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Griffiths et al.

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(45) **Date of Patent: Sep. 22, 2015**

(54) **LATCHING ACTUATOR**

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(21) Appl. No.: **13/444,754**

(22) Filed: **Apr. 11, 2012**

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Related U.S. Application Data

(60) Provisional application No. 61/474,173, filed on Apr. 11, 2011.

(51) **Int. Cl.**
F15B 21/06 (2006.01)
F15B 21/02 (2006.01)
F15B 15/26 (2006.01)

(52) **U.S. Cl.**
CPC ***F15B 15/261*** (2013.01); *F15B 21/06* (2013.01)

(58) **Field of Classification Search**
CPC F15B 21/261; F15B 21/26; F15B 21/06
USPC 60/527; 137/62; 222/390
See application file for complete search history.

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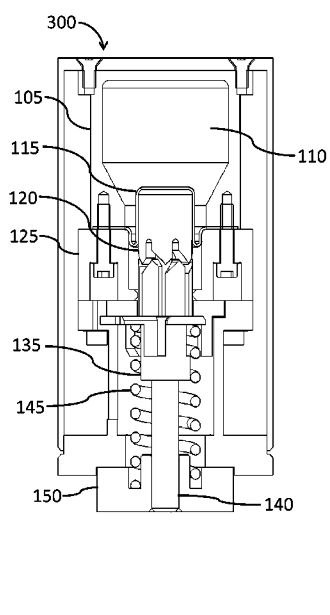
Assistant Examiner — Deming Wan

(57) **ABSTRACT**

A latching actuator capable of repeated operation in a cryogenic, remote, or difficult-to-access environment, capable of enduring many cycles without user intervention or maintenance, capable of latching in a fixed position without consuming additional power, or to operate independent of external environmental conditions. In selected embodiments, a latching actuator may comprise an expansion chamber that houses a working substance capable of undergoing a phase change, a logic mechanism, a biasing assembly, and an output pin. In one embodiment, a wax motor may provide the motive force to toggle a latching mechanism. An actuator may be capable of positioning an output pin in two or more discrete latching positions and may be used to create a thermal connection between two structures, to engage or disengage a clutch, or to position an optical element in an optical instrument. An actuator may also be used as a launch lock apparatus.

