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(54) **DEVELOPABLE AND COLLAPSABLE
EXTERNAL CUTTING OR GRIPPING
MECHANISM**

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(2013.01); **B23D 21/145** (2013.01); **E02D**
9/04 (2013.01); **A61B 17/295** (2013.01)

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B26B 27/00; A61B 17/295; E02D 9/005;
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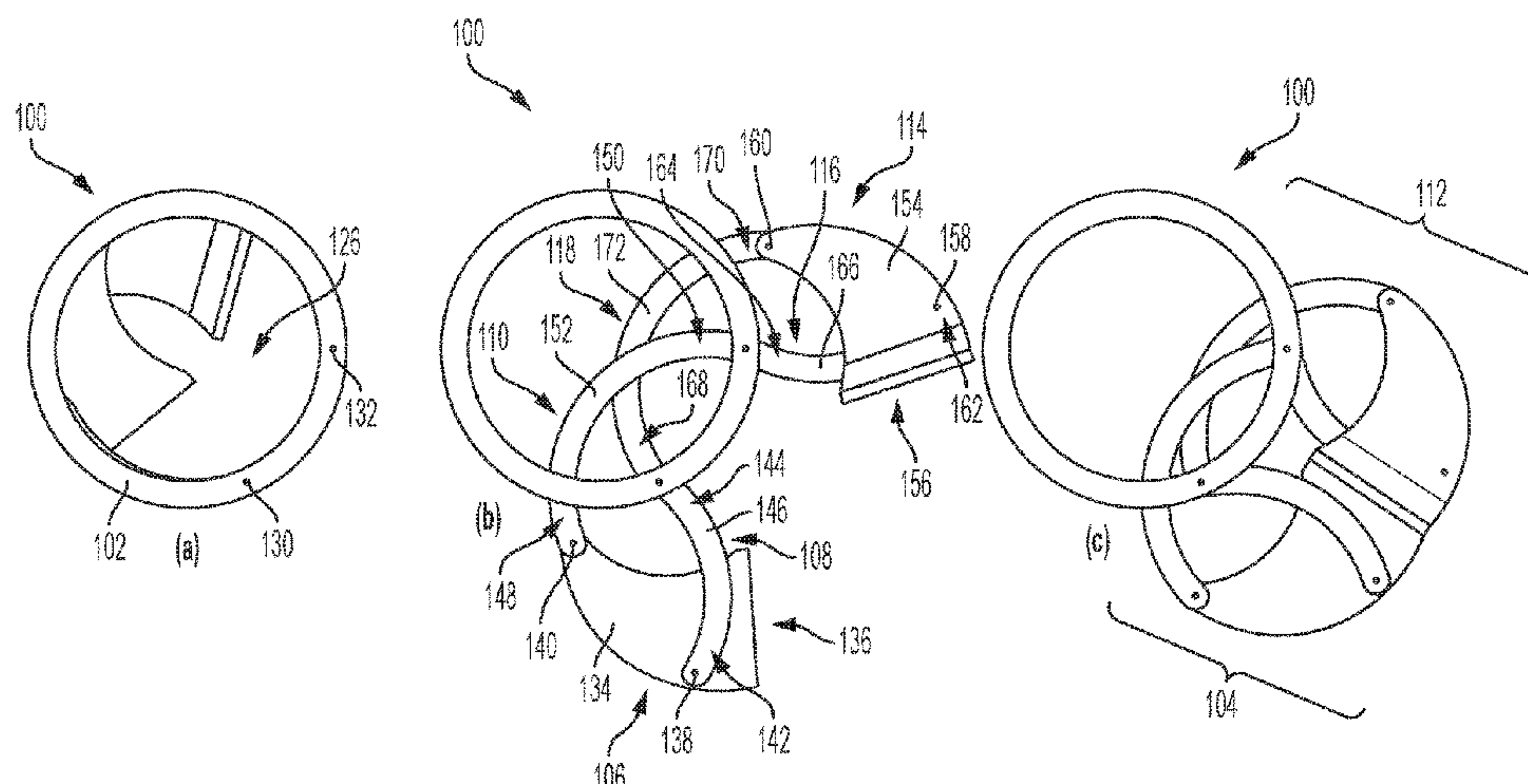
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(57) **ABSTRACT**

A hollow rod developable actuator tool including a cylinder
defining the outer circumference of the hollow rod, a first
tool mechanism, and a second tool mechanism. The hollow
rod developable actuator tool transitions from a first closed
state wherein the first tool mechanism and second tool
mechanism are contained entirely within the outer circum-
ference of the hollow rod to a second open state wherein the
first tool mechanism and second tool mechanism extend
outside the outer circumference of the hollow rod.

