vehicle power distribution system.

[0002] As electrical power levels continue to increase across industries, manufacturers struggle to design systems that safely handle accidents and emergencies resulting in high current short-circuits. This difficulty often results from an inability to find switching devices designed to withstand and/or interrupt high levels of fault current/voltages (i.e. short-circuits). Further, desirable solutions should reduce system complexity, system weight, and cost.

SUMMARY

[0003] Embodiments in accordance with the present disclosure are directed to a high-voltage fault break contactor with a permanent disconnect feature that achieves high-power interrupt performance with self-triggering capability and rapid arc suppression by utilizing levitation force and a two stage restrike prevention mechanism. In a particular example, the fault breaking contactor device is a single-pole-single-throw, normally-open contactor operating at maximum of at least 1,000 volts (V) and designed to continuously carry at least 750A without active cooling. The fault breaking contactor can interrupt high currents at high voltages without the need for an external short circuit protection system or triggering device. This contactor includes an integrated two-stage electrode latching mechanism for permanent disconnect after short circuit event, preventing the switch from re-striking after opening.

[0004] Contactors, assemblies, apparatuses, and devices with a permanent disconnect feature and methods of operating a contactor with a permanent disconnect feature are disclosed. In a particular embodiment, a contactor assembly with a permanent disconnect feature is disclosed that includes a moveable contact configured to engage and disengage stationary contacts. The contactor assembly also includes an actuator assembly for driving the moveable contact and a two-stage restrike prevention mechanism configured to prevent restrike at a first current level and provide permanent disconnect at a second current level.

[0005] In another embodiment, a method of operating a high-voltage fault break contactor with a permanent disconnect feature is disclosed that includes actuating a moveable contact to disengage the moveable contact from stationary contacts. The method also includes in response to a first hold force induced by a current of the contactor exceeding a first current threshold, preventing restrike using a first retention mechanism. In addition, the method also includes in response to a second hold force induced by the current exceeding a second current threshold, engaging a second retention mechanism to provide permanent disconnect of the moveable contact from the stationary contacts, the second current threshold greater than the first current threshold.

[0006] These and other features, aspects, and advantages of the present disclosure will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. 1A shows a cross section of an example contactor for a high-voltage fault break contactor with a permanent disconnect feature in accordance with at least one embodiment of the present disclosure.

[0008] FIG. 1B shows an exploded view of the contactor shown in FIG. 1A.

[0009] FIG. 2A shows a detailed view of a stationary contact assembly of the contactor shown in FIGS. 1A and 1B in accordance with at least one embodiment of the present disclosure.

[0010] FIG. 2B shows a detailed view of an example enclosure assembly of the contactor shown in FIGS. 1A and 1B in accordance with at least one embodiment of the present disclosure.

[0011] FIG. 2C shows a detailed view of an example arc chamber assembly of the contactor shown in FIGS. 1A and 1B in accordance with at least one embodiment of the present disclosure.

[0012] FIG. 2D shows a detailed view of an example moveable contact assembly of the contactor shown in FIGS. 1A and 1B in accordance with at least one embodiment of the present disclosure.

[0013] FIG. 2E shows a detailed view of an example contact retention assembly of the contactor shown in FIGS. 1A and 1B in accordance with at least one embodiment of the present disclosure.

[0014] FIG. 3A shows a default open position of the contactor shown in FIGS. 1A and 1B in accordance with at least one embodiment of the present disclosure.

[0015] FIG. 3B shows a closing operation of the contactor shown in FIGS. 1A and 1B in accordance with at least one embodiment of the present disclosure.

[0016] FIG. 3C shows a closed position of the contactor shown in FIGS. 1A and 1B in accordance with at least one embodiment of the present disclosure.

[0017] FIG. 3D shows a faulted open position of the contactor shown in FIGS. 1A and 1B in accordance with at least one embodiment of the present disclosure.

[0018] FIG. 4 sets forth a flow chart of an example method of operating a contactor with a permanent disconnect feature in accordance with at least one embodiment of the present disclosure.

[0019] FIG. 5 sets forth a flow chart of another example method of operating a contactor with a permanent disconnect feature in accordance with at least one embodiment of the present disclosure.

[0020] FIG. 6 sets forth a flow chart of another example method of operating a contactor with a permanent disconnect feature in accordance with at least one embodiment of the present disclosure.

DETAILED DESCRIPTION

[0021] The terminology used herein for the purpose of describing particular examples is not intended to be limiting for further examples. Whenever a singular form such as “a”, “an” and “the” is used and using only a single element is neither explicitly or implicitly defined as being mandatory, further examples may also use plural elements to implement the same functionality. Likewise, when a functionality is subsequently described as being implemented using multiple elements, further examples may implement the same functionality using a single element or processing entity. It will be further understood that the terms “comprises”, “comprising”, “includes” and/or “including”, when used, specify the presence of the stated features, integers, steps, operations, processes, acts, elements and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, processes, acts, elements, components and/or any group thereof.

[0022] It will be understood that when an element is referred to as being “connected” or “coupled” to another element, the elements may be directly connected or coupled via one or more intervening elements. If two elements A and B are combined using an “or”, this is to be understood to disclose all possible combinations, i.e. only A, only B, as well as A and B. An alternative wording for the same combinations is “at least one of A and B”. The same applies for combinations of more than two elements.

[0023] Accordingly, while further examples are capable of various modifications and alternative forms, some particular examples thereof are shown in the figures and will subsequently be described in detail. However, this detailed description does not limit further examples to the particular forms described. Further examples may cover all modifications, equivalents, and alternatives falling within the scope of the disclosure. Like numbers refer to like or similar elements throughout the description of the figures, which may be implemented identically or in modified form when compared to one another while providing for the same or a similar functionality.

[0024] Embodiments in accordance with the present disclosure provide a high-voltage fault break contactor with a permanent disconnect feature that incorporates that self-triggering capability and rapid arc suppression by utilizing levitation force and a two-stage restrike prevention mechanism. In a particular example, the fault breaking contactor is a single-pole-single-throw, normally-open contactor operating at maximum of at least 1,000 volts (V) and designed to continuously carry at least 750A without active cooling. The fault breaking contactor can interrupt high currents at high voltages without the need for an external short circuit protection system or triggering device. This contactor includes integrated two-stage electrode latching for permanent disconnect after short circuit event, preventing the switch to re-strike after opening.

[0025] For further explanation, FIG. 1A and FIG. 1B set forth an example high-voltage fault break contactor with a permanent disconnect mechanism, hereinafter contactor 100, in accordance with at least one embodiment of the present disclosure. FIG. 1A is a sectional view and FIG. 1B is an exploded view.

[0026] The contactor 100 includes a lower coil yoke 196 that surround a coil assembly 193 that includes a plunger tube 194 and a coil enclosure 195. A lower static core 190 is positioned between the plunger tube 194 and the coil enclosure 195. The coil enclosure 195 surrounds a coil (e.g., solenoid) 115 and the plunger tube 194 surrounds a moveable assembly having a plunger 108 coupled to a plunger shaft 110. The contactor 100 also includes an upper coil yoke 109 that is coupled to an upper flux tube 150 and a plunger spring 111 that is coupled between the upper coil yoke 109 and the plunger 108. In addition, the contactor 100 includes stationary (fixed) contacts 102, 104 and a moveable contact 106. The moveable contact 106 is configured to create or break the connection between the stationary contacts 102, 104 in response to movement of the moveable assembly. The stationary contacts 102, 104 are coupled to external connections 114 for coupling with external components, such as a power supply and an electrical application.

[0027] In the open state, the moveable contact 106 is not in contact with the stationary contacts 102, 104, such that no current flows between the stationary contacts 102, 104. In this open state, the plunger spring 111 is configured to apply a pre-load force on the plunger 108 to prevent the moveable assembly from moving to a closed state. In the closed state, the moveable contact 106 is in contact with the stationary contacts 102, 104 such that current flows between the stationary contacts 102, 104 through the moveable contact 106.

[0028] A controller (not shown in FIGs. 1A and 1B) may be coupled to the contactor 100 and configured to control a current flowing to the coil 115 of the contactor 100. The coil 115 consists of windings of conductive material such as copper or aluminum. When the coil 115 is connected to a power source and current flows through the windings, a strong magnetic field is generated that flows through the magnetic circuit pathways of the contactor. This electromagnetic field is guided by the coil yoke and static core(s) which are made of ferromagnetic materials such as low-carbon steel. This path that the magnetic field travels on is known as the magnetic circuit 152, illustrated in FIG. 1A by arrows. The magnetic field is guided to the plunger 108, which resides within the enclosed plunger tube 194, and magnetizes it. The magnetized plunger 108 is then attracted by a magnetic force to the upper flux tube 150. The magnetic field forces the plunger 108 with upper direction. When enough magnetic force is generated, the plunger 108 will overcome any retaining spring forces (pre-load force from the plunger spring 111) and begin to move. The plunger 108 and the plunger shaft 110 drive the moveable contact 106 toward the fixed contacts 102, 104 until the moveable contact 106 is in a closed position in which contact is established between the moveable contact 106 and the stationary contacts 102, 104, thus transitioning the contactor 100 from the open state to the closed state. When the moveable contact 106 touches the stationary contacts 102, 104, the high-voltage circuit is closed. When the plunger 108 contacts the upper flux tube 150, the magnetic circuit 152 is closed.

[0029] When the coil 115 is disconnected from the low-voltage power source, the ferromagnetic components lose their magnetization and the magnetic force on the plunger 108 decreases. This decrease in magnetic field separates the plunger 108 from the upper flux tube 150, opening the magnetic circuit 152. The plunger spring 111 returns the plunger 108 to its original position. That is, when the coil 115 is de-energized, the plunger 108 is driven downward from the force of the energy stored in the compressed plunger spring 111 and the contact spring 112, and the moveable assembly pulls the moveable contact 106 downward until the moveable contact 106 is in an open position, thus breaking the high voltage circuit between the moveable contact 106 and the stationary contacts 102, 104.