18 Claims, 12 Drawing Sheets



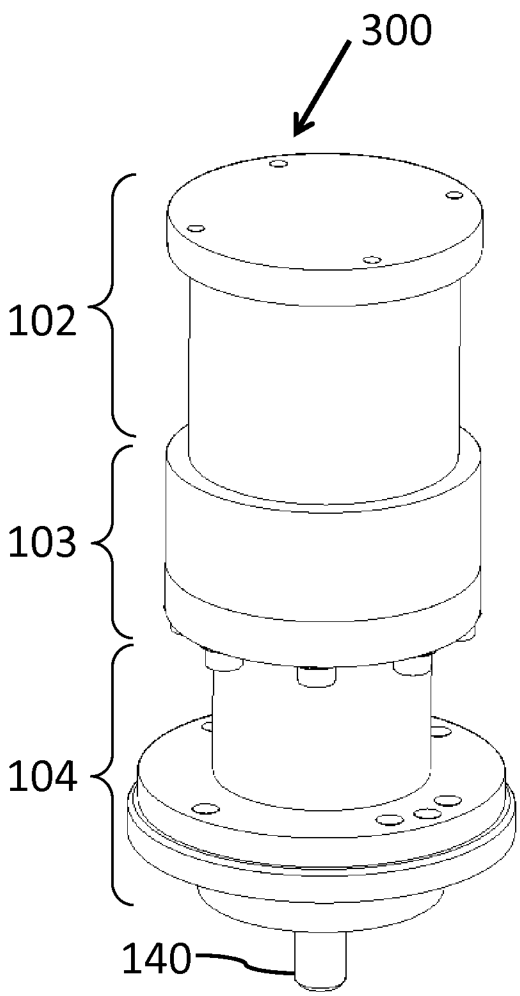


FIG. 1

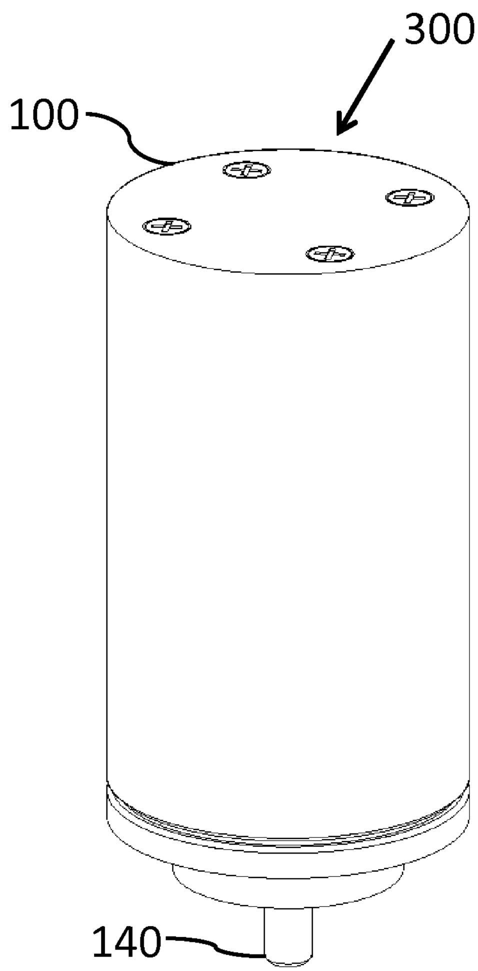


FIG. 2

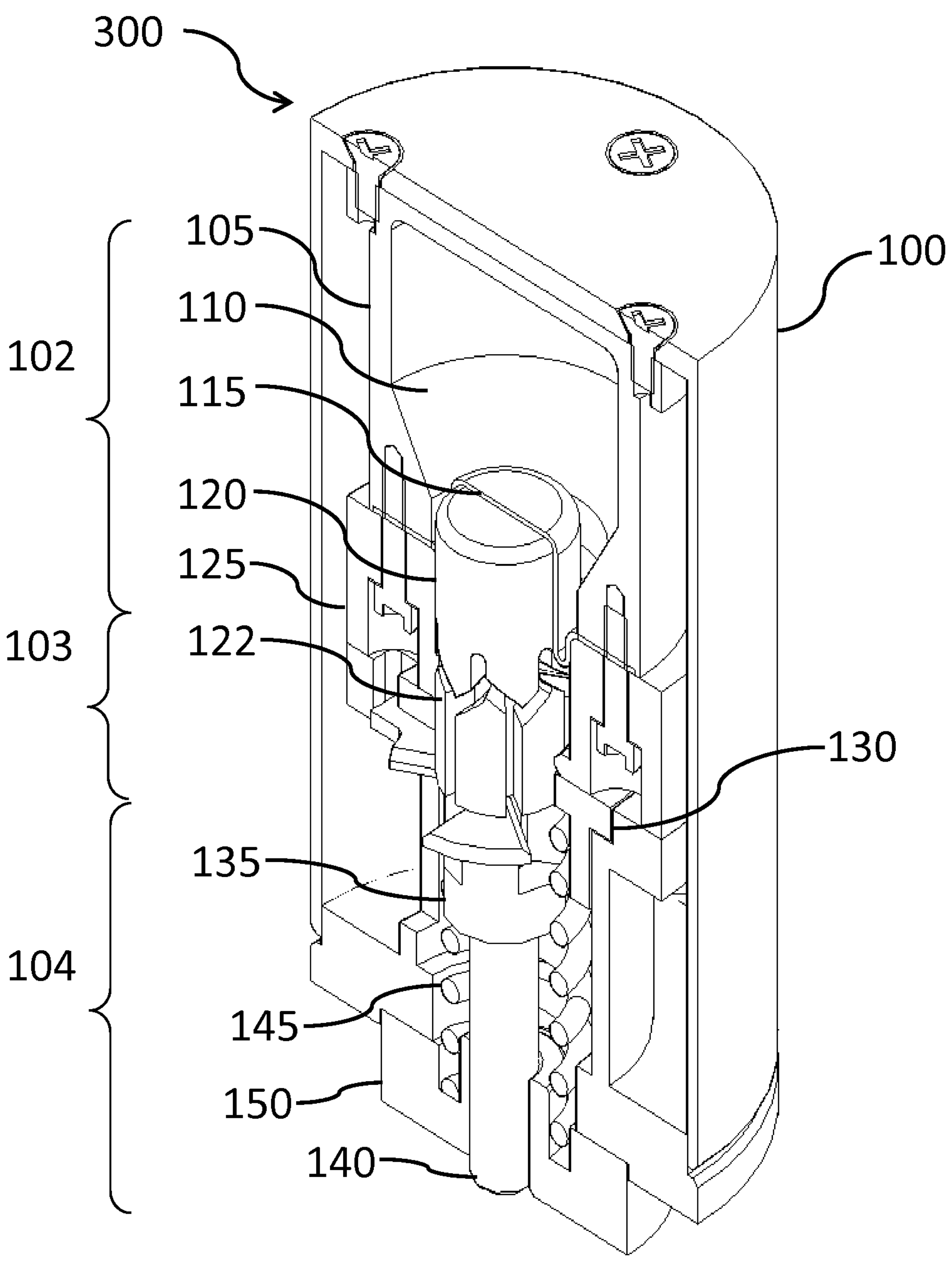


FIG. 3

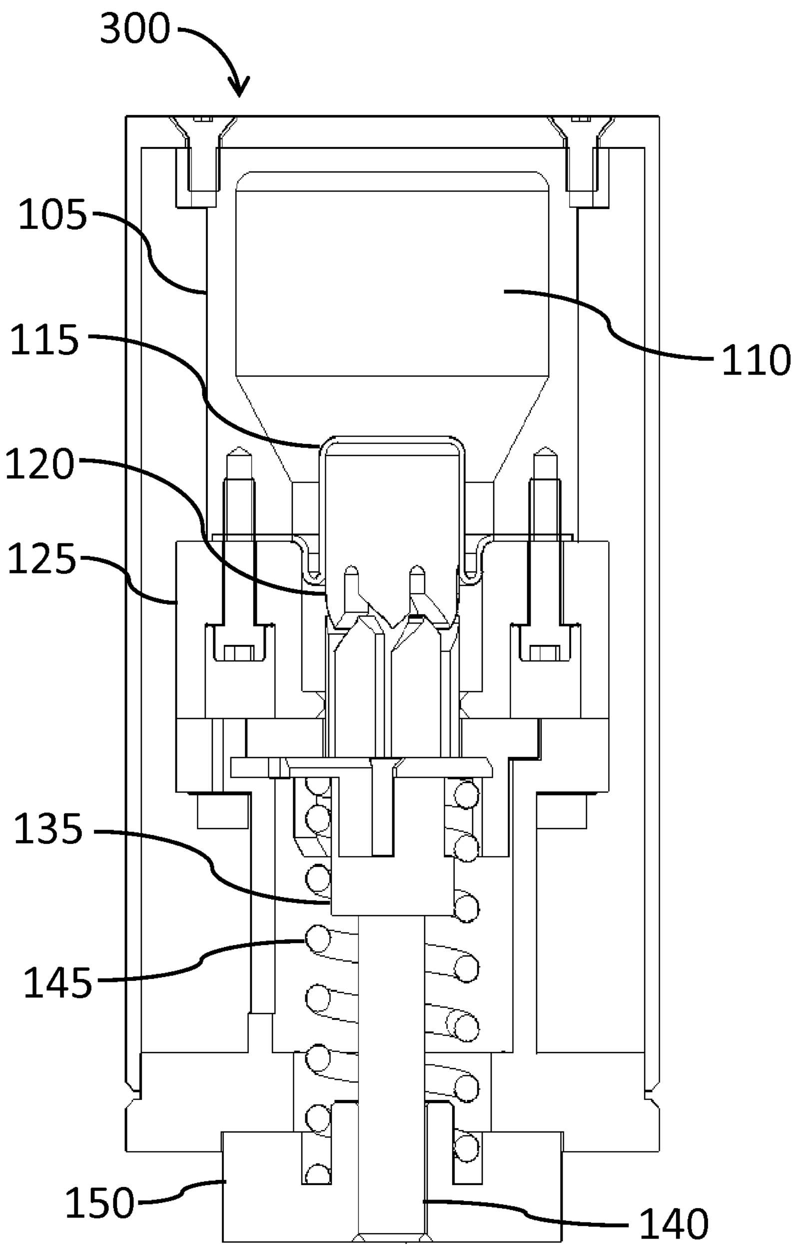


FIG. 4

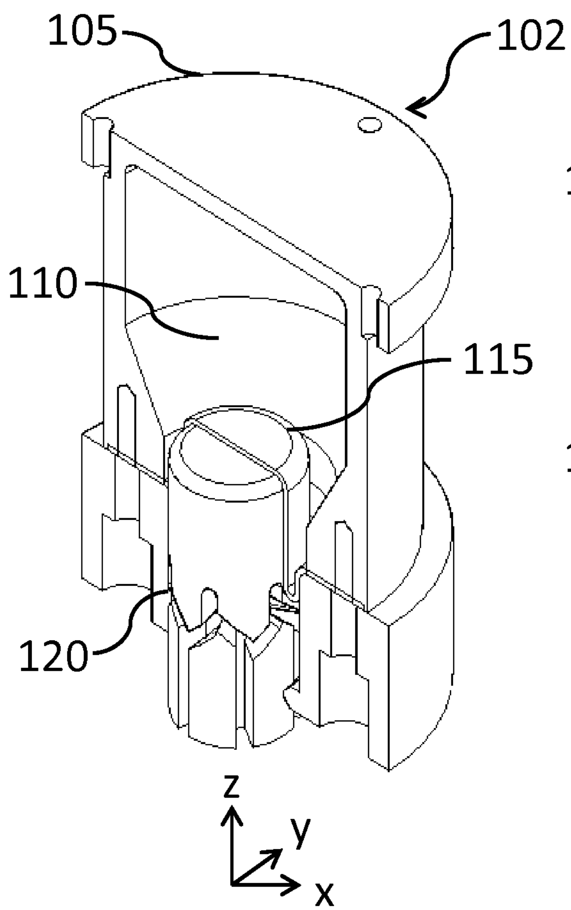


FIG. 5

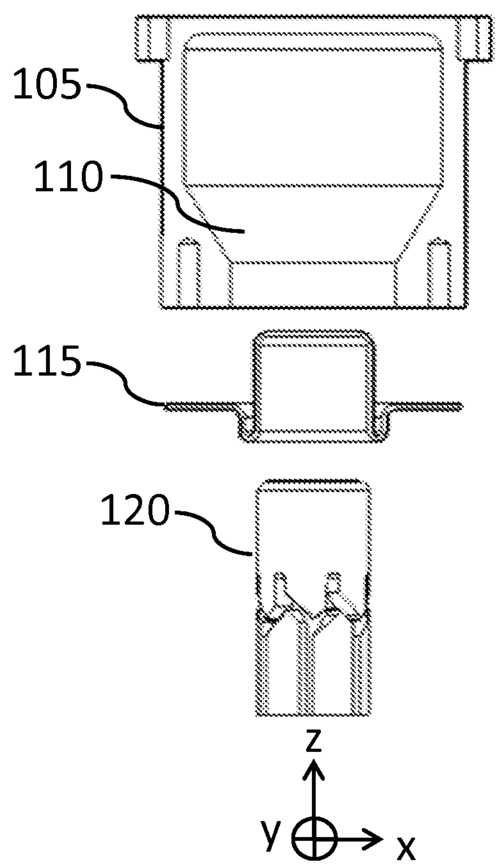


FIG. 6

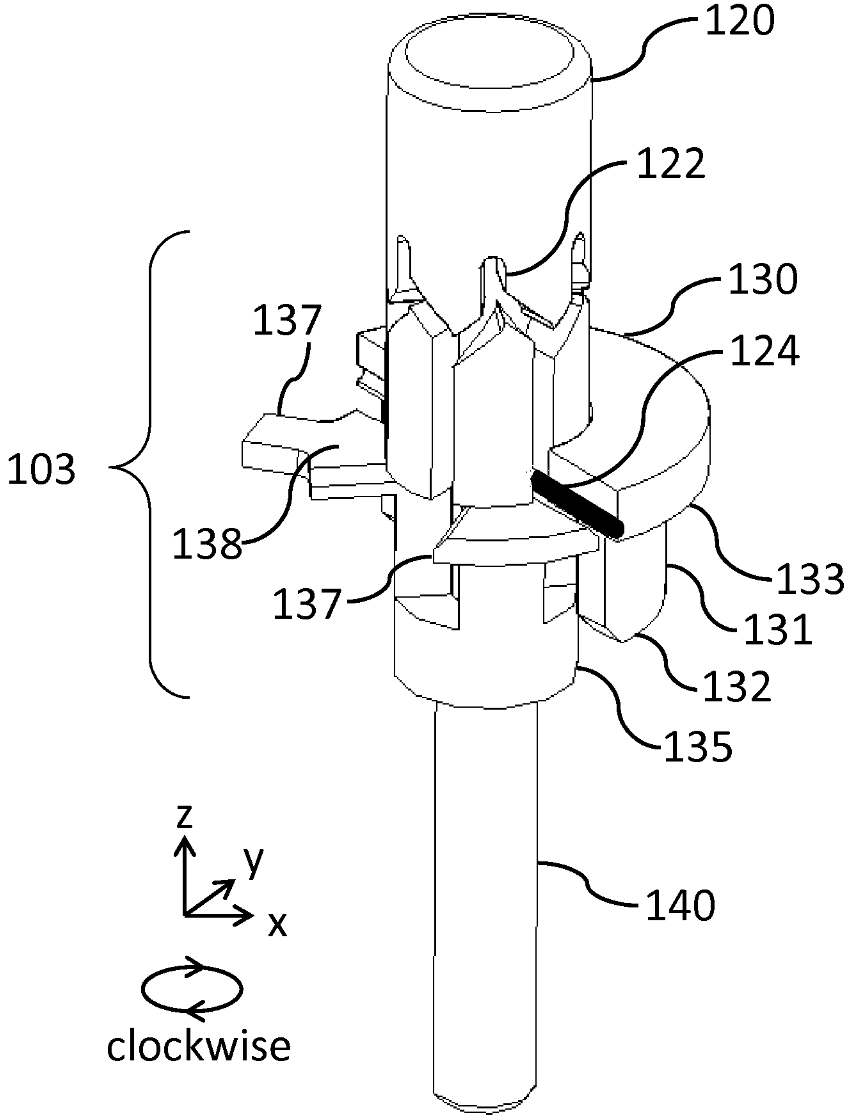

120
122
130
124
137
103
138
137
133
131
132
135
z
y
x
140
clockwise

FIG. 7

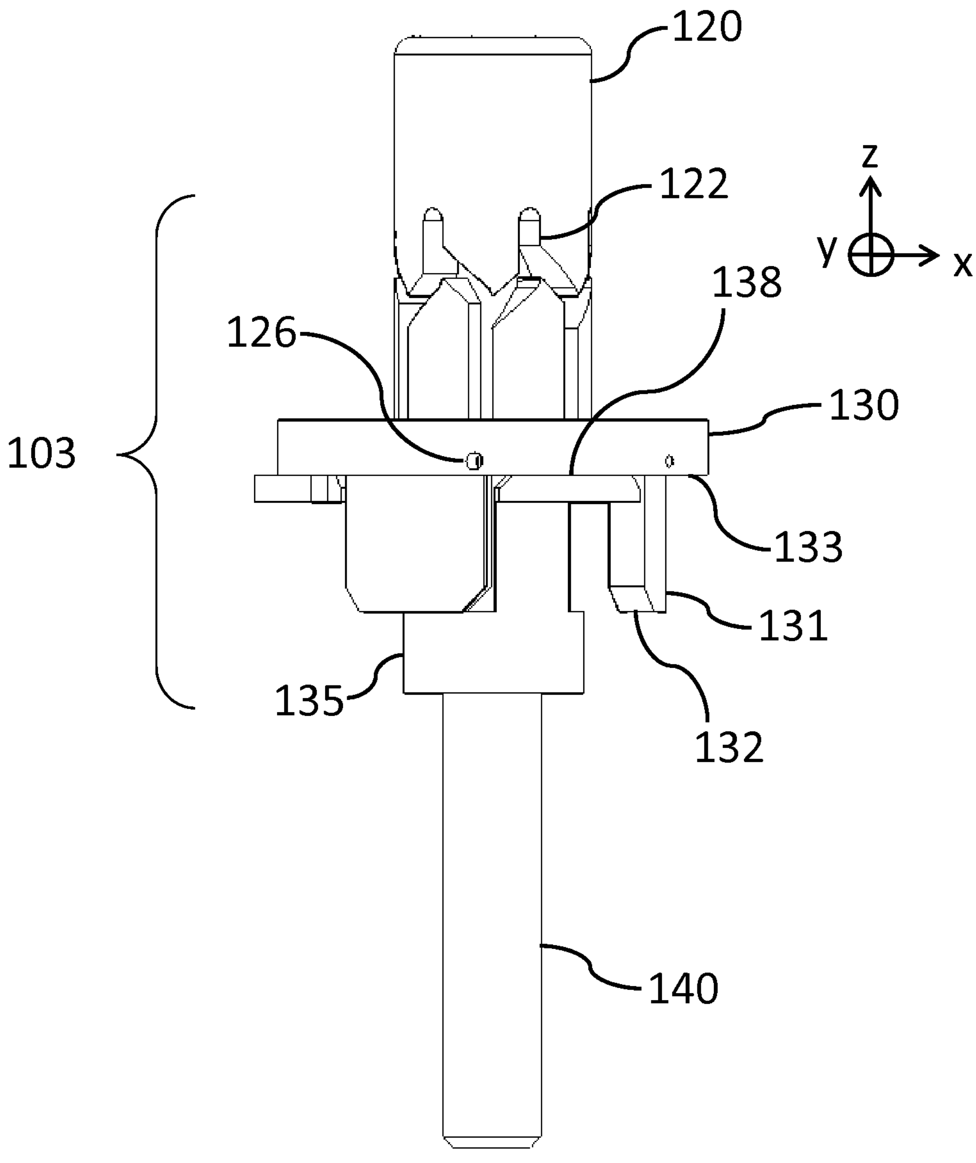


FIG. 8

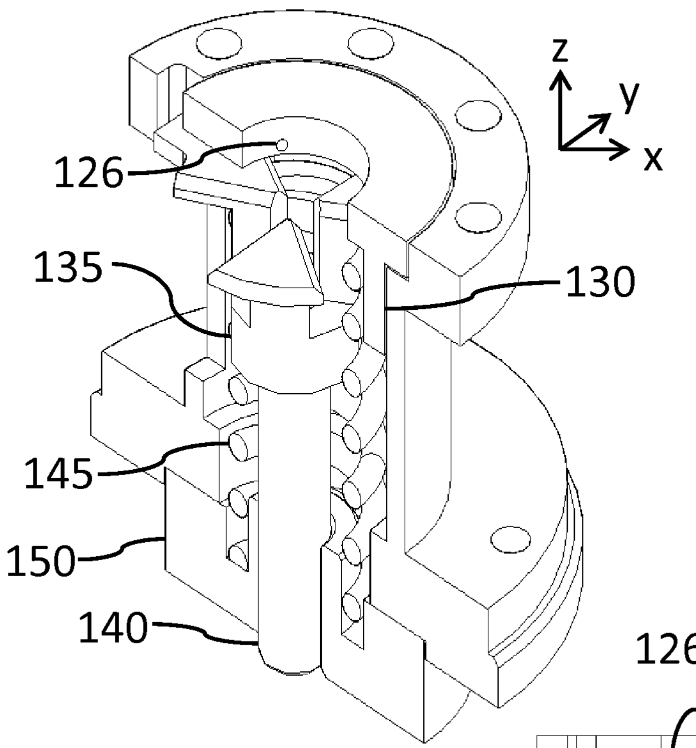


FIG. 9

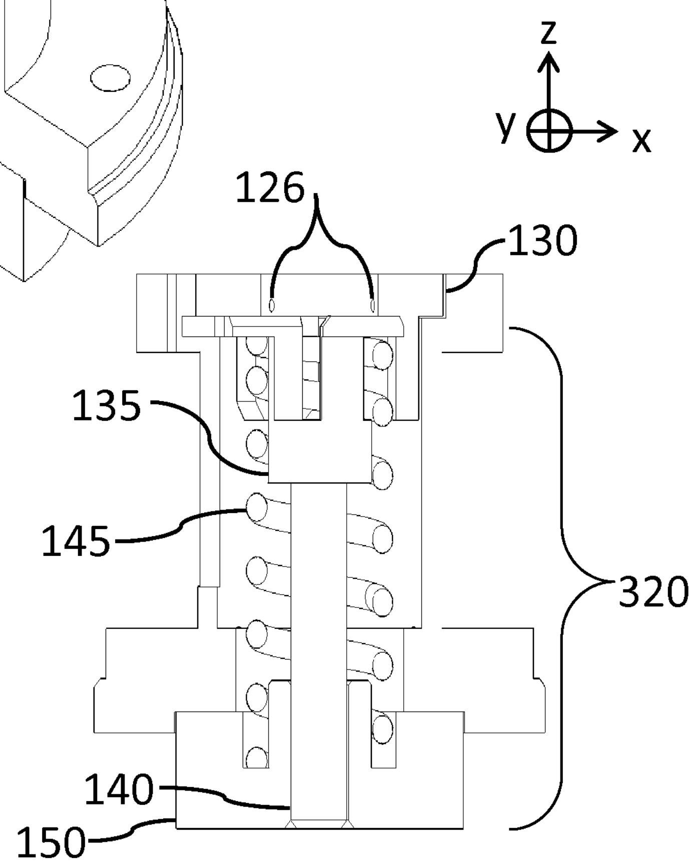


FIG. 10

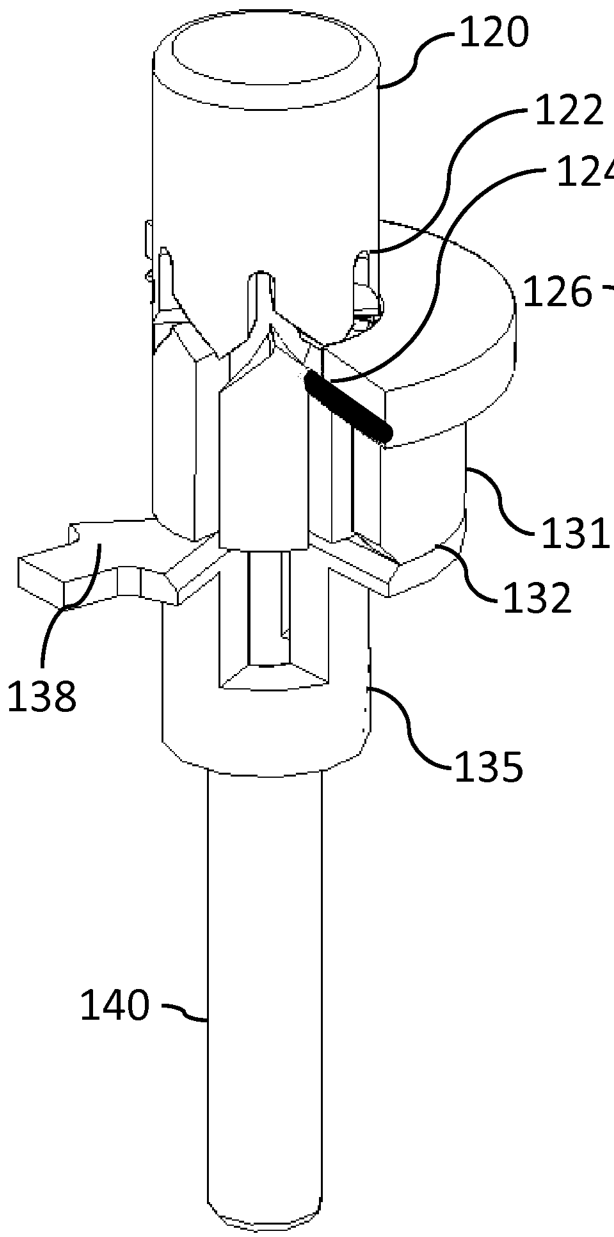


FIG. 11

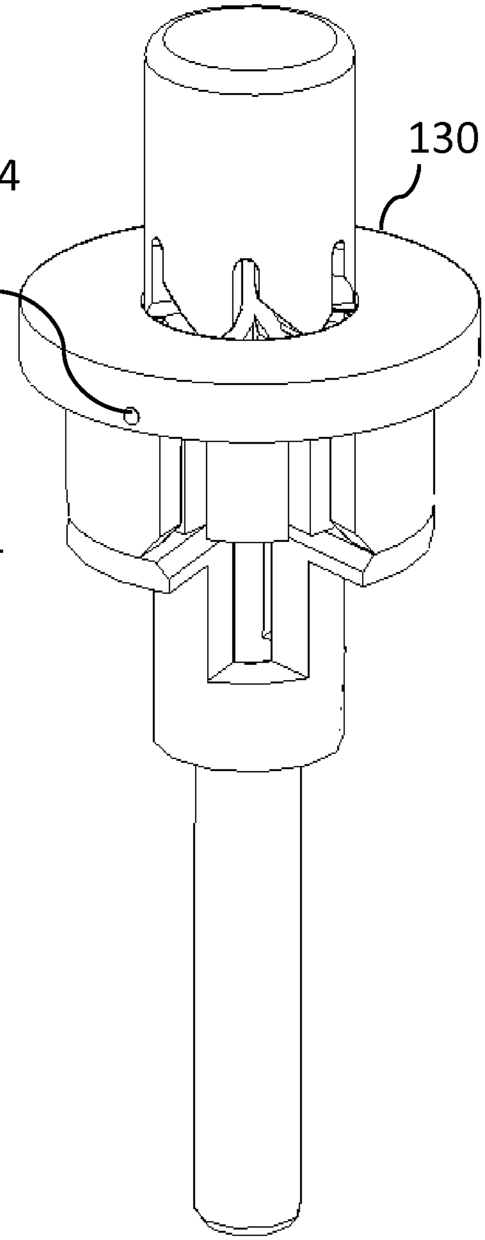


FIG. 12

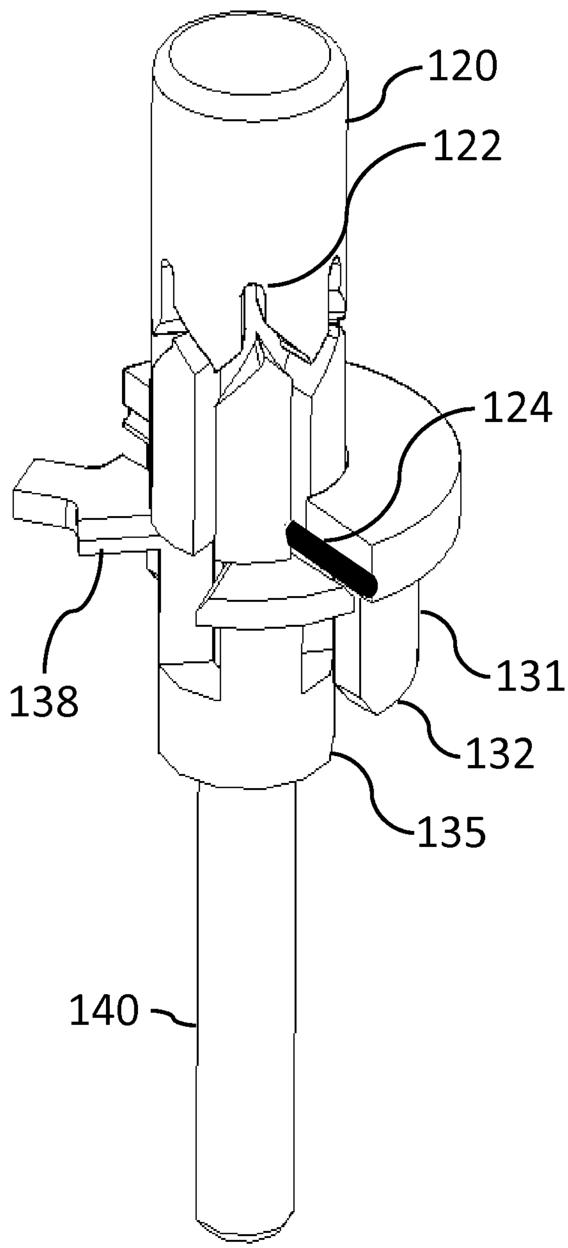


FIG. 13

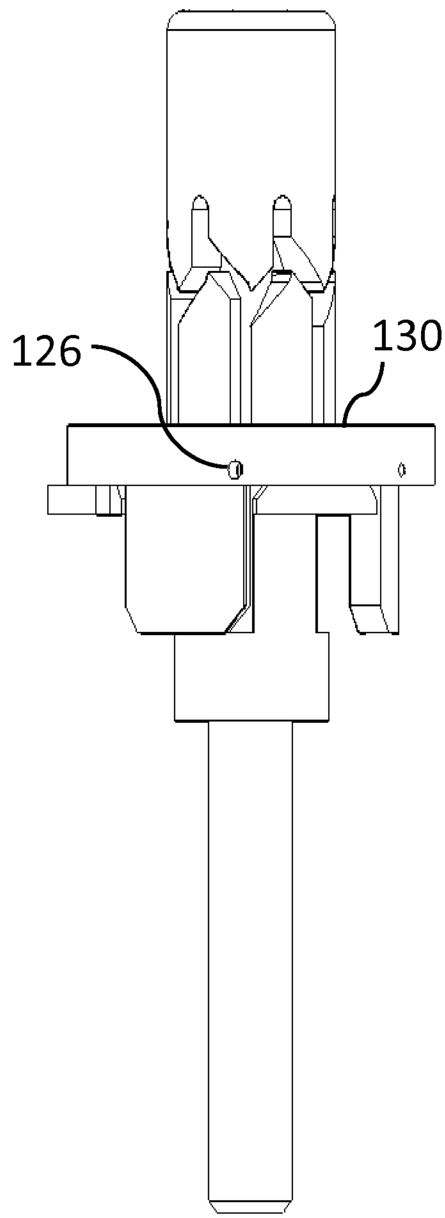


FIG. 14

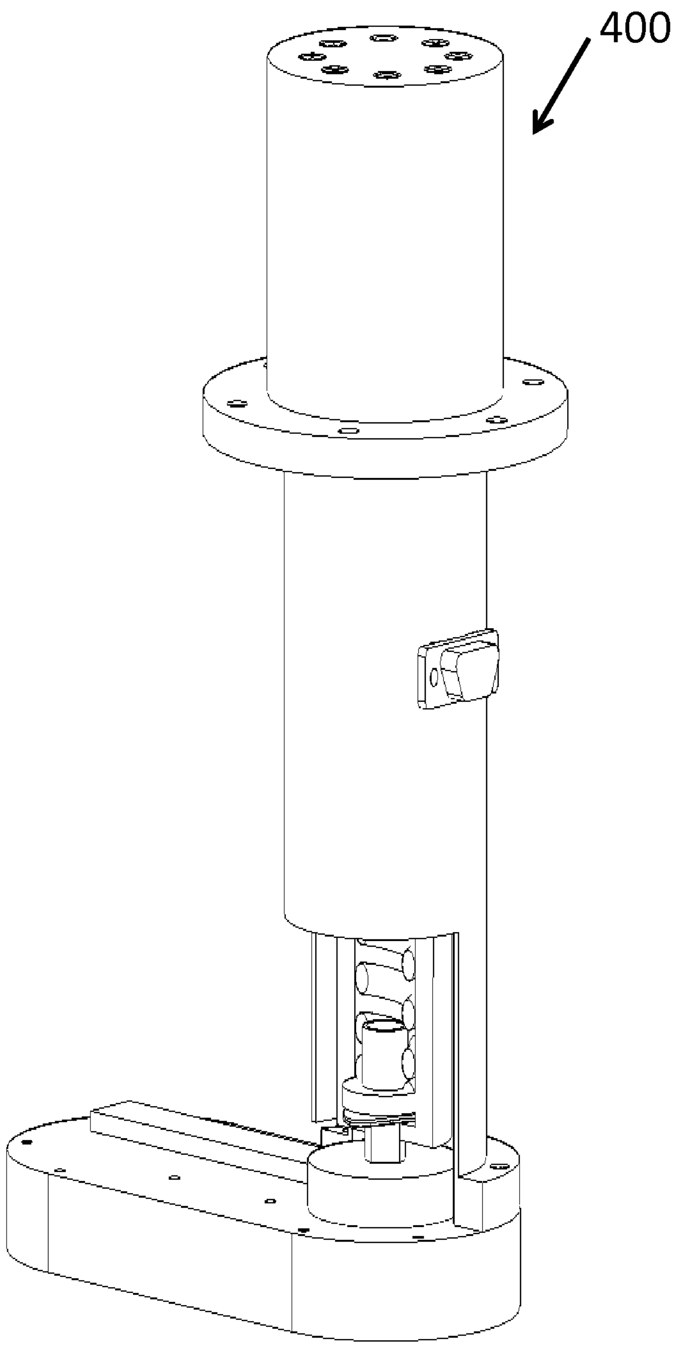


FIG. 15

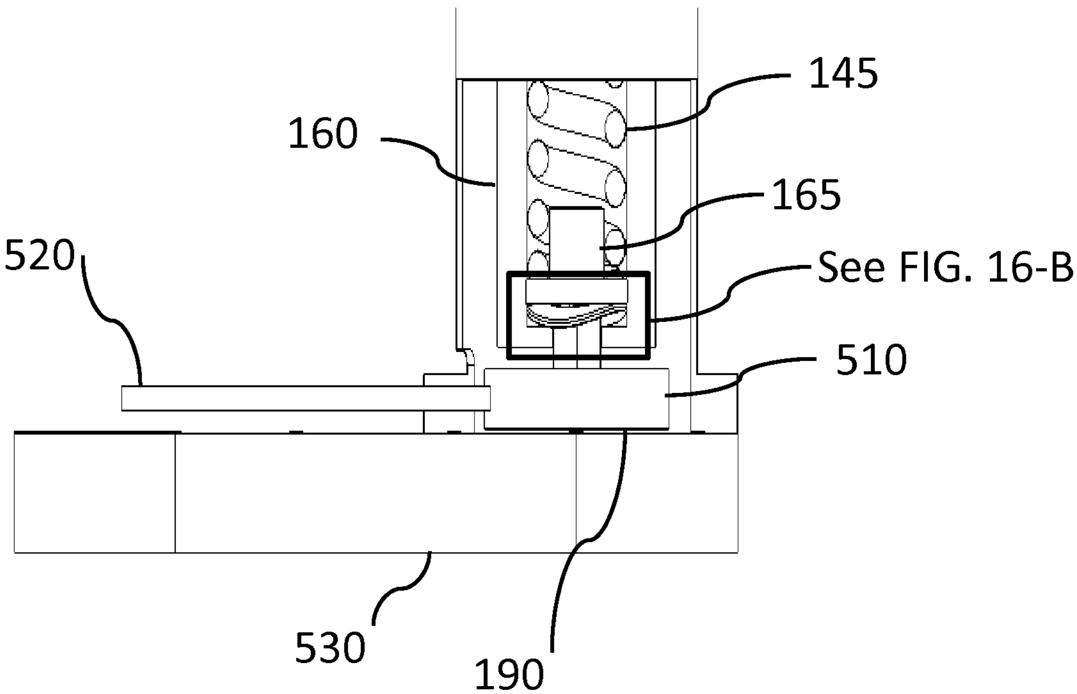


FIG. 16-A

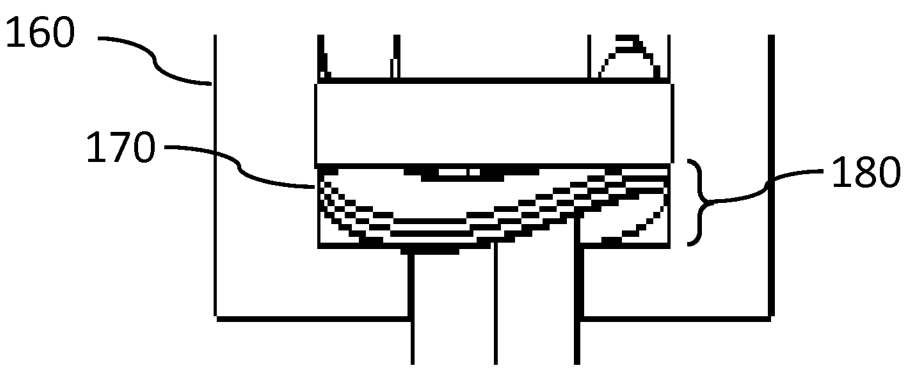


FIG. 16-B

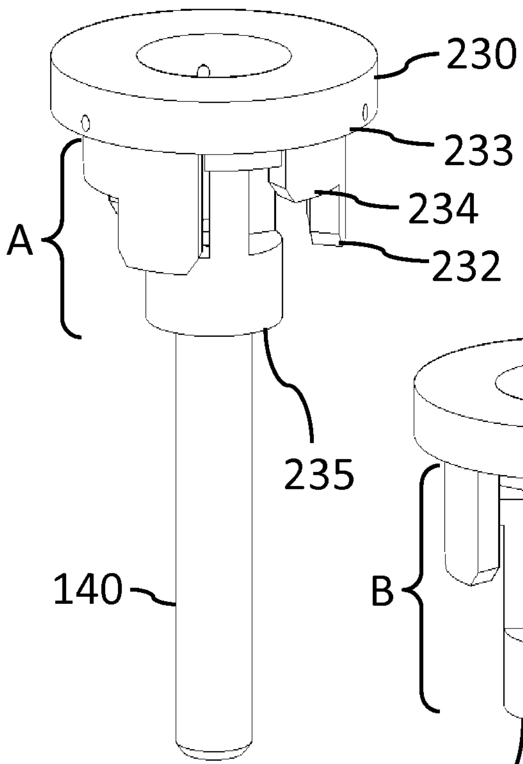


FIG. 17

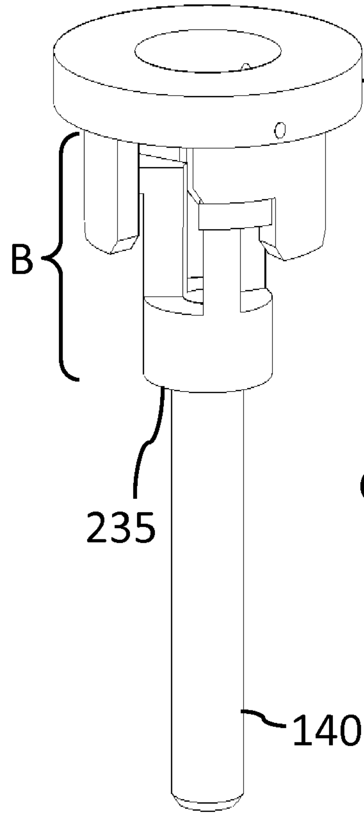


FIG. 18

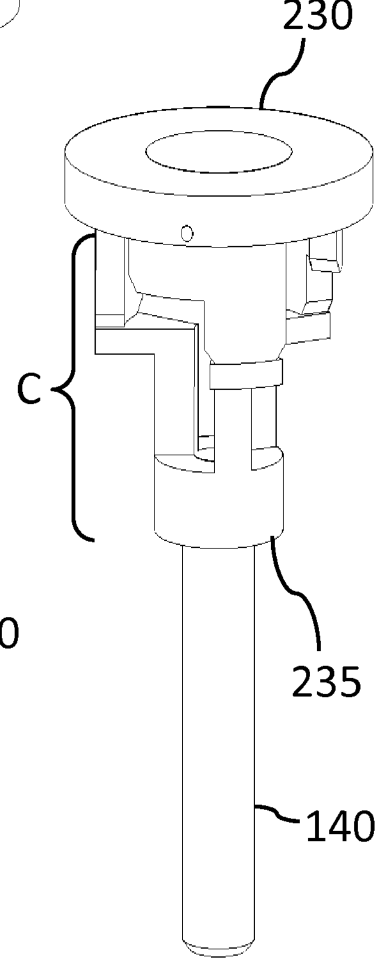


FIG. 19

LATCHING ACTUATOR

RELATED APPLICATIONS

This patent application claims the benefit of U.S. Provisional Application 61/474,173, filed Apr. 11, 2011 and entitled CRYOGENIC LATCHING INSTRUMENT COOLER, which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