20 Claims, 7 Drawing Sheets



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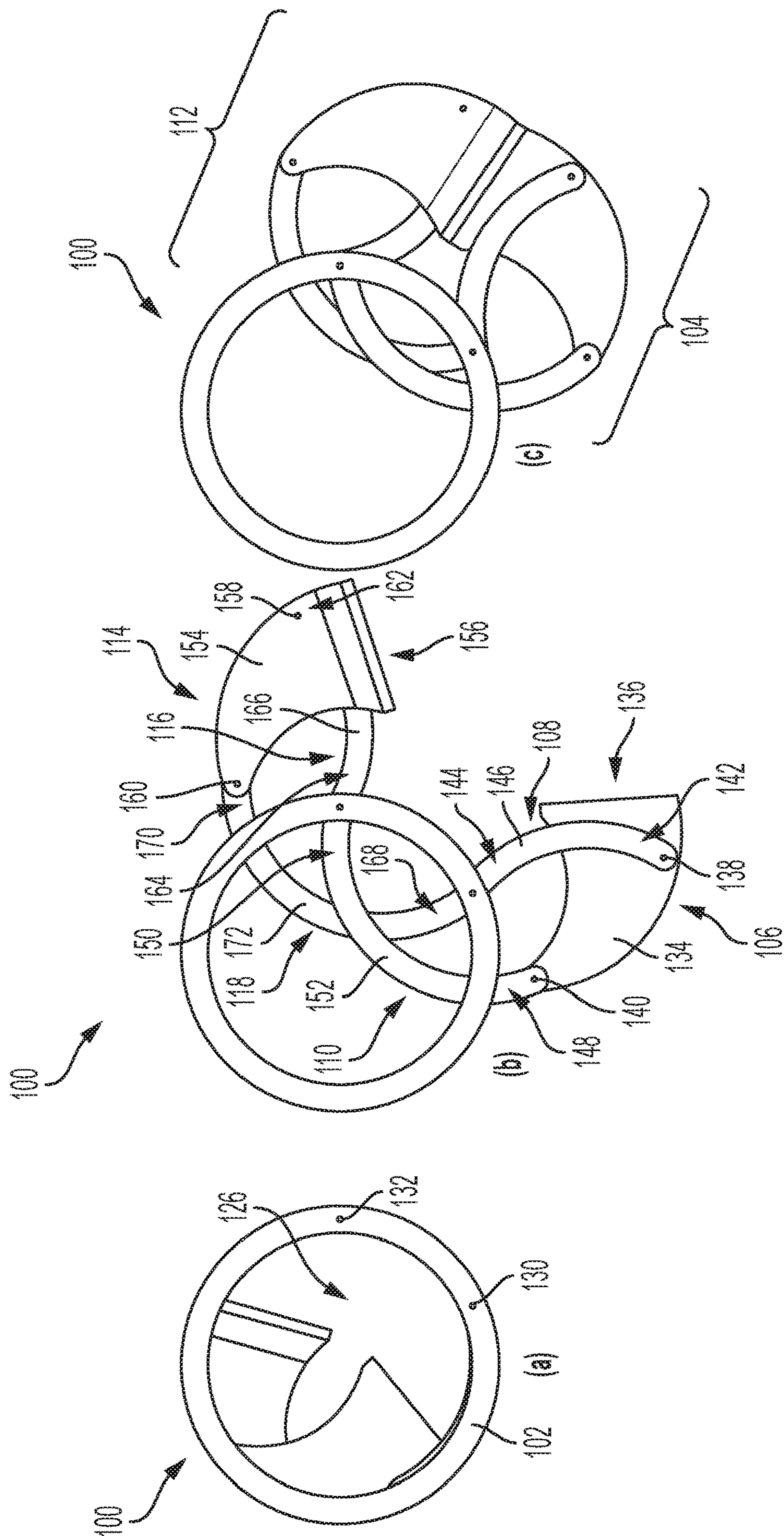
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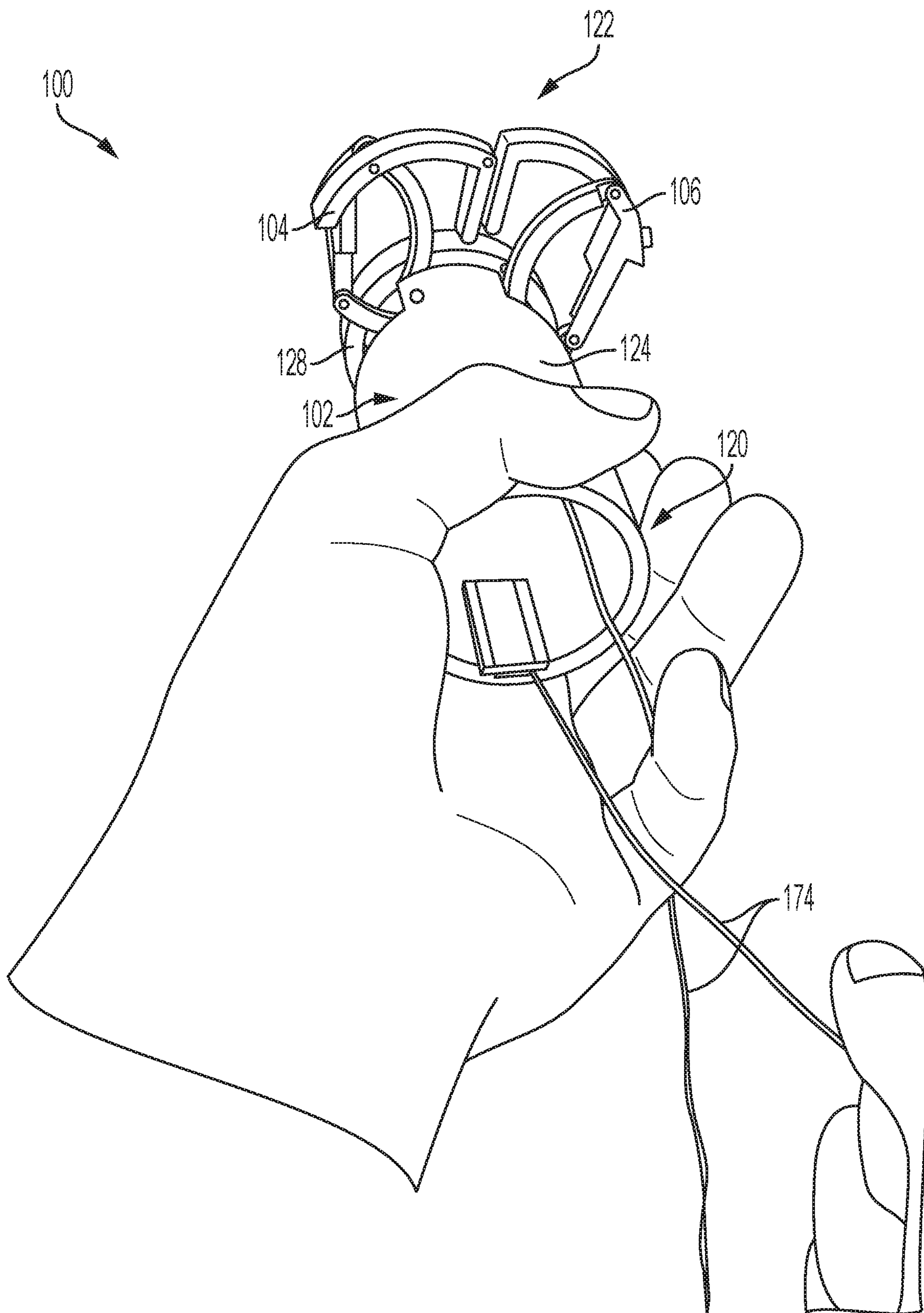
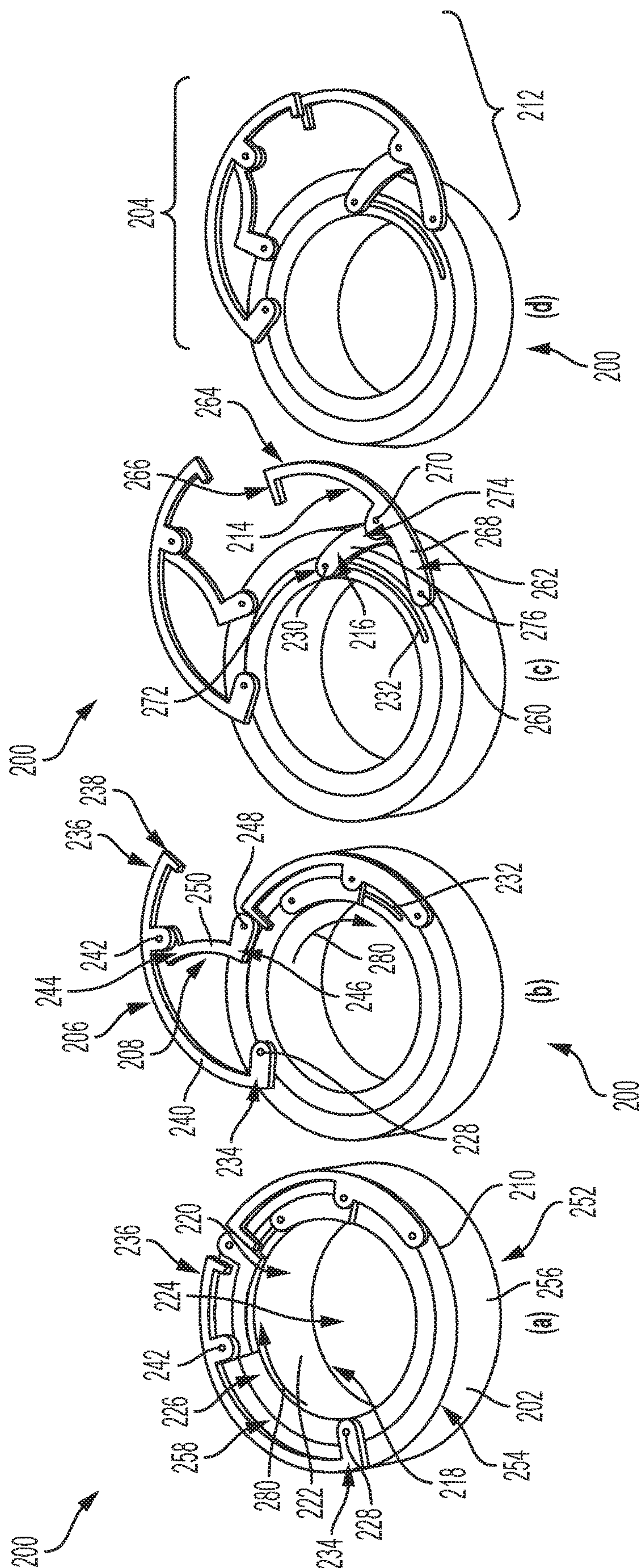