[0030] An arc chamber 116 and an arc shield 117 are disposed within the enclosure 118. The arc shield 117 includes the contact retention spring 121 to prevent restrike during a circuit break event. The contactor 100 may be disposed in a plastic casing 119. Aspects of the contactor 100 are described in greater detail with reference to FIGS. 2A to 2E.

[0031] For further explanation, FIG. 2A sets forth a front view of an example stationary contact assembly including the stationary contacts 102, 104 of FIGS. 1A and 1B. The stationary contacts 102, 104 are with optimized contact geometry for high-power break. In this example, the stationary contacts 102, 104 include fusing tips 201. Fusing tips are specialized components of the electrical contacts designed to melt under high-current conditions, creating a safety mechanism during fault events. Made of low-melting-point materials, the fusion tips handle normal current flow efficiently but rapidly heat and vaporize during surges. This melting increases the contact gap, reducing the risk of electrical arcing and ensuring galvanic isolation to interrupt current flow. By protecting the main contact assembly and enabling fast fault isolation, fusing tips enhance system safety, reliability, and cost efficiency.

[0032] For further explanation, FIG. 2B sets forth a front view of an example enclosure assembly including the enclosure 118 and stationary contacts 102, 104 of FIGS. 1A and 1B. The metal enclosure 118 includes eyelets 119 (e.g., ceramic eyelets) surrounding the stationary contacts 102, 104 and optional auxiliary terminals. Ceramic eyelets provide electrical insulation for the stationary contacts while allowing them to pass through the metal enclosure, ensuring safe and efficient operation. In a particular embodiment, their material properties, such as high thermal resistance and mechanical strength, enable them to withstand the intense heat and stress generated during high-power arcing. These eyelets contribute to the hermetic seal of the enclosure, preventing leaks and protecting internal components from external contaminants so the contactor can withstand extended high-power arcing without rupture.

[0033] FIG. 2C sets forth an overhead view of an arc chamber assembly that includes the arc chamber 116 and arc shield 117 of FIGS. 1A and 1B fitted together. In some examples, the arc chamber 116 is a plastic arc chamber with shadowing effected by an internal labyrinth geometry. Shadowing in the context of an arc chamber refers to a design strategy that uses obstructive geometries, such as internal labyrinth paths, to control and limit the movement of electrical arcs. These features "shadow" certain areas, preventing direct arc propagation and forcing arcs to follow longer, more complex paths. This reduces the intensity and likelihood of arcing across critical components, improving insulation and enhancing the overall safety and performance of the system. The arc chamber provides for longer terminal-to-terminal pitch and extended magnet size. In electrical systems, pitch refers to the physical distance between two terminals or conductive elements, often measured center-to-center. A longer pitch reduces the likelihood of electrical arcing or breakdown by increasing the insulation distance between high-voltage components. This design feature is critical for enhancing safety and reliability in high-power and high-voltage applications. The longer pitch, compared to a conventional implementation, enhances high voltage insulation strength.

[0034] FIG. 2D sets forth a front view of an example moveable contact assembly including the moveable contact 106 of FIGs. 1A and 1B. In some examples, the moveable contact 106 has a shrug geometry, or offset height geometry, as depicted. The shrug geometry allows for aggressive shadowing by creating baffles across contact points. In this context, shrug geometry refers to a specific design feature where the moveable contact has an offset or non-linear shape, creating physical barriers or baffles at the contact points. These baffles disrupt the direct path of electrical arcs, enhancing the shadowing effect within the contact assembly. By forcing arcs to follow a more complex route, shrug geometry improves arc containment and reduces the risk of electrical breakdown. This design is particularly effective in high-power applications, where controlling arc behavior is essential for safety and performance. The moveable contact assembly also includes a longer plunger shaft 110 compared to a conventional implementation, that increases the maximum travel gap/contact gap of the assembly to compensate for high voltage interrupt. A longer plunger shaft increases the travel gap, which is the maximum distance the moveable contact 106 can separate from the stationary contacts 102, 104 during operation. This extended gap provides a greater physical barrier, making it harder for electrical arcs to bridge the contacts 102, 104, 106, especially during high-voltage interruptions. By suppressing arcs more effectively, it enhances the reliability and safety of the contactor in high-power applications. The increased travel gap also allows the assembly to handle higher voltages without risking insulation breakdown or unintended current flow. This design is particularly advantageous in systems requiring rapid fault isolation, as it ensures complete disconnection even under extreme electrical conditions. Additionally, the longer shaft improves overall performance and durability, accommodating the stresses of high-energy operations with minimal wear.

[0035] FIG. 2E sets forth a perspective view of the arc shield of FIGS. 1A and 1B including a two-stage catch/retention mechanism designed to provide operational flexibility and enhanced safety during different fault conditions. This mechanism adapts to varying current levels to optimize performance. In the first stage, active during lower current fault events, the retention spring 121 catches the moveable contact 106 after interruption, preventing restrike, which is the reformation of an electrical arc between the stationary contacts. This ensures the system remains temporarily open and isolated, stopping unintended current flow while allowing the contactor to be reset once the fault is cleared. This reset-ability is particularly valuable for non-critical faults, enabling the system to resume normal operation quickly without requiring component replacement or extended downtime.

[0036] In the second stage, when the system experiences a severe fault with current surges exceeding a threshold (e.g., 8kA), plastic latches 203 are engaged to lock the moveable contact 106 into a position that enforces a permanent disconnect. This prevents any possibility of restriking, ensuring the system remains fully isolated until it can be inspected and repaired. The use of plastic latches provides precise activation under high-current stress while maintaining a cost-effective and durable design. Together, these two stages ensure dual-mode functionality, combining reset-ability for minor faults with robust safety measures for extreme conditions. This intelligent design enhances system reliability, minimizes downtime, and protects both the equipment and operators during high-power operations.

[0037] For further explanation, FIGS. 3A-3D illustrate various states of the contactor, showcasing its operational phases and unique design features that enhance performance and safety in high-power systems. In FIG. 3A, the contactor is depicted in its default normally open position, with the moveable contact 106 separated from the stationary contacts 102, 104. Notably, the nominal gap between the moveable and stationary contacts is larger than that of conventional designs, reducing the risk of unintended electrical arcs and improving insulation strength. This increased default gap ensures a higher baseline level of safety and readiness for high-voltage conditions.

[0038] In FIG. 3B, the contactor is shown in the process of closing, where the moveable contact 106 makes its initial impact with the stationary contacts 102, 104. This phase represents the transition to a closed circuit, enabling current flow. Following this, as depicted in FIG. 3C, the plunger shaft 110 executes an over-travel motion, pressing the moveable contact more firmly against the stationary contacts. This over-travel action ensures secure electrical contact, minimizes resistance, and reduces the likelihood of contact bounce, which could otherwise lead to arcing or signal interruptions.

[0039] The design’s safety mechanisms are highlighted in FIG. 3D, which illustrates the contactor’s response to a high-current event, such as a surge exceeding 8kA. In such scenarios, levitation forces, induced by electromagnetic effects of the high current, drive the moveable contact 106 away from the stationary contacts 102, 104. To ensure safety, the plastic latches 203 engage the moveable contact, locking it in place to provide a permanent disconnect and isolating the circuit from further current flow. This action prevents restrike and protects the system from damage. Additionally, the travel gap at this stage is twice the nominal gap, further enhancing the isolation. The process is complemented by the melting of fusing tips, which increases the contact gap even more, expediting arc extinguishment and improving the overall robustness of the system under extreme conditions.

[0040] This sequence of states demonstrates the contactor's sophisticated design, which balances operational efficiency with advanced safety measures. From an enlarged default gap to over-travel for secure closure and advanced mechanisms for fault isolation, the contactor is engineered to handle demanding high-power applications with reliability and precision.

[0041] For further explanation, FIG. 4 sets forth a flow chart of an example method of operating a contactor with a permanent disconnect feature in accordance with the present disclosure. The method of FIG. 4 includes closing 402 a contactor, the contactor including one or more stationary contacts, a moveable contact, and a two-stage contact retention mechanism. For example, the contactor may be the same as or similar to the contactor shown in FIGS. 1A and 1B. Closing the contactor may be carried out by energizing the coil of the contactor as shown in FIGS. 3B and 3C.

[0042] The method of FIG. 4 also includes engaging 404, by a first retention mechanism, the moveable contact in response to a first hold force induced by a current exceeding a first current threshold. In some examples, engaging 404 the moveable contact in response to a first hold force induced by a current exceeding a first current threshold is carried out by the retention spring 121 engaging the moveable contact 106, as described above.

[0043] The method of FIG. 4 also includes engaging 406, by a second retention mechanism, the moveable contact in response to a second hold force induced by the current exceeding a second current threshold. In some examples, engaging 406 the moveable contact in response to the current exceeding a second current threshold is carried out by the contact latches 203 engaging the moveable contact 106, as described above.

[0044] For further explanation, FIG. 5 sets forth a flow chart of another example method of operating a contactor with a permanent disconnect feature in accordance with the present disclosure. The method of FIG. 5 includes actuating 502 a moveable contact to disengage the moveable contact from stationary contacts. For example, the contactor may be the same as or similar to the contactor shown in FIGS. 1A and 1B. Actuating 502 is carried out by a controller removing the electrical current supplied to a solenoid. This de-energization causes the solenoid's plunger to retract, which in turn disengages the moveable contact from the stationary contacts. The removal of current interrupts the magnetic field, allowing mechanical or spring-loaded forces to complete the disengagement process.