The present disclosure relates to control systems, more particularly, to novel systems and methods for affecting a latching actuator in a remote or difficult-to-access environment such as a reduced pressure, cryogenic, or outer space environment.

BACKGROUND

Some switch systems capable of operating in a remote environment are currently available. Cunningham et al. (U.S. Pat. No. 4,388,965) disclose an automatic thermal switch that controls heat flow between two thermally conductive plates. In a normally open switch configuration, the environmental temperature to which a first plate is exposed heats the plate. A rise in temperature of the first plate drives a phase-change of ammonia, Freon, or deionized water to a gas inside a power unit which is capable of driving a piston. The increased pressure caused by the phase change motivates the piston to create a thermal path between the first and second plates. The thermal path is maintained so long as the temperature of the first plate is maintained at or above the phase-change temperature of the working substance by the ambient temperature. In a normally closed switch configuration, raising the temperature of one of the thermally conductive plates causes a reaction that breaks a thermal path between the first and second plates.

Applicants filed U.S. Non-Provisional application Ser. No. 11/467,431, on Aug. 25, 2006, entitled APPARATUS, SYSTEM, AND METHOD FOR MODIFYING A THERMAL CONNECTION, which is incorporated herein by reference in its entirety. In that application, Applicants disclosed, inter alia, a wax actuator that could extend and/or retract a plunger to motivate a thermal connector in a cryogenic atmosphere. Applicants learned after filing the application, however, that the anticipated actuator was not available and was incapable of performing the expected functions. Application Ser. No. 11/467,431 was abandoned.

SUMMARY

Applicants have identified the need for a latching actuator capable of repeated operation in a cryogenic, remote, or difficult-to-access environment, capable of enduring many cycles without user intervention or maintenance, or capable of latching in a fixed position without consuming additional power to maintain a latched position or to operate independent of external environmental conditions. The present disclosure in aspects and embodiments addresses these various needs and problems.

A latching actuator may be used in several different applications. In one exemplary application, a latching actuator may be used to create a thermal connection between two structures to transfer heat from one structure to another structure. In another exemplary application, a latching actuator may be used to engage or disengage a clutch. The clutch may be part of a motion transfer system that transfers radial or

linear motion between moveable parts of a machine (e.g., a motor and another part of a machine). In another exemplary application, a latching actuator may drive a shutter, lens, mirror, or other optical element in an optical instrument. In yet another exemplary application, a latching actuator may be used to secure moveable components in a device to prevent damage to the components or the device while the device is being transported (e.g., a launch lock apparatus). In this last exemplary use, the latching actuator may be used to secure delicate satellite components while being launched into outer space.

In selected embodiments, a latching actuator may comprise an expansion chamber that houses a working substance capable of undergoing a phase change, a logic mechanism (e.g., latching section), a biasing assembly, and an output pin. In one embodiment, a wax motor may provide a motive force to toggle a latching mechanism.