FIG. 2



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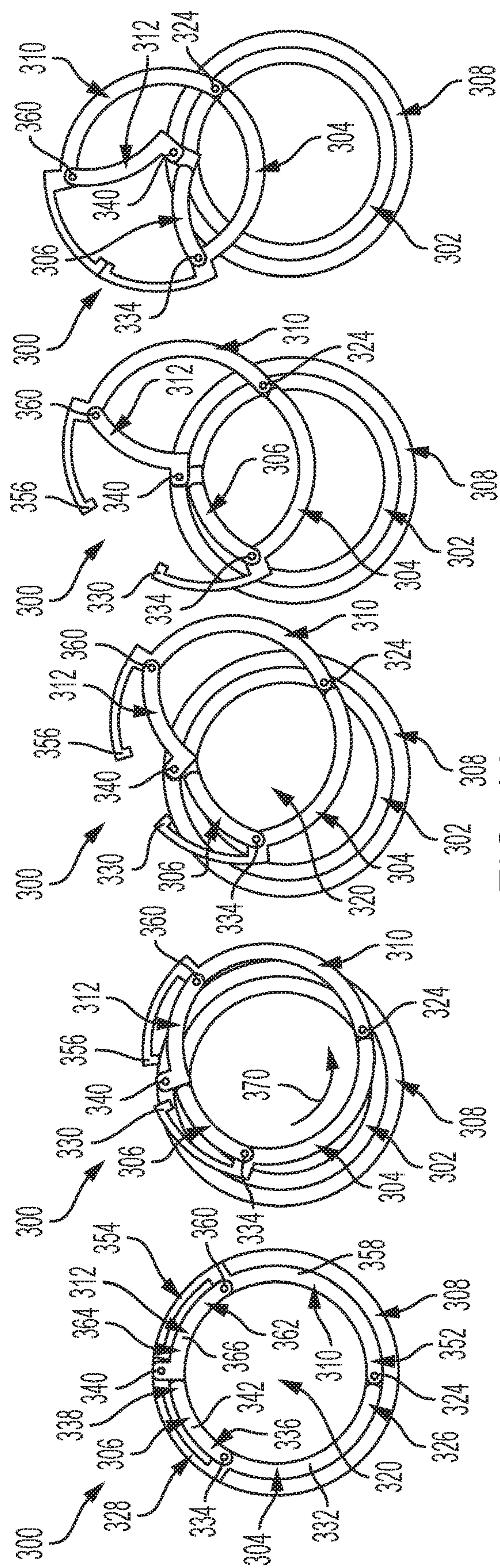