[0045] The method of FIG. 5 also includes in response to a first hold force induced by a current of the contactor exceeding a first current threshold, preventing 504 restrike using a first retention mechanism. In response to a first hold force induced by a current of the contactor exceeding a first current threshold, preventing restrike using a first retention mechanism may be carried out by leveraging a retention spring (e.g., retention spring 121) within the arc shield assembly. During a lower-current fault event, this retention spring engages to hold the moveable contact 106 after it is pulled away from the fixed contacts 102 and 104, thereby ensuring the circuit remains open and isolated without the risk of arc reformation. This mechanism temporarily isolates the system and allows for a reset once the fault is cleared, providing an efficient and safe way to prevent restrike during minor fault conditions.

[0046] In addition, the method of FIG. 5 includes in response to a second hold force induced by the current exceeding a second current threshold, engaging 506 a second retention mechanism to provide permanent disconnect of the moveable contact from the stationary contacts, the second current threshold greater than the first current threshold. In response to a second hold force induced by the current exceeding a second current threshold, engaging 506 a second retention mechanism to provide a permanent disconnect may be carried out by activating plastic latches 203 designed for high-current fault scenarios. When the current surpasses this higher threshold, the latches engage to lock the moveable contact 106 in a fully disconnected position, ensuring no possibility of reconnection or restrike. This mechanism enforces complete isolation until inspection and repair, providing a robust safety response to extreme electrical conditions while protecting the system and its components.

[0047] For further explanation, FIG. 6 sets forth a flow chart of another example method of operating a contactor with a permanent disconnect feature in accordance with the present disclosure. The method of FIG. 6 expands upon the method of FIG. 5 by including melting 602 fusing tips on the stationary contacts to increase a contact gap between the stationary contacts and the moveable contact. Melting 602 fusing tips on the stationary contacts to increase the contact gap may be carried out by designing the tips with low-melting-point materials that respond to high current surges. When the current exceeds a critical threshold, the intense heat generated by the surge causes the fusing tips to rapidly melt and vaporize. This melting action effectively increases the physical separation between the stationary contacts and the moveable contact, reducing the likelihood of electrical arcing or restrike. By incorporating this fail-safe mechanism, the fusing tips ensure enhanced system safety and isolation during severe fault events, protecting both the contactor and the connected equipment.

[0048] In view of the foregoing, embodiments disclose a high-voltage fault break contactor, with permanent disconnect mechanism, that accomplishes a stringent break requirement that is order of magnitude above traditional level. No external trigger is necessary for a short circuit interruption. Thus, embodiments reduce the complexity and cost of battery protection module.

[0049] In view of the foregoing, a high-voltage fault break contactor with a permanent disconnect mechanism provides a number of advantages including:

- High current interruption without the need for an external short circuit protection system;
- High current interruption without pyrotechnics;
- Shrug geometry of the moveable contact substantially improves post-break insulation resistance.
- Hermetically sealed metal enclosure allows for very high maximum internal pressure;
- Fusing tips accelerate galvanic isolation as electrode melts away.
- Two-stage latching mechanism allows for reset-ability at low current, while preventing restrike with permanent disconnect at an extreme current level

[0050] The flowchart and diagrams in the Figures illustrate the architecture, functionality, and operation of implementations of apparatus and methods according to various embodiments of the present disclosure. In some alternative implementations, the functions noted in the blocks or step in the method may occur out of the order noted in the figures. For example, two blocks shown in succession may, in fact, be performed substantially concurrently, or the blocks may sometimes be performed in the reverse order, depending on the functionality involved.

[0051] Advantages and features of the present disclosure can be further described by the following statements:

[0052] 1. A contactor assembly with a permanent disconnect feature, the contactor assembly comprising: a moveable contact configured to engage and disengage stationary contacts; an actuator assembly for driving the moveable contact; and a two-stage restrike prevention mechanism configured to prevent restrike at a first current level and provide permanent disconnect at a second current level.

[0053] 2. The contactor assembly of statement 1, wherein the two-stage retention mechanism includes a first retention mechanism and a second retention mechanism; wherein the first retention mechanism engages the moveable contact above a first current threshold and the second retention mechanism engages the moveable contact above a second current threshold; and wherein the second current threshold is greater than the first current threshold.

[0054] 3. The contactor assembly of statements 1 or 2, wherein the first retention mechanism comprises one or more retention springs.

[0055] 4. The contactor assembly of any of statements 1-3, wherein the one or more retention springs allow the contactor assembly to be reset after low-current fault interruptions without requiring component replacement.

[0056] 5. The contactor assembly of any of statements 1-4, wherein the second retention mechanism comprises one or more permanent latches.

[0057] 6. The contactor assembly of any of statements 1-5, wherein the stationary contacts include fusing tips that melt in a presence of a threshold current.

[0058] 7. The contactor assembly of any of statements 1-6, wherein the fusing tips are made of a material with a lower melting point than a remainder of the stationary contacts to ensure selective melting in the presence of the threshold current.

[0059] 8. The contactor assembly of any of statements 1-7 further comprising a hermetically sealed metal enclosure with ceramic eyelets that insulate the stationary contacts.

[0060] 9. The contactor assembly of any of statements 1-8, wherein the moveable contact has an offset height geometry that creates baffles for arc containment.

[0061] 10. The contactor assembly of any of statements 1-9 further comprising an arc chamber with an internal labyrinth geometry that shadow arc paths.

[0062] 11. The contactor assembly of any of statements 1-10, wherein the two-stage retention mechanism is self-triggering.

[0063] 12. A method of operating a high-voltage fault break contactor with a permanent disconnect feature, the method comprising: actuating a moveable contact to disengage the moveable contact from stationary contacts; in response to a first hold force induced by a current of the contactor exceeding a first current threshold, preventing restrike using a first retention mechanism; and in response to a second hold force induced by the current exceeding a second current threshold, engaging a second retention mechanism to provide permanent disconnect of the moveable contact from the stationary contacts, the second current threshold greater than the first current threshold.

[0064] 13. The method of statement 12 further comprising melting fusing tips on the stationary contacts to increase a contact gap between the stationary contacts and the moveable contact.

[0065] 14. The method of statements 12 or 13, wherein the fusing tips are made of a material with a lower melting point than a remainder of the stationary contacts to ensure selective melting in a presence of a threshold current.

[0066] 15. The method of any of statements 12-14, wherein the moveable contact has an offset height geometry that creates baffles for arc containment.

[0067] 16. The method of any of statements 12-15, wherein the first retention mechanism comprises one or more retention springs.

[0068] 17. The method of any of statements 12-16, wherein the one or more retention springs allow the contactor to be reset after low-current fault interruptions without requiring component replacement.

[0069] 18. The method of any of statements 12-17, wherein the second retention mechanism comprises one or more permanent latches.

[0070] 19. The method of any of statements 12-18, wherein the contactor further includes a hermetically sealed metal enclosure with ceramic eyelets that insulate the stationary contacts.

[0071] 20. The method of any of statements 12-19 wherein the contactor further includes an arc chamber with an internal labyrinth geometry that shadow arc paths.

[0072] One or more embodiments may be described herein with the aid of method steps illustrating the performance of specified functions and relationships thereof. The boundaries and sequence of these functional building blocks and method steps have been arbitrarily defined herein for convenience of description. Alternate boundaries and sequences can be defined so long as the specified functions and relationships are appropriately performed. Any such alternate boundaries or sequences are thus within the scope and spirit of the claims. Further, the boundaries of these functional building blocks have been arbitrarily defined for convenience of description. Alternate boundaries could be defined as long as the certain significant functions are appropriately performed. Similarly, flow diagram blocks may also have been arbitrarily defined herein to illustrate certain significant functionality.

[0073] To the extent used, the flow diagram block boundaries and sequence could have been defined otherwise and still perform the certain significant functionality. Such alternate definitions of both functional building blocks and flow diagram blocks and sequences are thus within the scope and spirit of the claims.

[0074] It will be understood from the foregoing description that modifications and changes may be made in various embodiments of the present disclosure without departing from its true spirit. The descriptions in this specification are for purposes of illustration only and are not to be construed in a limiting sense. The scope of the present disclosure is limited only by the language of the following claims.

CLAIMS

What is claimed is:

1. A contactor assembly with a permanent disconnect feature, the contactor assembly comprising:
a moveable contact configured to engage and disengage stationary contacts;
an actuator assembly for driving the moveable contact; and
a two-stage restrike prevention mechanism configured to prevent restrike at a first current level and provide permanent disconnect at a second current level.
2. The contactor assembly of claim 1, wherein the two-stage restrike prevention mechanism includes a first retention mechanism and a second retention mechanism; wherein the first retention mechanism engages the moveable contact above a first current threshold and the second retention mechanism engages the moveable contact above a second current threshold; and wherein the second current threshold is greater than the first current threshold.
3. The contactor assembly of claim 2, wherein the first retention mechanism comprises one or more retention springs.
4. The contactor assembly of claim 3, wherein the one or more retention springs allow the contactor assembly to be reset after low-current fault interruptions without requiring component replacement.
5. The contactor assembly of claim 2, wherein the second retention mechanism comprises one or more permanent latches.
6. The contactor assembly of claim 1, wherein the stationary contacts include fusing tips that melt in a presence of a threshold current.
7. The contactor assembly of claim 6, wherein the fusing tips are made of a material with a lower melting point than a remainder of the stationary contacts to ensure selective melting in the presence of the threshold current.
8. The contactor assembly of claim 1 further comprising a hermetically sealed metal enclosure with ceramic eyelets that insulate the stationary contacts.
9. The contactor assembly of claim 1, wherein the moveable contact has an offset height geometry that creates baffles for arc containment.
10. The contactor assembly of claim 1 further comprising an arc chamber with an internal labyrinth geometry that shadow arc paths.
11. The contactor assembly of claim 1, wherein the two-stage restrike prevention mechanism is self-triggering.

12. A method of operating a high-voltage fault break contactor with a permanent disconnect feature, the method comprising:
actuating a moveable contact to disengage the moveable contact from stationary contacts;
in response to a first hold force induced by a current of the contactor exceeding a first current threshold, preventing restrike using a first retention mechanism; and
in response to a second hold force induced by the current exceeding a second current threshold, engaging a second retention mechanism to provide permanent disconnect of the moveable contact from the stationary contacts, the second current threshold greater than the first current threshold.