In still other embodiments, a latching actuator may be capable of positioning an output pin in three or more discrete latching positions. The actuator may cycle an output pin through multiple positions by cyclically actuating a wax motor. Additionally, the latching actuator may be capable of maintaining each latched, discrete position without the need to consume additional energy and may be able to operate independent of external environmental conditions.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing features of the present invention will become more fully apparent from the following description and appended claims, taken in conjunction with the accompanying drawings. Understanding that these drawings depict only typical embodiments of the invention and are, therefore, not to be considered limiting of its scope, the invention will be described with additional specificity and detail through use of the accompanying drawings in which:

FIG. **1** is an isometric view of a representative latching actuator;

FIG. **2** is an isometric view of the latching actuator of FIG. **1** with a housing;

FIG. **3** is a cutaway perspective view of the latching actuator of FIG. **1**;

FIG. **4** is cutaway elevation view of the latching actuator of FIG. **1**;

FIG. **5** is a cutaway perspective view of a representative motor assembly of the latching actuator of FIG. **1**;

FIG. **6** is an exploded view of the motor assembly of FIG. **5**;

FIG. **7** is an isometric view of a representative logic mechanism of the latching actuator of FIG. **1**;

FIG. **8** is an elevation view of a representative logic mechanism of FIG. **7**;

FIG. **9** is an isometric view of a representative biasing assembly of the latching actuator of FIG. **1**;

FIG. **10** is an elevation view of a representative biasing assembly of FIG. **9**;

FIG. **11** is an isometric view of a representative logic mechanism of the latching actuator of FIG. **1**;

FIG. **12** is an isometric view of a representative logic mechanism of the latching actuator of FIG. **1**;

FIG. **13** is an isometric view of a representative logic mechanism of the latching actuator of FIG. **1**;

FIG. **14** is an isometric view of a representative logic mechanism of the latching actuator of FIG. **1**;

FIG. **15** is an isometric view of a representative latching switch;

FIG. **16**-A is an elevation view of a portion of a representative latching switch;

FIG. **16**-B is a close-up view of a portion of FIG. **16**-A;

FIG. **17** is an isometric view of a representative logic mechanism;

FIG. **18** is an isometric view of a representative logic mechanism; and

FIG. **19** is an isometric view of a representative logic mechanism.

DETAILED DESCRIPTION

The present disclosure covers apparatuses and associated methods for a latching actuator. In the following description, numerous specific details are provided for a thorough understanding of specific preferred embodiments. However, those skilled in the art will recognize that embodiments can be practiced without one or more of the specific details, or with other methods, components, materials, etc. In some cases, well-known structures, materials, or operations are not shown or described in detail in order to avoid obscuring aspects of the preferred embodiments. Furthermore, the described features, structures, or characteristics may be combined in any suitable manner in a variety of alternative embodiments. Thus, the following more detailed description of the embodiments of the present invention, as illustrated in some aspects in the drawings, is not intended to limit the scope of the invention, but is merely representative of the various embodiments of the invention.

In this specification and the claims that follow, singular forms such as "a," "an," and "the" include plural forms unless the content clearly dictates otherwise. All ranges disclosed herein include, unless specifically indicated, all endpoints and intermediate values. In addition, "optional" or "optionally" refer, for example, to instances in which subsequently described circumstance may or may not occur, and include instances in which the circumstance occurs and instances in which the circumstance does not occur. The terms "one or more" and "at least one" refer, for example, to instances in which one of the subsequently described circumstances occurs, and to instances in which more than one of the subsequently described circumstances occurs.

In some embodiments, a latching actuator may operate in a remote or difficult-to-access environment. A remote environment may be a reduced pressure environment. In one embodiment, the latching actuator is configured to operate in environmental pressures in the range of 101 KPa to 0.0001 μPa, such as from 1 KPA to 0.001 μPa, or from 1 PA to 0.01 μPa. In a specific embodiment, the latching actuator is configured to operate in a vacuum in the range of 1 μPa to 0.01 μPa. A reduced pressure environment may be found in outer space, e.g., within or beyond Earth's mesosphere or thermosphere. A reduced pressure environment may also be found within a vacuum chamber in a terrestrial environment, where re-pressurizing the chamber may be required to gain access to an apparatus within the chamber. Similarly, a latching actuator may operate in a difficult-to-access environment, such as inside a complex machine or on or within an apparatus that itself is in a remote or difficult-to-access environment.

A representative latching actuator may also operate in a cryogenic atmosphere. A cryogenic atmosphere may reach temperatures as low as −150° C. (123 K) or as low as −270° C. (3 K), or possibly even lower temperatures. A cryogenic atmosphere may be found in outer space, e.g., within or beyond Earth's mesosphere or thermosphere. A cryogenic environment may also be found within a vacuum chamber in a terrestrial environment, where warming up and re-pressurizing the chamber may be required to gain access to an apparatus within the chamber.

Alternatively, in some embodiments, a latching actuator may operate at standard or elevated temperature conditions. For example, a latching actuator may operate from 0° C. to 135° C., such as from 10 to 100° C., or from 20 to 80° C., or from 30 to 70° C., or from 40 to 60° C.

As the latching actuator may be configured to operate in difficult-to-access environments or in a cryogenic atmosphere, the latching actuator may also be capable of enduring thousands of repeated cycles without user intervention or maintenance.

In one embodiment, the latching actuator is capable of latching in two or more fixed positions without consuming additional power to maintain the latched, fixed positions. In this sense, "latched" refers to a fixed, pre-determined position that does not consume or require additional energy input to maintain the position.

The latching actuator may also be capable of maintaining a latched position independent of environmental conditions. For example, the latching actuator may adjust from one latched position to another latched position independent of ambient temperature, pressure, or humidity. In this manner, the latching actuator may be capable of operating independent of environmental conditions.

The following examples are illustrative only and are not intended to limit the disclosure in any way.

EXAMPLES

It will be appreciated that several of the above-disclosed and other features and functions, or alternatives thereof, may be desirably combined into many other different systems or applications. Also, various presently unforeseen or unanticipated alternatives, modifications, variations or improvements therein may be subsequently made by those skilled in the art, and are also intended to be encompassed by the following claims.

FIGS. **1** and **2** illustrate through isometric views a representative embodiment of a latching actuator. In selected embodiments, a latching actuator **300** comprises a motor housing assembly **102**, a logic mechanism **103**, a biasing assembly **104**, and an output pin **140**. Actuator **300** may also include a housing **100**.

FIG. **3** illustrates a cut-away isometric view of some of the internal components of the representative latching actuator of FIGS. **1** and **2**. As shown in FIG. **3**, a motor housing assembly **102** comprises an expansion chamber housing **105** that encases an expansion chamber **110**. Expansion chamber **110** contains a working substance (not shown) capable of changing phase. Motor housing assembly may also include a diaphragm **115** that encloses an opening in expansion chamber **110**.

FIG. **3** also illustrates some of the internal components of a representative logic mechanism **103**. Logic mechanism **103** may comprise a latch housing **125**, a piston **120**, logic channel **122**, a rotating latch **130**, and an axial latch **135**. In addition, FIG. **3** illustrates some of the internal components of biasing assembly **104**, which may comprise a reset spring **145**, and an alignment bushing **150**. Finally, FIG. **3** illustrates output pin **140**. For clarity purposes, FIG. **3** illustrates half portions of expansion chamber housing **105**, expansion chamber **110**, diaphragm **115**, latch housing **125**, rotating latch **130**, reset spring **145**, and bushing **150**. FIG. **3** further illustrates piston

120, axial latch 135 and output pin 140 as whole components. FIG. 4 illustrates a cut-away elevation view of the latching actuator of FIG. 1.

FIG. 5 illustrates an isometric cut-away view of motor housing assembly 102, together with some other components. Motor housing assembly 102 may comprise an expansion chamber housing 105 enveloping expansion chamber 110, and diaphragm 115. For clarity purposes in FIG. 5, the expansion chamber housing 105, expansion chamber 110, and diaphragm 115 are shown as being cut in half. FIG. 5 also illustrates piston 120 as a whole component. FIG. 6 illustrates an exploded, plan view of the components of the motor housing assembly of FIG. 5 and piston 120.

Referring to FIG. 5, expansion chamber 110 contains a working substance (not shown) that is capable of changing phase from a solid to a liquid if the temperature of the working substance is at or above a phase change temperature. In the solid phase, the working substance may substantially fill the expansion chamber. As the working substance changes phase from a solid to a liquid, the volume of the working substance will expand. The working substance volume may be constrained by expansion chamber housing 105 on all but one side. The unconstrained opening of expansion chamber housing 105 may be sealed by diaphragm 115. Piston 120 may be adjacent to the opposite side of diaphragm 115. An increase in pressure caused by the expansion of the working substance inside expansion chamber 110 acts to provide a motive force on diaphragm 115 and piston 120 in a downward motion (negative z-direction).

A working substance may be selected based on its ability to melt at a specific temperature (e.g., the phase change temperature) that relates to the operating conditions of the latching actuator. In preferred embodiments, the working substance will melt and expand or solidify and contract at a consistent temperature over many cycles. In a representative embodiment, the working substance is paraffin wax. In one embodiment, the phase change temperature of paraffin wax may be in the range of 17 to 42° C. In another embodiment, the phase change temperature of paraffin wax may be in the range of 80 to 101° C. In another embodiment, the phase change temperature of paraffin wax may be in the range of 105 to 135° C. In yet another embodiment, the phase change temperature of paraffin wax may be in the range of 17 to 135° C.

The ability of the working substance to melt at a specific temperature may be one feature that allows the representative latching actuator to operate independent of environmental conditions. For example, a representative actuator may be able to maintain a latched, discrete position independent of ambient temperature, pressure, or humidity. The actuator may also be able to maintain a latched position without the need to consume additional energy or absorb heat from some source.

The working substance may also be chosen based on its expansion characteristics, which correspond to the amount of displacement that might be created in by the expansion chamber 110 or the motive force on diaphragm 115 and piston 120 when the working substance changes phase from a solid to a liquid. The expansion characteristic of paraffin from a solid to liquid phase may provide the motive force for operating a latching actuator. In some embodiments, paraffin wax may expand anywhere from 9 to 20% by volume as it changes phase. In some embodiments, the volumetric expansion of the working substance corresponds to a motive force of between 220 and 450 Newtons through output pin 140. In some embodiments where the working substance changes phase from a solid to a liquid, as opposed to changing from a liquid to a gas, the motive force on output pin may be much higher, for example as much as 500 or 100 Newtons. In this sense, the motive force caused by the phase change may only be limited by the structural integrity of the volumetric expansion chamber. Alternatively, the volumetric expansion of the working substance may correspond to a motive force from 10 to 50, 50 to 100, or 100 to 200 Newtons.