FIG. 4A

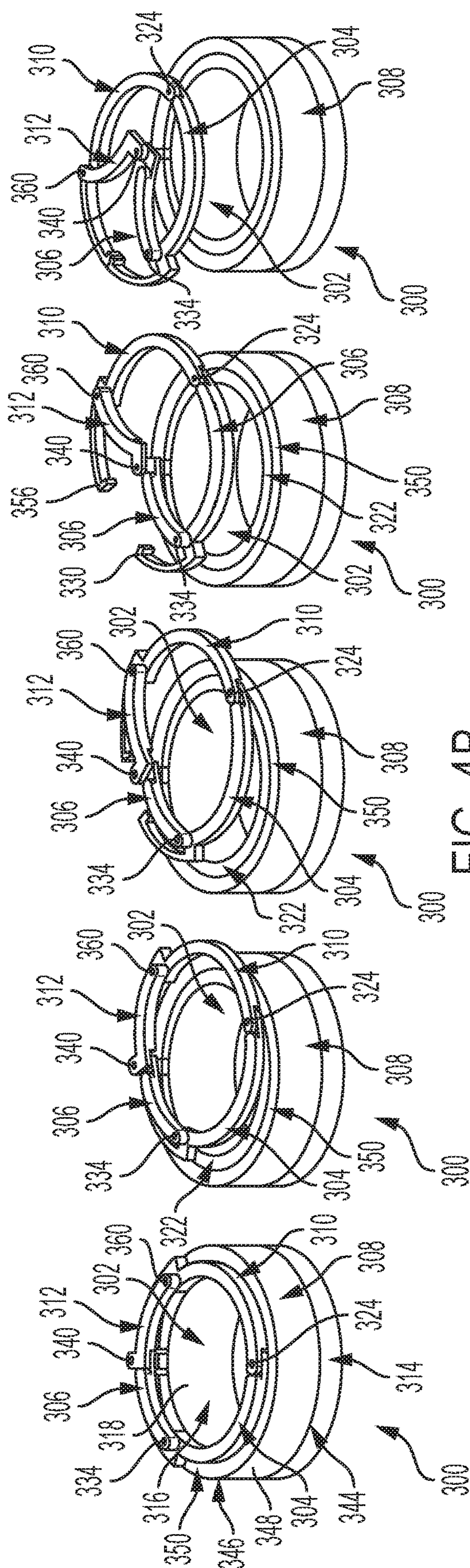


FIG. 4B

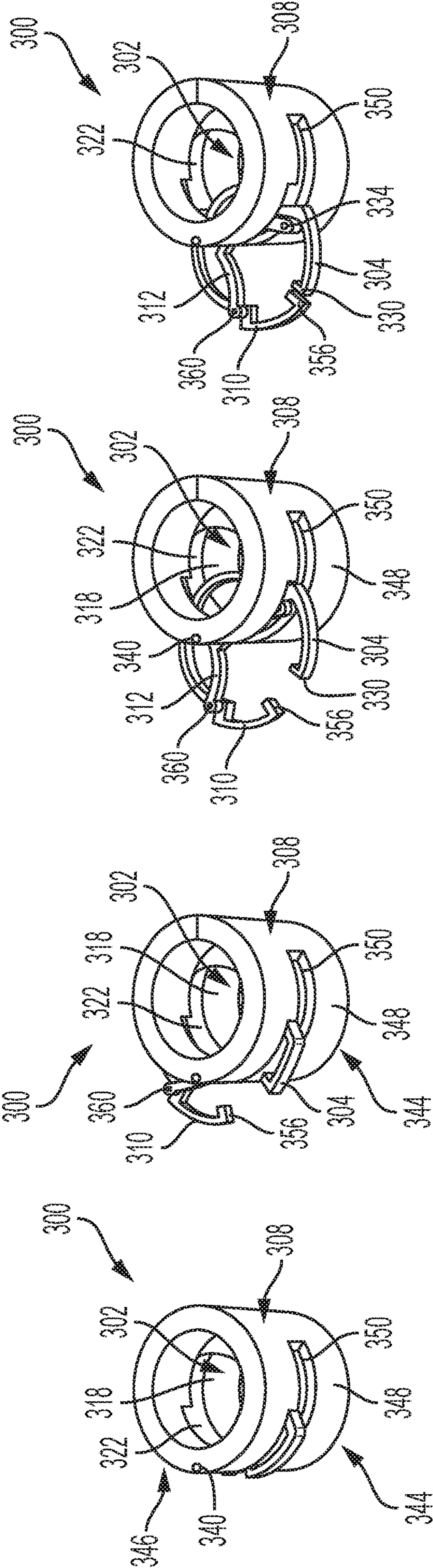


FIG. 4C

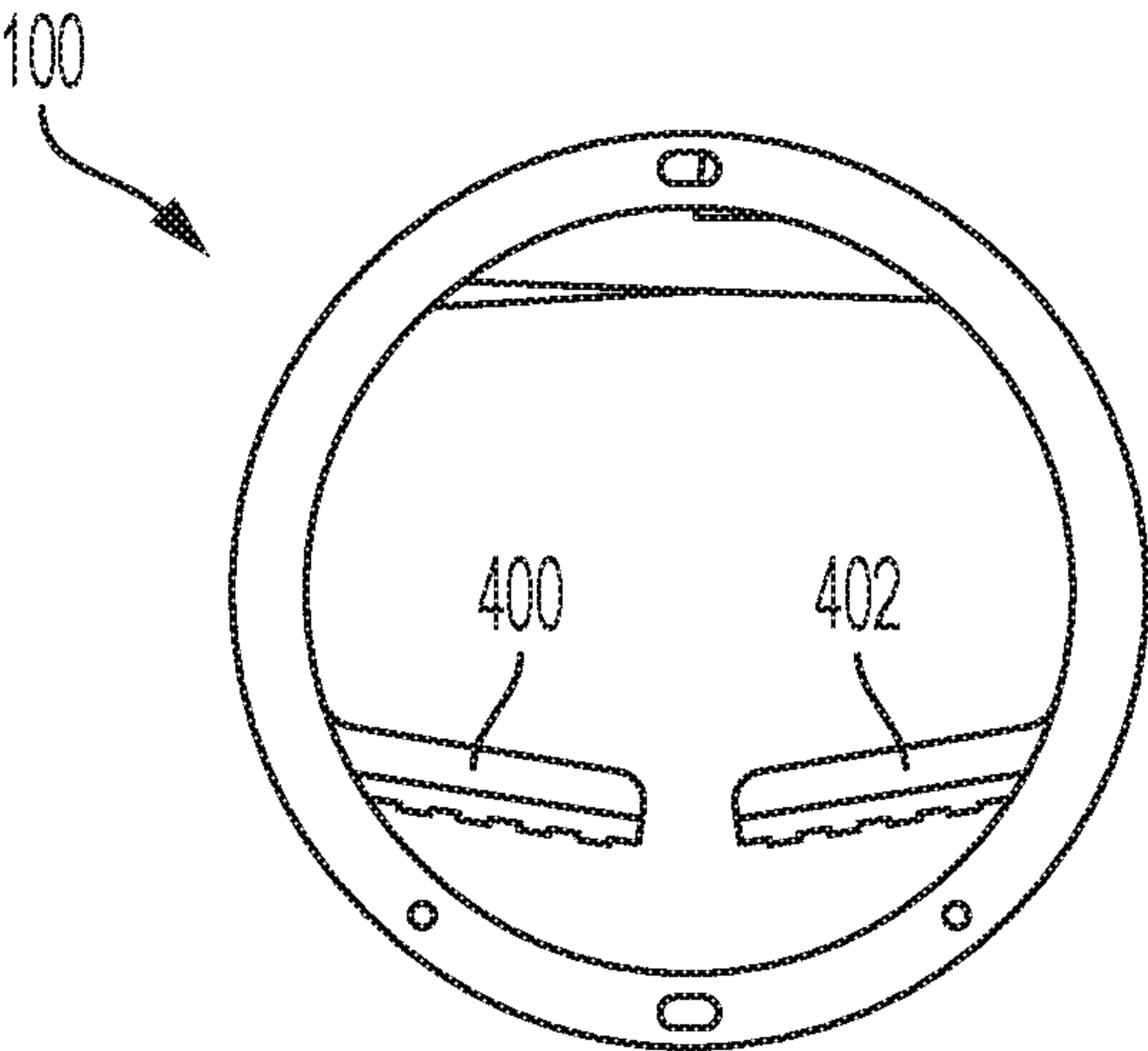


FIG. 5A

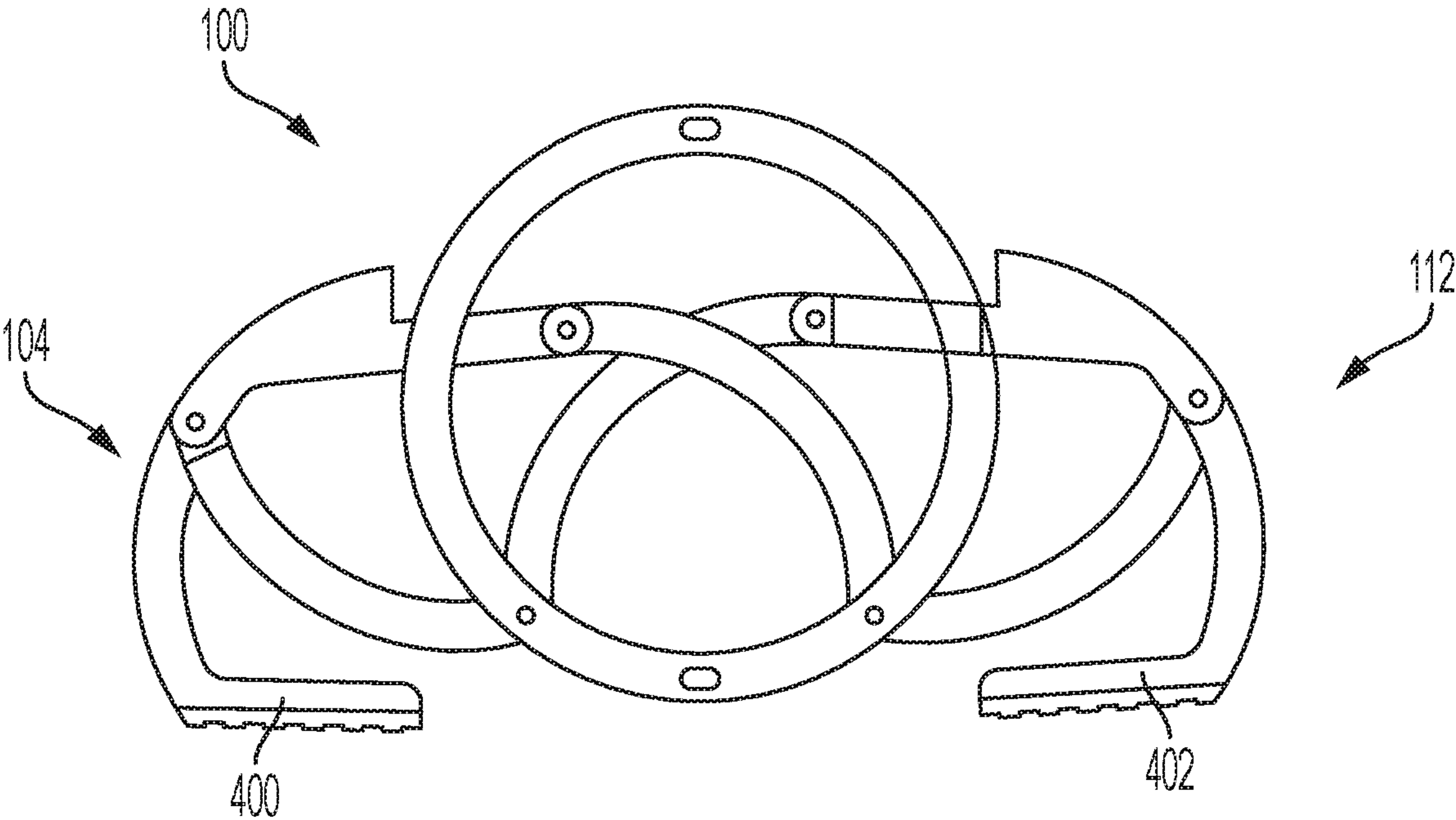


FIG. 5B

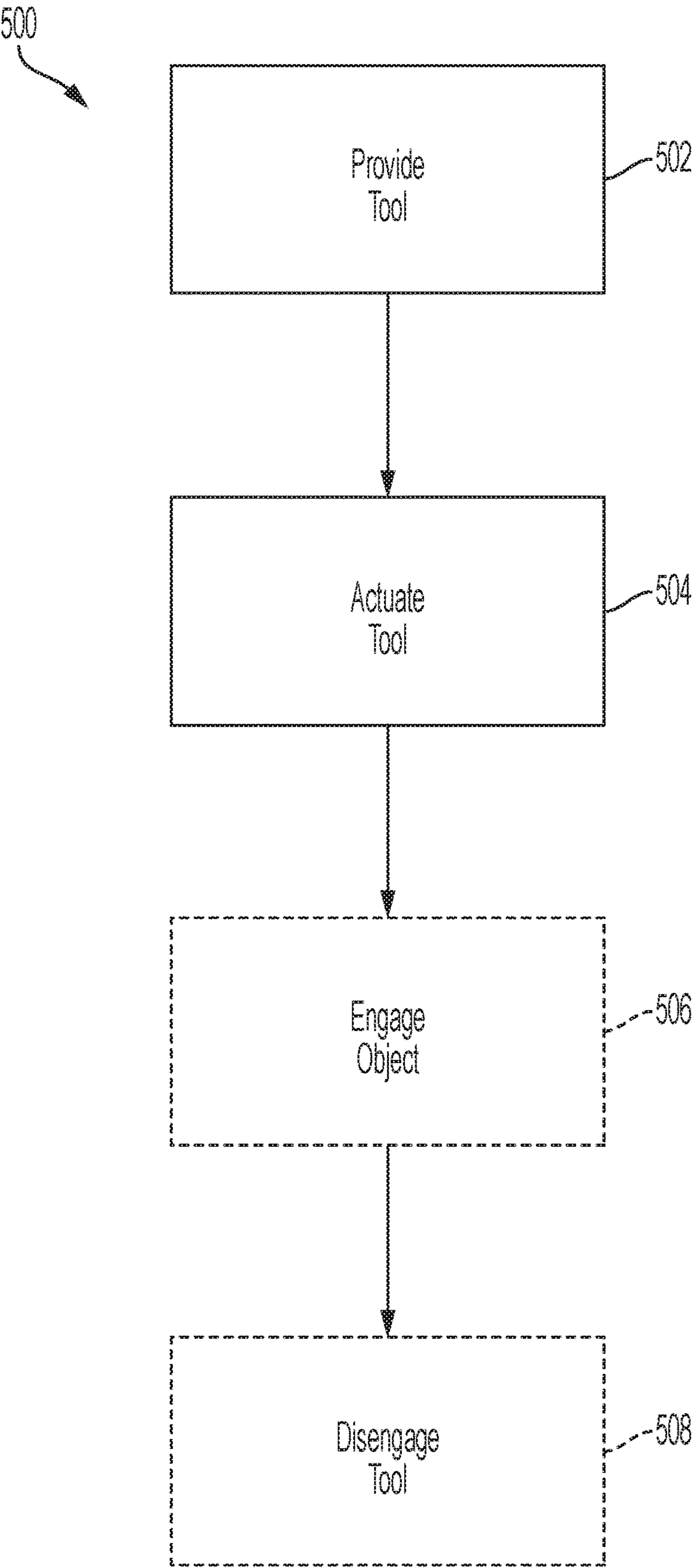


FIG. 6

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DEVELOPABLE AND COLLAPSABLE EXTERNAL CUTTING OR GRIPPING MECHANISM

CROSS-REFERENCE TO RELATED APPLICATION(S)

This application is a national stage filing under 35 U.S.C. 371 of International Application No. PCT/US2019/051727, filed Sep. 18, 2019, which claims priority to, and the benefit of, U.S. Provisional Application 62/732,903, filed Sep. 18, 2018, for all subject matter common to both applications. The entire teachings of the above applications are incorporated herein by reference. International Application No. PCT/US2019/051727 was published under PCT Article 21(2) in English.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

This invention was made with government support under NSF Award No. 1663345 awarded by the National Science Foundation. The government has certain rights in the invention.

FIELD OF THE INVENTION

The present invention relates to tools, and more specifically to actuating mechanisms disposed within hollow rods suitable for performing tasks such as cutting, gripping, and/or squeezing, objects outside the hollow rod.

BACKGROUND

Generally, in the field of tools having actuating mechanisms disposed within hollow cylindrical shafts, tubes, or rods, conventional tools often allow only one mechanism to operate at the end of the rod. This is especially the case when the inner cross-sectional areas of the hollow rods are small. For example, down-hole drilling equipment, minimally invasive surgical tools, and the like, often make use of a single tool to operate at the distal end of the shaft/tube/rod and are representative of such shaft, tube, or rod type tool implementations.

SUMMARY

There is a need for hollow rod developable actuator tools having multiple developable actuating mechanisms disposed within hollow rods having small cross-sectional areas. The present invention is directed toward further solutions to address this need, in addition to having other desirable characteristics.