13. The method of claim 12 further comprising melting fusing tips on the stationary contacts to increase a contact gap between the stationary contacts and the moveable contact.

14. The method of claim 13, wherein the fusing tips are made of a material with a lower melting point than a remainder of the stationary contacts to ensure selective melting in a presence of a threshold current.

15. The method of claim 12, wherein the moveable contact has an offset height geometry that creates baffles for arc containment.

16. The method of claim 12, wherein the first retention mechanism comprises one or more retention springs.

17. The method of claim 16, wherein the one or more retention springs allow the contactor to be reset after low-current fault interruptions without requiring component replacement.

18. The method of claim 12, wherein the second retention mechanism comprises one or more permanent latches.

19. The method of claim 12, wherein the contactor further includes a hermetically sealed metal enclosure with ceramic eyelets that insulate the stationary contacts.

20. The method of claim 12 wherein the contactor further includes an arc chamber with an internal labyrinth geometry that shadow arc paths.

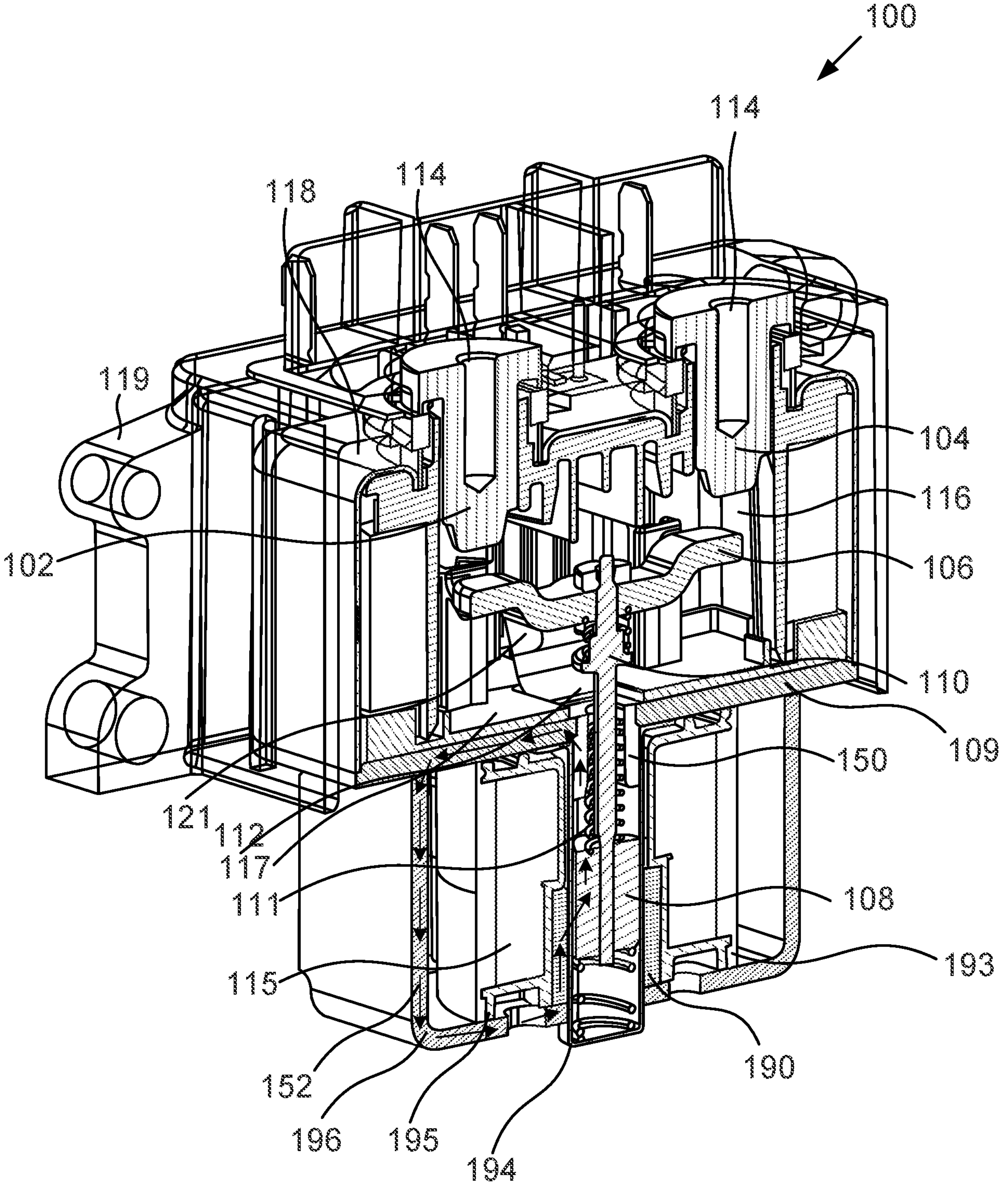
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FIG. 1A