The size, shape, or volume of expansion chamber 110 may also be modified to provide more or less volumetric expansion of the working substance. The volumetric expansion of the working substance corresponds to the amount of displacement or motive force exerted by the working substance or the distance piston 120 may travel (along the z-axis). Increasing the volume of expansion chamber 110 will provide a greater expansion volume and will allow for an increased motive force or increased travel distance for piston 120. In one embodiment, the volume of the expansion chamber may be less than 3 cm^3. Alternatively, the volume of the expansion chamber may be from 3 to 5, 5 to 15, 15 to 30, 30 to 40, or 40 to 50 cm^3. In yet another embodiment, the volume of the expansion chamber may be greater than 50 cm^3.

Diaphragm 115 comprises a diaphragm material that may be selected based on its ability to withstand repeated cycles in a cryogenic environment without chemical, thermal, or mechanical degradation. In a representative embodiment, diaphragm 220 is a nitrile rolling diaphragm.

To actuate latching actuator 300, the working substance inside expansion chamber 110 may be heated. In selected embodiments, an electrical resistance heater (not shown) may apply heat to the exterior of expansion chamber housing 105. In one embodiment, thin KAPTON heaters adhered to the outside of expansion chamber housing 105 may be used. Expansion of the working substance may force piston 120 toward rotating latch 130. Once the heaters are turned off, the working substance may begin to cool, solidify, and contract. Preloads in reset spring 145 may force piston 120 and diaphragm 115 back into or towards expansion chamber 115.

Any suitable material may be used to make motor housing assembly 102. In selected embodiments, all components in motor housing assembly 102, except for diaphragm 115, may be made of aluminum. Other embodiments may use a material with a larger thermal capacity, thereby maintaining the working substance closest to the diaphragm in the liquid phase during the cooling cycle. This may allow for a more reliable, complete retraction. Additionally, other embodiments may include internal heaters and temperature sensors, thinner walls, and larger diameter diaphragms. Such arrangements may reduce size, increase operating pressure, or improve reliability. In selected embodiment, the geometry or shape of piston 120 may assist in constraining or maintaining the shape of diaphragm 115. Piston 120 may also provide a hard attachment point for other (e.g., lower) components of latching actuator 300.

FIGS. 7 and 8 illustrate an isometric view and elevation view, respectively, of exemplary logic mechanism 103 in relation to output pin 140. In selected embodiments, logic mechanism 103 may include a piston 120, a logic channel 122 circumscribed into the outside circumference of piston 120, a rotator latch 130, and an axial latch 135. For clarity purposes, FIG. 7 illustrates only half of rotator latch 130, whereas the other elements of logic mechanism 103 are illustrated as whole components.

Rotator latch 130 may comprise a disc that surrounds piston 120 and may be held in place axially relative to the motion of piston 120. Rotator latch 130 may be in housing 100 between two bearings sets (not shown). Accordingly, in such embodiments, the relative motion of rotator latch 130 may be substantially limited to rotation. In selected embodiments, rotator latch **130** further comprises a lower disc surface **133**, one or more rotator teeth **131**, and one or more logic pins **124**. Rotator teeth **131** may also include a lower tooth surface **132**. Logic pin **124** may be secured to rotator latch **130** through pin slots **126** (shown in FIG. **8**) such that logic pin **124** and rotator latch **130** move radially together (around the z-axis). In selected embodiments, axial latch **135** further comprises axial teeth **137**, which have a top tooth surface **138**. In this embodiment, piston **120**, axial latch **135**, and output pin **140** are mechanically connected such that the three components move up and down together (along the z-axis). Logic pins **124** and the sloped surfaces of logic channel **122** form the "logic elements" of logic mechanism **103** as they perform a latch, unlatch, and latch sequence (described below).

Any suitable material may be used to generate logic mechanism **103**. In certain embodiments, all materials in this assembly may be aluminum with the exception of logic pins **124** and rotator latch **130** bearings (not shown) which may both be stainless steel. Other embodiments may utilize advanced machining capabilities to miniaturize logic channel **122** and other components. Still other embodiments may omit rotator latch **130** bearings in housing **100** entirely (e.g., form rotator latch **130** out of a wear resistant thermal plastic such as TORLON to further reduce the dynamic friction generated during rotation).

FIGS. **9** and **10** illustrate an isometric and elevation view, respectively, of biasing assembly **104** together with axial latch **135** and rotating latch **130**. Also shown are pin slots **126**. In certain embodiments, biasing assembly **104** comprises reset spring **145** and alignment bushing **150**. For clarity purposes, FIG. **9** illustrates axial latch **135** as a whole and other parts as being cut in half. In operation, reset spring **145** biases the top tooth surfaces **138** of axial latch **135** against the lower tooth surface **132** of rotator latch **130** when output pin **140** is in an extended position. Alternatively, as shown in FIGS. **9** and **10**, reset spring **145** biases the top tooth surfaces **138** of axial latch **135** against the lower disc surface **133** of rotator latch **130** when output pin **140** is in a retracted position.

Referring back to FIGS. **7** and **8**, in selected embodiments, logic mechanism **103** operates from a latched-retracted position to an unlatched position in the following manner: output pin **140** is in a latched-retracted position such that rotator teeth **131** are locked between axial teeth **137** and the top surfaces **138** of axial teeth **137** are biased against lower disc surface **133** of rotator latch **130**. In this position, the working substance in expansion chamber **110** is in a contracted, solid phase such that logic mechanism **103** consumes no energy to maintain output pin **140** in this latched-retracted position. Power applied to a heat source (not shown) located on, in, or near expansion chamber **110** (shown in FIG. **4**) may cause a working substance in expansion chamber **110** to change from a solid to a liquid phase. As the working substance changes phase from solid to liquid, the working substance expands, driving piston **120**, axial latch **135** and output pin **140** in a downward motion (negative z-direction) relative to rotator latch **130** and logic pins **124**. As piston **120** moves downward, logic pins **124** travel up towards the top of logic channel **122**. As logic pins **124** approach the upper portion of logic channel **122**, lower tooth surfaces **132** of rotator teeth **131** become positioned above (along the z-axis) the top tooth surfaces **138** of axial teeth **137**. Continued relative downward motion of logic channel **122** circumscribed in the outside diameter of piston **120** may generate rotation of rotator latch **130**. In selected embodiments, during this rotation, there may be no axial load on rotator latch **135**. As logic pins **124** reach the top of logic channel **122**, rotator latch **130** rotates in a clockwise direction relative to axial latch **135**. In this unlatched position, the working substance may be in a liquid phase.

Continuing with FIGS. **7** and **8**, in selected embodiments, logic mechanism **103** operates from an unlatched position to a latched-extended position in the following manner: as power is turned off from the heat source (not shown), heat will dissipate from the working substance through expansion chamber housing **105** (shown in FIGS. **5** and **6**), causing the substance to cool, solidify, and contract. As the working substance contracts, reset spring **145** (shown in FIGS. **9** and **10**) will press axial latch **135** and piston **120** in an upward motion (positive z-direction) relative to rotator latch **130** and logic pins **124**. As piston **120** moves upward, logic pins **124** travel down logic channel **122**. As logic pins **124** continue moving down logic channel **122**, rotator latch **130** rotates in a clockwise direction relative to axial latch **135** until rotator teeth **131** are centered above top surface **138** of axial teeth **137**. As the working substance continues to cool, solidify and contract, axial latch **135** and piston **120** continue moving upward and logic pins **124** continue traveling down logic channel **122** until lower tooth surface **132** of rotator teeth **131** press against top tooth surface **138** of axial teeth **137**. In this position, output pin **140** is in an extended position and the working substance in expansion chamber **110** may be in a contracted, solid phase such that latching actuator **300** consumes no energy to maintain output pin **140** in this latched-extended position.

In certain embodiments, travel of axial latch **135** may be monitored or controlled by an infrared switch (not shown). In selected embodiments, triggering such a switch may interrupt power to heat source on, in, or near motor housing assembly **102** and initiate cool down and retraction. In selected embodiments, a latching system in accordance with the present invention may operate in a high vacuum environment, under cryogenic conditions, endure thousands of cycles, and perform favorably under typical launch vibration loadings.

FIGS. **11** and **12** illustrate two isometric views of rotator latch **130** and axial latch **135**, together with output pin **140**, in an extended-latched position. FIG. **11** illustrates half of rotator latch **130** and shows logic pin **124** whereas FIG. **12** illustrates all of rotator latch **130** and pin slot **126**. Similarly, FIGS. **13** and **14** illustrate two isometric views of rotator latch **130** and axial latch **135**, together with output pin **140**, in a retracted-latched position. FIG. **13** illustrates half of rotator latch **130** and shows logic pin **124** whereas FIG. **14** illustrates all of rotator latch **130** and pin slot **126**.

In selected embodiments, some of the logic mechanism elements (e.g., logic pins **124** and logic channel **122**) may never be under any substantial static or dynamic system loads. The internal spring pressure generated by reset spring **145** may be removed from the rotator latch **130** prior to any activity on the part of the logic elements. Additionally, static loads generated while in either the latched-extended or latched-retracted position may be supported by rotator latch **130** and axial latch **135**, not the logic elements (e.g., logic pins **124** and logic channel **122**). Accordingly, in selected embodiments, the only stresses within the logic elements may be generated by the frictional forces within the bearing sets, which may be minimal. Accordingly, a latching system may be formed of relatively small, light components that are able to withstand repeated cycles with minimal wear. In this sense, repeated cycles may refer to more than 1, 10, 100, or even 1000 cycles without the need to replace components or for an operator to reset the positions of components or provide other maintenance to the logic mechanism or its components.