In accordance with example embodiments of the present invention, a hollow rod developable actuator tool is provided. The hollow rod developable actuator tool includes a first link comprising a cylinder, a first tool mechanism, and a second tool mechanism.

The cylinder of the first link includes a first end having a first aperture, a second end having a second aperture, a wall extending between the first end and second end defining an outer circumference of the hollow rod and a central passage therethrough from the first end to the second end, and a cavity in the wall having a first joint and a second joint offset from the first joint mounted therein.

The first tool mechanism includes second link in a first plane perpendicular to the central passage comprising a first

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tool member, a third link in a second plane perpendicular to the central passage, and a fourth link in the second plane perpendicular to the central passage. The first tool member of the second link comprises a body having a first end and a second end, a contact area on the first end of the body, a third joint in proximity to the first end of the body, a fourth joint at the second end of the body. The third link comprises a first end pivotably connected to a first joint on the first link, a second end pivotably connected to the third joint of the second link, and a body extending between the first end and second end. The fourth link comprises a first end pivotably connected to a second joint on the first link, a second end pivotably connected to the fourth joint of the second link, and a body extending between the first end and second end.

The second tool mechanism includes a fifth link in the second plane perpendicular to the central passage comprising a second tool member, a sixth link in the first plane perpendicular to the central passage, and a seventh link in the first plane perpendicular to the central passage. The second tool member of the fifth link comprises a body having a first end and a second end, a contact area on the first end of the body, a fifth joint in proximity to the first end of the body, and a sixth joint at the second end of the body. The sixth link comprises a first end pivotably connected to a second joint on the first link, a second end pivotably connected to the fifth joint of the fifth link, and a body extending between the first end and second end. The seventh link comprises a first end pivotably connected to a first joint on the first link, a second end pivotably connected to the sixth joint of the fifth link, and a body extending between the first end and second end.

The hollow rod developable actuator tool transitions from a first state wherein first tool mechanism and second tool mechanism are contained entirely inside the outer circumference of the hollow rod to a second state where the first tool mechanism and second tool mechanism pass through the cavity in the wall of the first link to extend outside the outer circumference of the hollow rod.

In accordance with aspects of the present invention, the first tool mechanism and second tool mechanism are configured to engage an object between the contact areas of the first and second tool members when in the second open state. In certain such aspects, at least one of the contact area of the first tool mechanism and the contact area of the second tool mechanism is a blade.

In accordance with aspects of the present invention, at least one of the contact area of the first tool mechanism and the contact area of the second tool mechanism is a stabilizing foot.

In accordance with aspects of the present invention, at least one of the body of the second link, the body of the third link, the body of the fourth link, the body of the fifth link, the body of the sixth link, and the body of the seventh link is curved to match the curvature of the first link making the second link, third link, fourth link, fifth link, sixth link, and seventh link flush with the outer circumference when the actuator tool is in the first state.

In accordance with aspects of the present invention, the cavity of the first link is disposed in proximity to the second end of the first link.

In accordance with aspects of the present invention, the transition from the first state to the second state is actuated by cables extending length of the cylinder of the first link.

In accordance with example embodiments of the present invention, a hollow rod developable actuator tool is provided. The hollow rod developable actuator tool includes a first link comprising an inner cylinder, a first tool mechanism

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having a second link and a third link, a fourth link comprising an outer cylinder, and a second tool mechanism having a fifth link and a sixth link.

The inner cylinder of the first link comprises a first end having a first aperture, a second end having a second aperture, a first wall extending between the first aperture and second aperture defining an inner circumference of the hollow rod and a central passage therethrough from first aperture to the second aperture, and a first cavity in the wall having a first joint and a second sliding joint.

The first tool mechanism includes a second link comprising a first tool member and a third link. The first tool member of the second link comprises a first end pivotably connected to the wall of the first link at the first joint, a second end having a contact area, a body extending between first end and second end, and a third joint offset from the second end of the body of the second link. The third link comprises a first end pivotably connected to the third joint of the second link, a second end pivotably connected to a fourth joint, and a body extending between the first end and second end.

The outer cylinder of the fourth link includes a first end having a first aperture, a second end having a second aperture, a second wall extending between the first end and second end defining an outer circumference of the hollow rod and a central passage therethrough from first end to the second end, and a second cavity in the second wall having the fourth joint and a fifth joint.

The second tool mechanism includes a fifth link comprising a second tool member and a sixth link. The second tool member of the fifth link comprises a first end pivotably connected to the wall of the fourth link at the fifth joint, a second end having a contact area, a body extending between first end and second end, and a sixth joint offset from the second end of the body of the fifth link. The sixth link comprises a first end pivotably connected to the sliding second joint on the first link, a second end pivotably connected to the sixth joint of the fifth link, and a body extending between the first end and second end.

When the inner cylinder of the first link is rotated in relation to the outer ring of the fourth link, the actuator tool transitions from a first state wherein first tool mechanism and second tool mechanism are contained within the cavities of the walls to a second state where the first tool mechanism and second tool mechanism extend outside the outer circumference of the hollow rod.

In accordance with aspects of the present invention, the first tool mechanism and second tool mechanism are configured to engage an object between the contact areas of the first and second tool mechanisms. In certain aspects, at least one of the contact area of the first tool mechanism and the contact area of the second tool mechanism is a blade.

In accordance with aspects of the present invention, at least one of the contact area of the first tool mechanism and the contact area of the second tool mechanism is a stabilizing foot.

In accordance with aspects of the present invention, the body of the second link, and the body of the fifth link are curved to match the curvature of the fourth link, and the body of the third link and the body of the sixth link are curved to match the curvature of the first link making the second link, third link, fifth link, and sixth link flush with the inner and outer circumference when the actuator tool is in the first state.

In accordance with aspects of the present invention, the cavity of the first link and the cavity of the fourth link are

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disposed in proximity to the second end of the first link and the second end of the fourth link.