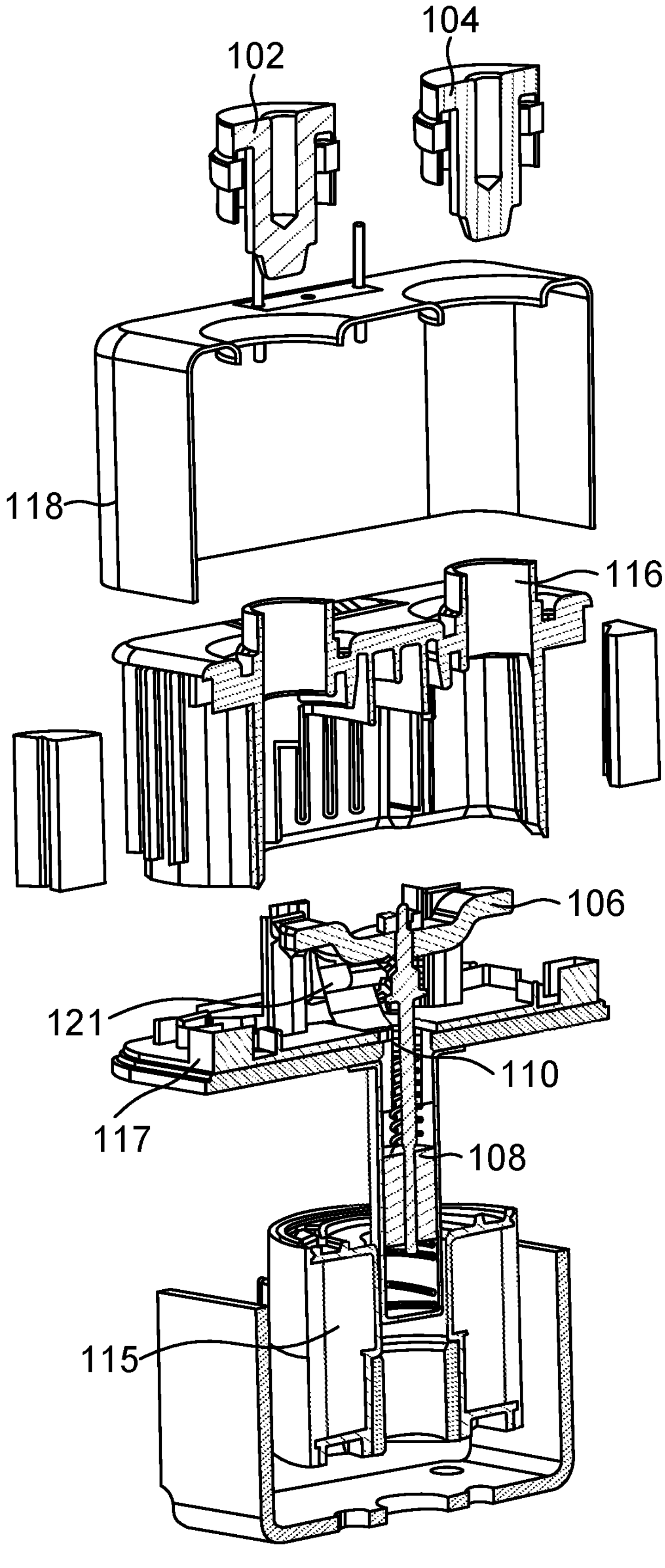


FIG. 1B

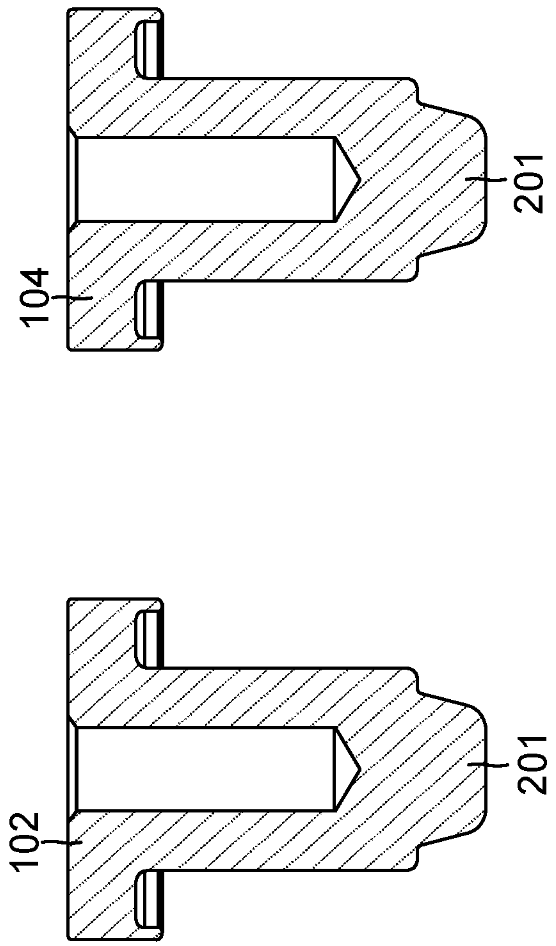


FIG. 2A

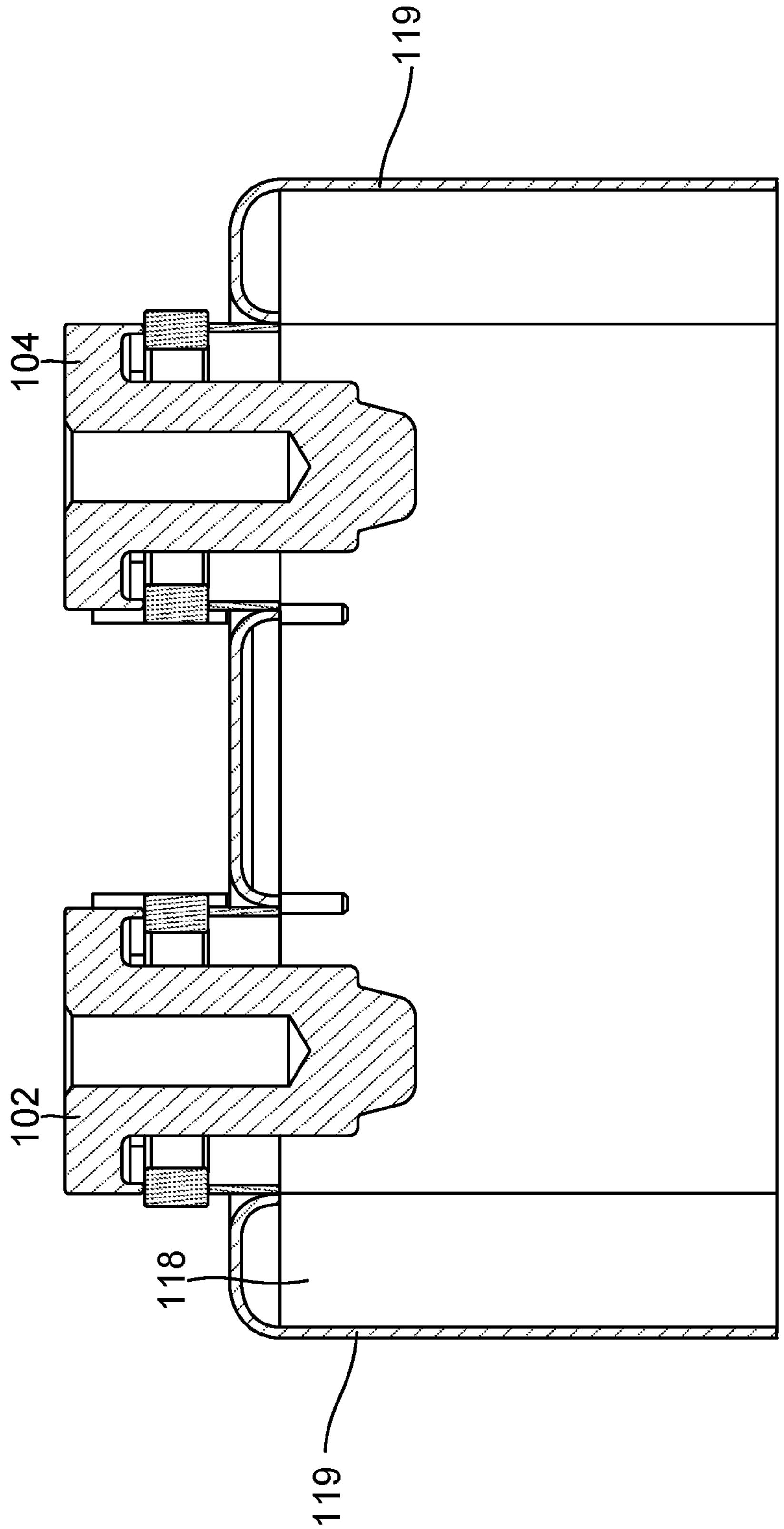