In certain embodiments, the latching actuator may cycle between a latched-extended position to a latched-retraced position in the same manner as described above. For each cycle, rotator latch **130** may rotate sixty degrees. This rotation may align rotator teeth **131** with axial teeth **137** such that rotator teeth **131** are latched on top of or in between axial teeth **137**. Subsequent cycles may continue to generate equal rotations, advancing to a latched-retracted configuration or a latched-extended configuration, and so forth. The transitions between a latched-extended and a latched-refracted configuration may be caused by motor housing assembly **102** (e.g., heating of the working substance) and logic mechanism **103** and may operate independent of ambient conditions.

Latching Thermal Link

In one exemplary embodiment, as shown in FIG. **15**, a latching actuator may be used to create a thermal connection between two structures to transfer heat from one structure to another structure. For example, a first end of a thermal link (e.g., a flexible thermal link) may be thermally connected to a first structure. A second end of the thermal link may be positioned proximate or connected to the output piston of a latching system. Through the operation of a latching system, a user may selectively position the second end of the link into contact with a second structure. Accordingly, the latching system may selectively control whether the first structure is thermally connected to the second structure.

Referring to FIG. **16**-A, a latching actuator used to create a thermal connection may further comprise a lower housing **160**, a reset spring **145**, a link plunger **165**, and a separation spring **170**. Reset spring **145** provides compression between link plunger **165**, thermal link end block **510** and thermal sink **530**. Link plunger **165** may be mechanically coupled to a thermal link end block **510**, which in turn, may be thermally coupled to a flexible thermal link **520**. A representative latching actuator may latch thermal link end block **510** against thermal sink **530**.

Referring to FIGS. **16**-A and **16**-B, in a thermal link exemplary embodiment, there may be a gap **180** between link plunger **165** and the floor of lower housing **160**. This gap may be filled by separation spring **170**. A latching actuator may create a thermal connection between two structures by transitioning from a latched-retracted position to a latched-extended position, thereby closing gap **190** between thermal link end block **510** and thermal sink **530**. Accordingly, the transition from a latched-refracted configuration to a latched-extended configuration may include compression of reset spring **145** which effectively compresses separation spring **170** on the underside of link plunger **165** to reduce gap **180** and close gap **190**. The latching actuator may require no energy input or an elevated ambient temperature at or above the phase change temperature of a working substance to maintain a latched thermal connection between two structures.

To break the thermal connection between two structures, a latching actuator may transition from a latched-extended position to a latched-retracted position. Separation spring **170** may assist in retracting the mechanism (e.g., link plunger **165**) and reproduce the original gap **180**. The latching actuator may cycle between a latched-open (latched-retracted position) and a latched-closed (latched-extended) thermal connection many times in a remote, difficult-to-access, high-vacuum, or cryogenic atmosphere without the need for operator intervention or maintenance.

In selected embodiments such as that illustrated, gap **190** may be a relatively small gap (e.g., on the order of 0.5 mm). A latching system may move link plunger **165** a relatively small distance and produce a static latched pressure from about 220 Newtons to about 450 Newtons. Altering the configuration by reducing the size and length of reset spring **145**, while increasing the size and length of separation spring **170**, may produce a device capable of moving a greater distance, at the expense of reducing latching force.

Multi-Position Latching Actuator

A latching actuator may be configured to operate between two latched positions. In many applications, a latching actuator that operates between two latched positions may be adequate, for example, in closing and opening a thermal link between two structures. A two-position latching actuator may also be sufficient to engage or disengage a clutch, to open and close a shutter in an optical instrument, or to lock and unlock a launch lock apparatus. Alternatively, however, a latching actuator be configured to operate between more than two latched positions. For example, the actuator may be used to position a mirror in three or more latched orientations or positions as part of an optical instrument.

FIGS. **17**, **18**, and **19** illustrate isometric views of an alternative rotator latch **230** and axial latch **235** together with output pin **140** positioned in a retracted (labeled "A"), intermediate (labeled "B"), and extended (labeled "C") position, respectively. In this embodiment, rotator latch **230** may include additional teeth elevations to provide an intermediate, or third step height, thereby supporting latching at more than two positions. FIG. **17** illustrates rotator latch **230** with a lower disc surface **233**, a lower tooth surface **232**, and an intermediate tooth surface **234**. FIGS. **18** and **19** illustrate the same rotator latch **230** but the teeth surfaces are not labeled. In comparing FIGS. **17**, **18**, and **19**, FIG. **17** illustrates a latched, fully retracted position where axial latch **235** is positioned against lower disc surface **233** of rotator latch **230**; FIG. **18** illustrates a latched, intermediate position where axial latch **235** is positioned against intermediate tooth surface **234**; and FIG. **19** illustrates a latched, fully extended position where axial latch **235** is positioned against lower tooth surface **232**.

Although FIGS. **17**, **18**, and **19** illustrate a three-position embodiment of a latching actuator, still other embodiments are envisioned in the present disclosure. By adding teeth with multiple, discrete elevations to a rotator latch, and configuring the logic channel and axial latch accordingly, a latching actuator may latch in as many as four, five, six, or more discrete latching positions. An actuator may cycle through each discrete position by cyclically actuating or heating and cooling motor housing assembly **102**. Similarly, latching actuator **300** consumes no energy to maintain output pin **140** in each latched, discrete position and may be able to operate independent of external ambient conditions.

The present invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as illustrative, and not restrictive. All changes which come within the meaning and range of equivalency of the foregoing description are to be embraced within the scope of the invention.

What is claimed is:

1. A method for actuating a latching actuator, the method comprising:

heating a working substance and changing a phase of the working substance from a solid phase to a liquid phase and moving thereby an output pin from a latched-retracted position to an unlatched position; and

cooling the working substance and changing the phase of the working substance from the liquid phase to the solid phase and moving thereby the output pin from the unlatched position to a first latched-extended position.

2. The method of claim **1**, further comprising:

heating the working substance and changing the phase of the working substance from the solid phase to the liquid phase and moving thereby the output pin from the first latched-extended position to the unlatched position; and

cooling the working substance and changing the phase of the working substance from the liquid phase to the solid phase and moving thereby the output pin from the unlatched position to a second latched-extended position, the second latched-extended position being longer than the first latched-extended position.

3. The method of claim **2**, further comprising:

heating the working substance and changing the phase of the working substance from the solid phase to the liquid phase and moving thereby the output pin from the second latched-extended position to the unlatched position; and

cooling the working substance and changing the phase of the working substance from the liquid phase to the solid phase and moving thereby the output pin from the unlatched position to the latched-retracted position.

4. The method of claim **1**, further comprising:

heating the working substance and changing the phase of the working substance from the solid phase to the liquid phase and moving thereby the output pin from the first latched-extended position to the unlatched position; and

cooling the working substance and changing the phase of the working substance from the liquid phase to the solid phase and moving thereby the output pin from the unlatched position to the latched-retracted position.

5. A latching actuator comprising:

a motor housing assembly including a working substance therein capable of changing phase;

a logic mechanism mechanically coupled to the motor housing assembly;

a biasing assembly mechanically coupled to the logic mechanism;

an output pin mechanically coupled to the logic mechanism; and

wherein the logic mechanism is configured to latch the output pin in two or more fixed positions independent of an ambient condition and maintain the output pin in the two or more fixed positions without consuming additional energy.

6. The latching actuator of claim **5**, wherein the logic mechanism is configured to latch the output pin from a latched-retracted position to a latched-extended position and back to the latched-retracted position through repeated cycles without a need for user intervention.

7. The latching actuator of claim **5**, wherein the motor housing assembly comprises:

an expansion chamber housing that encases an expansion chamber and comprises an expansion chamber housing opening; and

a diaphragm enclosing the expansion chamber housing opening.

8. The latching actuator of claim **7**, wherein the diaphragm comprises a nitrile rolling diaphragm.

9. The latching actuator of claim **7**, wherein the working substance comprises a first portion of the working substance adjacent to the diaphragm and a second portion of the working substance positioned a distance away from the diaphragm; and the expansion chamber housing comprises a material with a thermal capacity capable of maintaining the first portion of the working substance in a liquid phase for a longer period of time during a cooling cycle than the second portion of the working substance.

10. The latching actuator of claim **7**, further comprising:

a piston that moves in response to a change in pressure within the expansion chamber; and

wherein the piston maintains the diaphragm in a shape of the piston.

11. The latching actuator of claim **5**, wherein a change in phase of the working substance from a solid phase to a liquid phase creates a motive force of at least 10 Newtons on the output pin.

12. The latching actuator of claim **5**, wherein the logic mechanism comprises:

a piston that moves in response to a change in pressure within the motor housing assembly;

a logic channel circumscribed along an outside circumference of the piston;

a rotating latch comprising a disc, the disc defining a hoop encircling the piston;

one or more logic pins mechanically coupled to the disc and configured to penetrate a portion of the logic channel; and

an axial latch comprising one or more teeth configured to interface with the rotating latch.

13. The latching actuator of claim **12**, wherein the rotating latch comprises a wear-resistant thermal plastic.

14. The latching actuator of claim **12**, wherein a relative motion of the rotating latch is substantially limited to rotation.

15. The latching actuator of claim **12**, further comprising an infrared switch configured to monitor a movement of the axial latch.

16. The latching actuator of claim **5**, wherein the logic mechanism is configured to latch the output pin in three or more fixed positions.

17. The latching actuator of claim **5** wherein the biasing assembly comprises:

a reset spring; and

an alignment bushing configured to align the reset spring with the output pin.

18. A thermal coupling system comprising:

a motor housing assembly including a working substance therein capable of changing phase;

a logic mechanism mechanically coupled to the motor housing assembly;

a biasing assembly mechanically coupled to the logic mechanism;

an output pin mechanically coupled to the logic mechanism;

a thermal link end block mechanically coupled to the output pin; and

a thermal sink;

wherein the logic mechanism is configured to latch the thermal link both against the thermal sink and a distance from the thermal sink independent of an ambient condition and maintain the thermal link either against the thermal sink or the distance from the thermal sink without consuming additional energy.

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