FIG. 2B

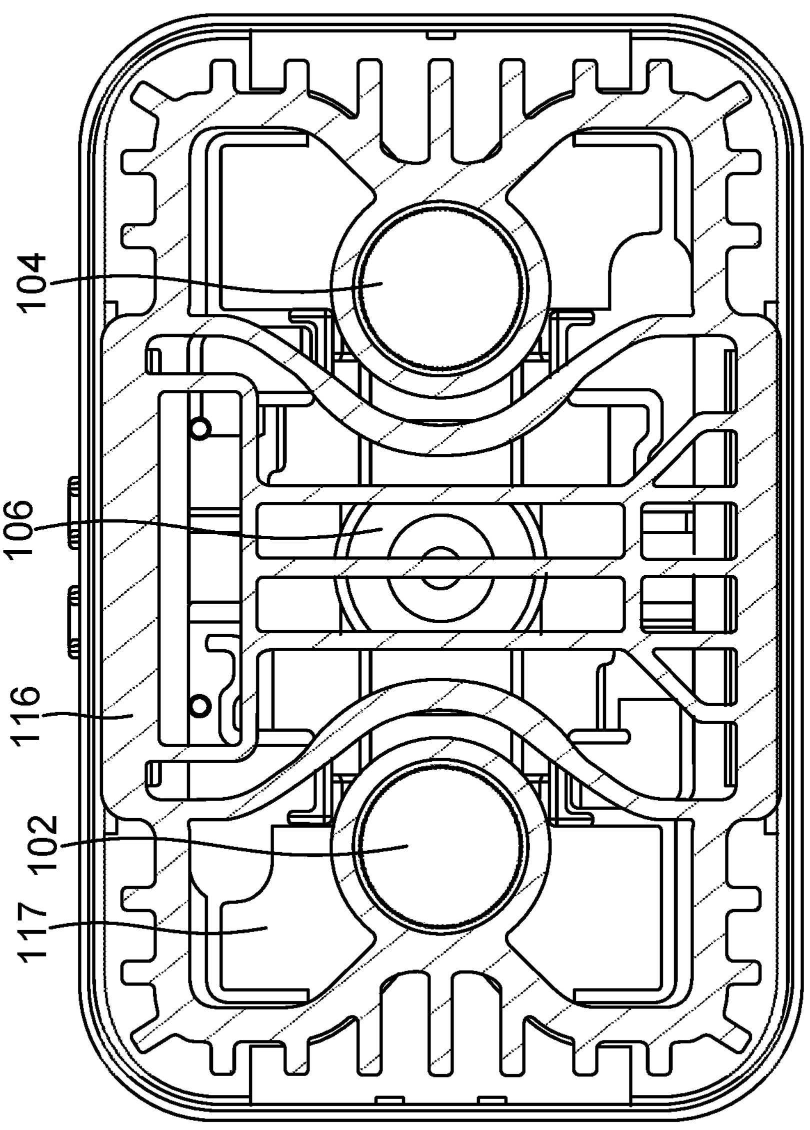


FIG. 2C

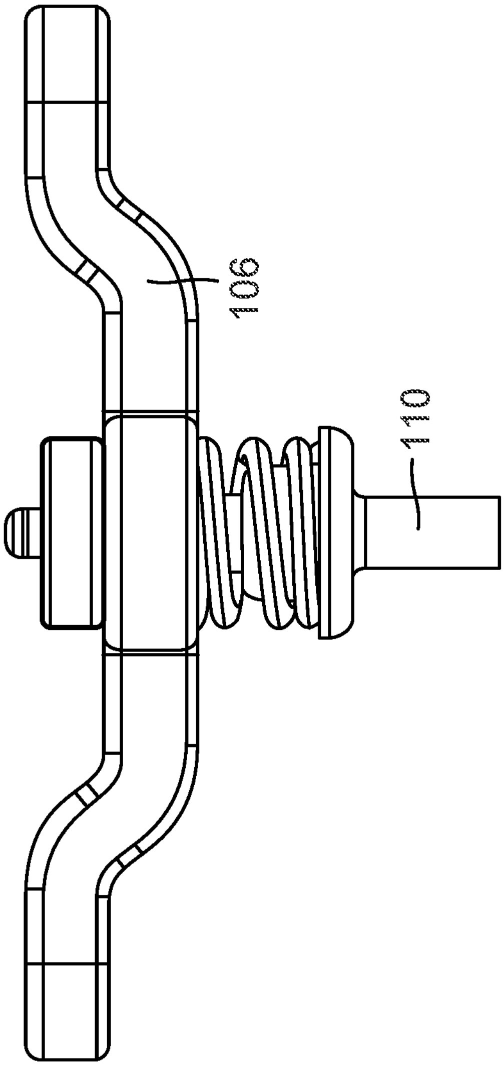


FIG. 2D

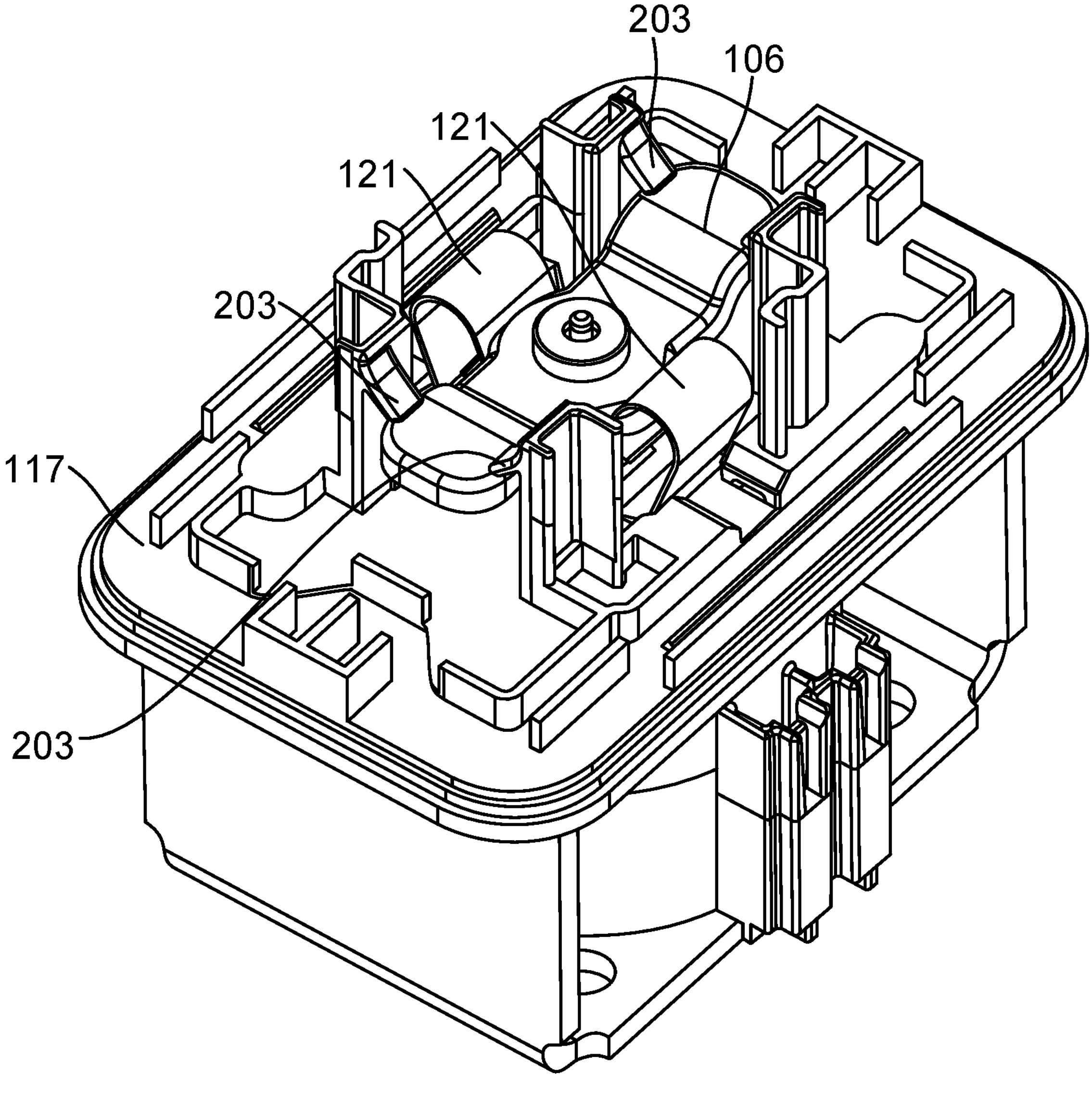


FIG. 2E

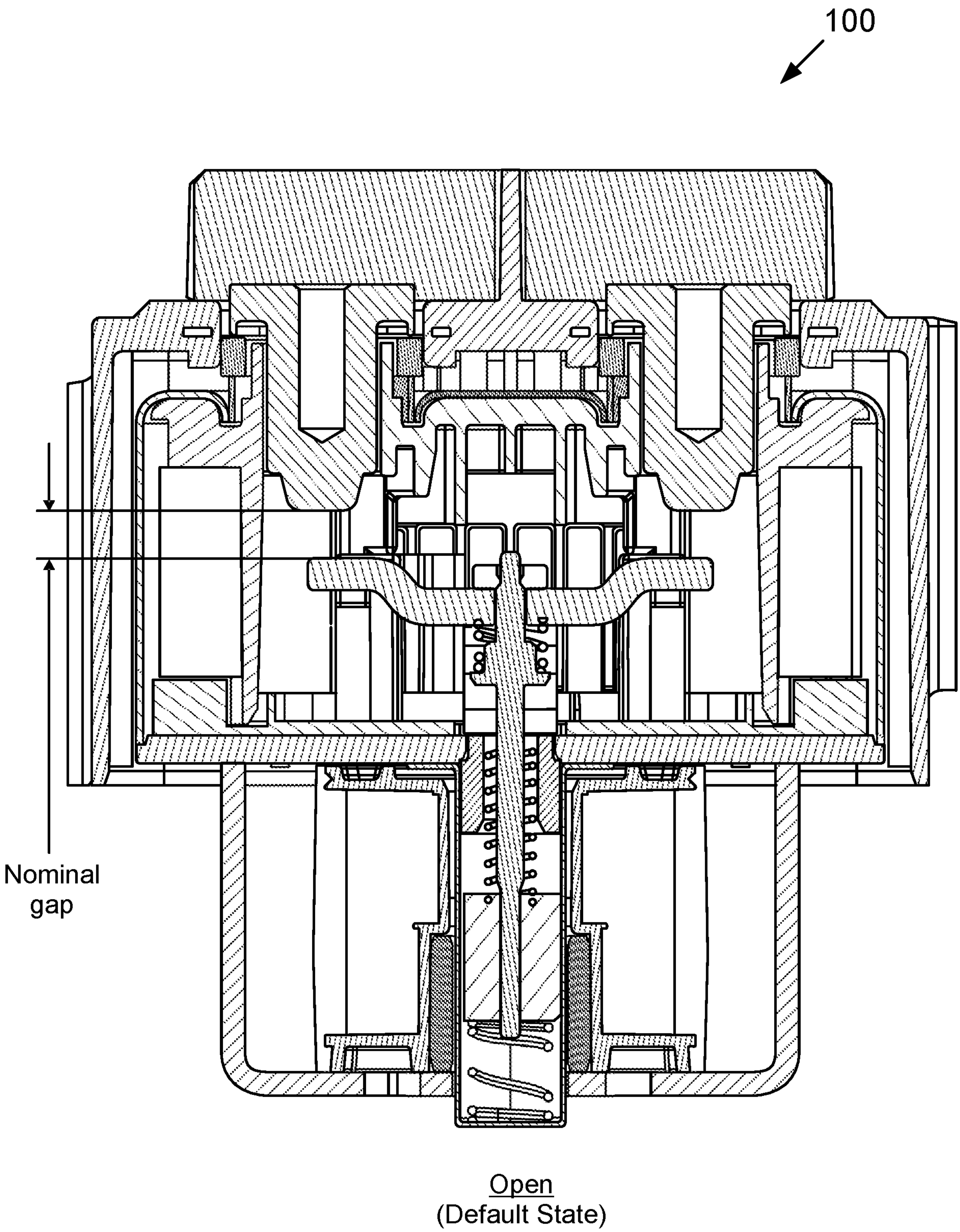
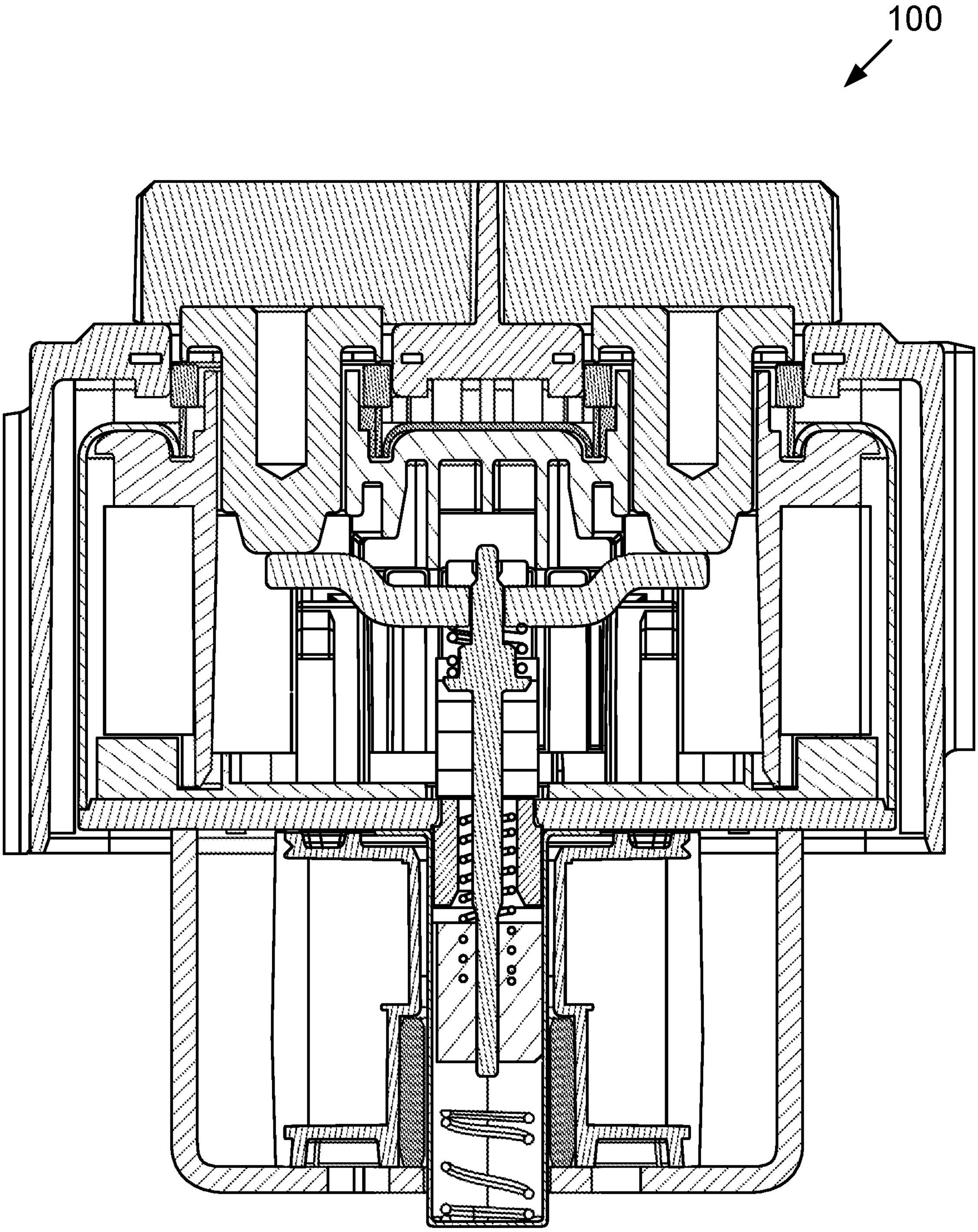
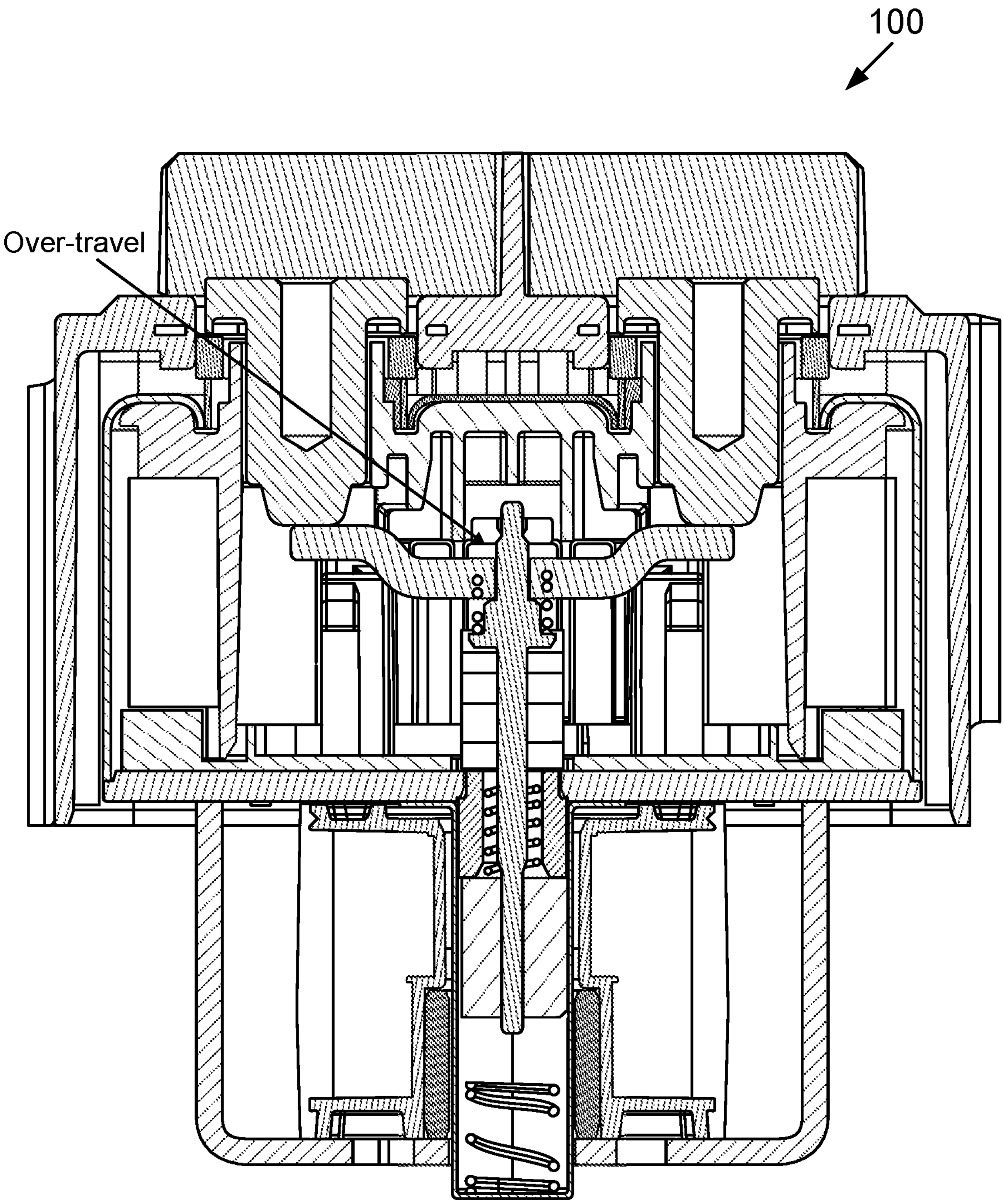


FIG. 3A



Closing
(Initial impact)

FIG. 3B



Switch Closed

FIG. 3C

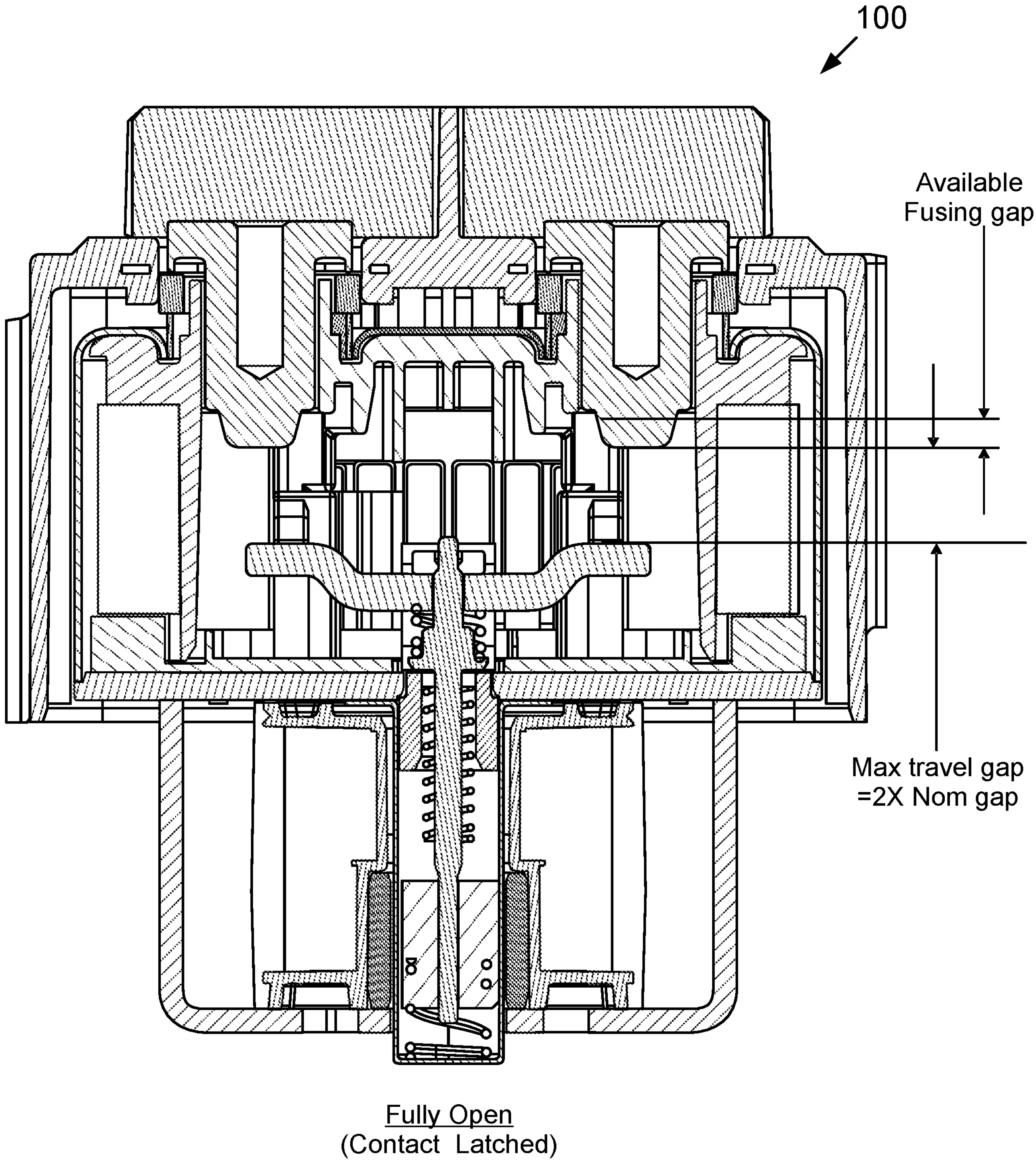

100
Available
Fusing gap
Max travel gap
=2X Nom gap
Fully Open
(Contact Latched)

FIG. 3D

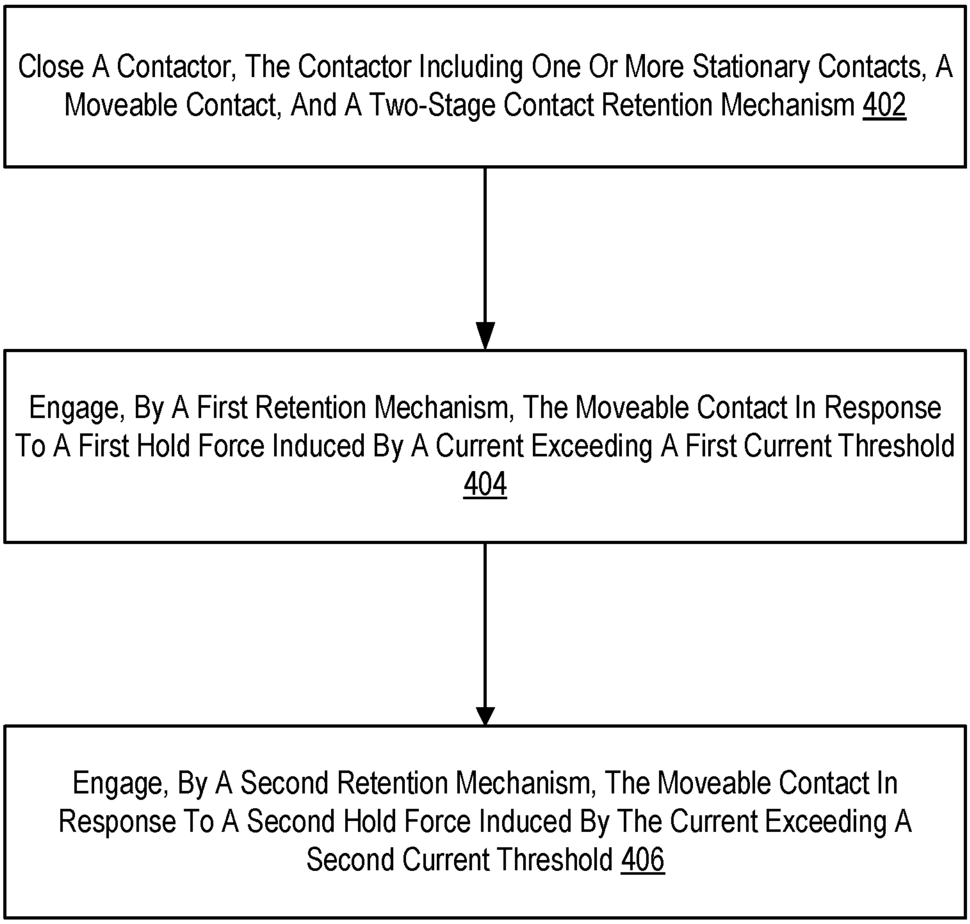

Close A Contactor, The Contactor Including One Or More Stationary Contacts, A Moveable Contact, And A Two-Stage Contact Retention Mechanism 402
Engage, By A First Retention Mechanism, The Moveable Contact In Response To A First Hold Force Induced By A Current Exceeding A First Current Threshold 404
Engage, By A Second Retention Mechanism, The Moveable Contact In Response To A Second Hold Force Induced By The Current Exceeding A Second Current Threshold 406

FIG. 4

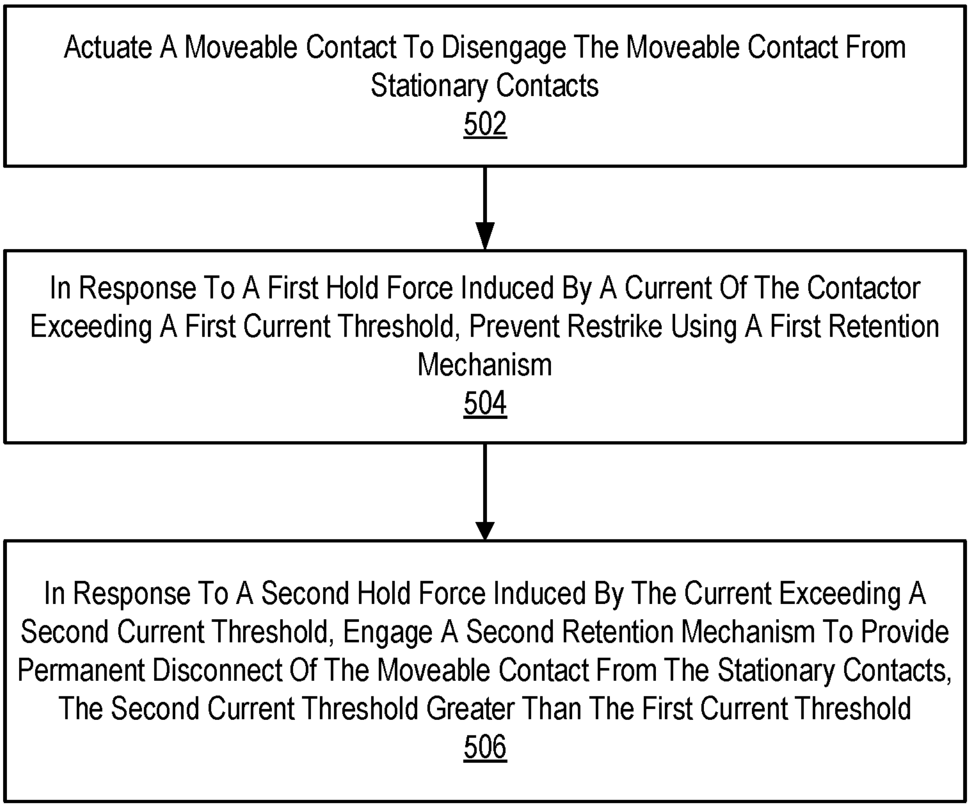

Actuate A Moveable Contact To Disengage The Moveable Contact From Stationary Contacts
502
In Response To A First Hold Force Induced By A Current Of The Contactor Exceeding A First Current Threshold, Prevent Restrike Using A First Retention Mechanism
504
In Response To A Second Hold Force Induced By The Current Exceeding A Second Current Threshold, Engage A Second Retention Mechanism To Provide Permanent Disconnect Of The Moveable Contact From The Stationary Contacts, The Second Current Threshold Greater Than The First Current Threshold
506

FIG. 5

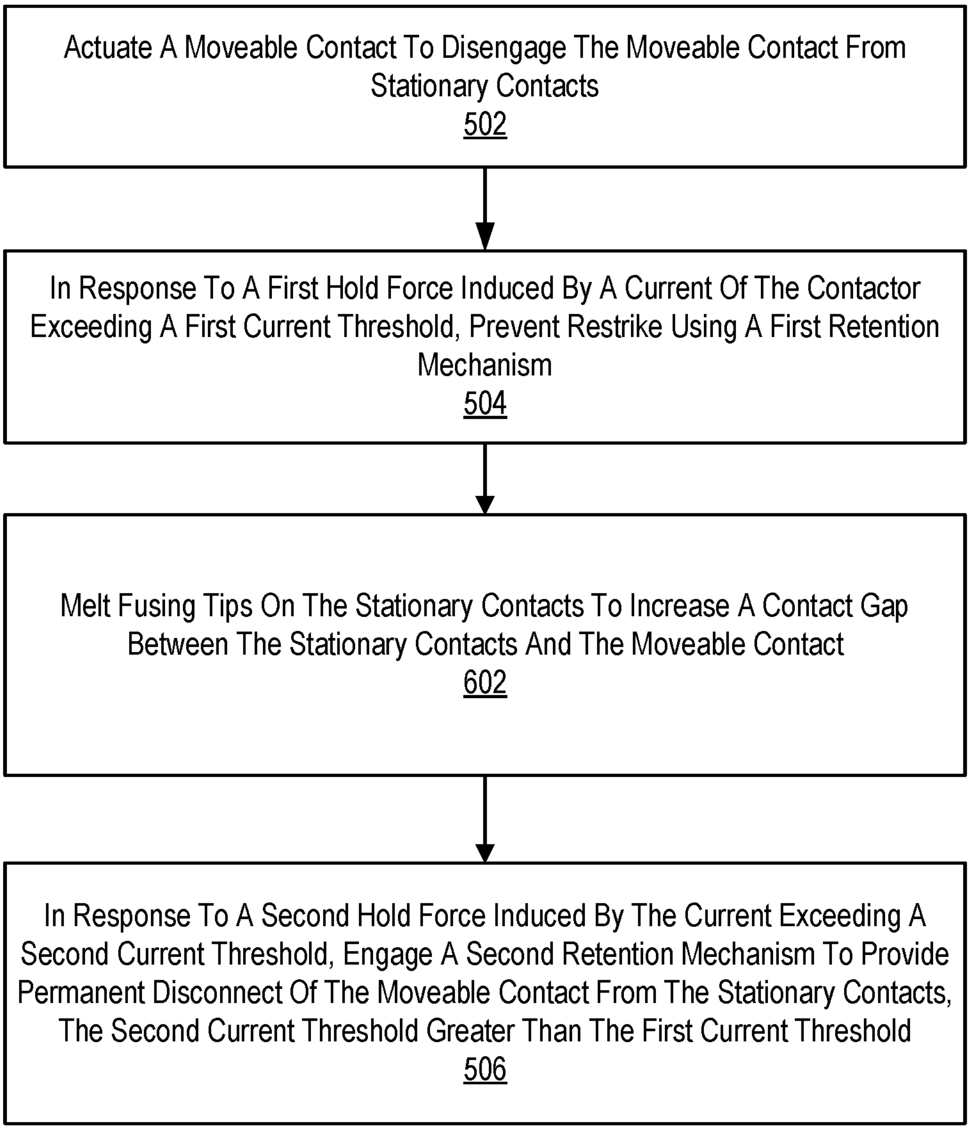

Actuate A Moveable Contact To Disengage The Moveable Contact From Stationary Contacts
502
In Response To A First Hold Force Induced By A Current Of The Contactor Exceeding A First Current Threshold, Prevent Restrike Using A First Retention Mechanism
504
Melt Fusing Tips On The Stationary Contacts To Increase A Contact Gap Between The Stationary Contacts And The Moveable Contact
602
In Response To A Second Hold Force Induced By The Current Exceeding A Second Current Threshold, Engage A Second Retention Mechanism To Provide Permanent Disconnect Of The Moveable Contact From The Stationary Contacts, The Second Current Threshold Greater Than The First Current Threshold
506

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2024/060359

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01H9/10 H01H50/04 H01H50/32
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)
H01H

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2022/020526 A1 (GIGAVAC LLC [US]) 27 January 2022 (2022-01-27) paragraphs [0063], [0067]; figures 3,5 -----	1-20
A	US 11 532 450 B2 (AUDI AG [DE]) 20 December 2022 (2022-12-20) claim 1; figure 1 -----	1

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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

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"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	Date of mailing of the international search report
10 March 2025	27/03/2025

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Simonini, Stefano

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2024/060359

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2022020526 A1	27-01-2022	CN 116601734 A	15-08-2023
		EP 4182567 A1	24-05-2023
		JP 2023535020 A	15-08-2023
		KR 20230051482 A	18-04-2023
		US 2022028639 A1	27-01-2022
		WO 2022020526 A1	27-01-2022
US 11532450 B2	20-12-2022	CN 111354603 A	30-06-2020
		DE 102018222466 A1	25-06-2020
		US 2020203106 A1	25-06-2020