In accordance with example embodiments of the present invention, a hollow rod developable actuator tool is provided. The hollow rod developable actuator tool includes a first link comprising an inner cylinder, a first tool mechanism having a second link and a third link, a fourth link comprising an outer cylinder, and a second tool mechanism having a fifth link and a sixth link.

The inner cylinder of the first link comprises a first end having a first aperture, a second end having a second aperture, a first wall extending between the first aperture and second aperture defining an inner circumference of the hollow rod and a central passage therethrough from first aperture to the second aperture, and a first cavity in the wall having a first joint.

The first tool mechanism includes a second link and a third link. The second link comprises a first end pivotably connected to the wall of the first link at the first joint, a second end having a contact area, a body extending between first end and second end, and a second joint offset from the second end of the body of the second link. The third link comprises a first end pivotably connected to the second joint of the second link, a second end pivotably connected to a third joint, and a body extending between the first end and second end.

The outer cylinder of the fourth link includes a first end having a first aperture, a second end having a second aperture, a second wall extending between the first end and second end defining an outer circumference of the hollow rod and a central passage therethrough from first end to the second end, and a second cavity in the second wall having the third joint.

The second tool mechanism includes a fifth link and a sixth link. The fifth link comprises a first end pivotably connected to the wall of the first link at the first joint, a second end having a contact area, a body extending between first end and second end, and a fourth joint offset from the second end of the body of the fifth link. The sixth link comprises a first end pivotably connected to the fourth joint on the fifth link, a second end pivotably connected to the third joint of the fourth link, and a body extending between the first end and second end.

When the inner cylinder of the first link is rotated in relation to the outer ring of the fourth link, the actuator tool transitions from a first state wherein first tool mechanism and second tool mechanism are contained within the cavities of the walls to a second state where the first tool mechanism and second tool mechanism extend outside the outer circumference of the hollow rod.

In accordance with aspects of the present invention, at least one of the first joint and the third joint may be a compliant mechanism.

In accordance with example embodiments of the present invention, a method for using a hollow rod developable actuator tool is provided. The method involves providing a hollow rod developable actuator tool; and actuating the hollow rod developable actuator tool to transitions from a first closed state to a second open state.

In accordance with aspects of the present invention, the hollow rod developable actuator tool includes a first link comprising a cylinder, a first tool mechanism, and a second tool mechanism.

In accordance with aspects of the present invention, the hollow rod developable actuator tool includes a first link comprising an inner cylinder, a first tool mechanism having

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a second link and a third link, a fourth link comprising an outer cylinder, and a second tool mechanism having a fifth link and a sixth link.

In accordance with aspects of the present invention, the method further includes engaging an object with contact areas of a first tool member and a second tool member.

BRIEF DESCRIPTION OF THE FIGURES

These and other characteristics of the present invention will be more fully understood by reference to the following detailed description in conjunction with the attached drawings, in which:

FIG. 1 shows successive illustrations of a hollow rod developable actuator tool with a central cutting and/or gripping developable actuator mechanism, the tool transitioning through different stages of actuation from stowed within the rod, to deployed open, to deployed closed;

FIG. 2 is an image of the hollow rod developable actuator tool of FIG. 1 in a deployed, closed, configuration, with a pull force applied to the activation pull string;

FIG. 3 shows successive isometric illustrations of a hollow rod developable actuator tool with a cutting and/or gripping developable actuator mechanism, the tool transitioning through different stages of actuation from stowed within the rod, to partially deployed, to deployed and closed;

FIG. 4A shows successive illustrations of a hollow rod developable actuator tool with a cutting and/or gripping developable actuator mechanism, the tool transitioning through different stages of actuation from stowed within the rod, to partially deployed, to deployed and closed;

FIG. 4B shows successive illustrations of the hollow rod developable actuator tool of FIG. 4A with a cutting and/or gripping developable actuator mechanism, the tool transitioning through different stages of actuation from stowed within the rod, to partially deployed, to deployed and closed;

FIG. 4C shows successive perspective illustrations of a hollow rod developable actuator tool with a cutting and/or gripping developable actuator mechanism using compliant mechanisms, the tool transitioning through different stages of actuation from stowed within the rod, to partially deployed, to deployed and closed;

FIGS. 5A and 5B show a hollow rod developable actuator tool in a stowed state and then in a fully deployed state, the tool directed toward a non-gripping application, such as using the mechanism as a landing gear or stabilizing feet for the cylindrical tube; and

FIG. 6 is a flow diagram of a methodology for using a hollow rod developable actuator tool.

DETAILED DESCRIPTION

An illustrative embodiment of the present invention relates to a hollow rod developable actuator tool. This tool includes a cylindrical tube that conceals curved-link (developable) four-bar mechanisms that can actuate to contact from two or more sides (such as to cut, grip, or squeeze) a workpiece that is outside the cylindrical tube. When the mechanism is stowed, the shaft can resemble a simple cylindrical tube with constant outer diameter. The mechanism is actuated by rotating the inner cylinder with respect to the outer cylinder, employing other rotating actuators, using actuation cables, shape memory alloys, or other actuation devices.

A single hollow rod developable actuator tool may enter a workspace through a confined entrance, while a mechanism passing through the center of the tool performs some

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function at the end of the hollow rod. While the mechanism is operating, it can actuate on the outside of the cylindrical tube to perform a task, such as to cut, grip, or squeeze any object on the outside of the hollow rod. This allows multiple functions to be performed with a single entry to the workspace.

Compliant components can be included in the system to make the systems bi-stable or multi-stable. Such segments can also be used put dual systems in the same plane.

FIGS. 1 through 6, wherein like parts are designated by like reference numerals throughout, illustrate an example embodiment or embodiments of a hollow rod developable actuator tool, according to the present invention. Although the present invention will be described with reference to the example embodiment or embodiments illustrated in the figures, it should be understood that many alternative forms can embody the present invention. One of skill in the art will additionally appreciate different ways to alter the parameters of the embodiment(s) disclosed, such as the size, shape, or type of elements or materials, in a manner still in keeping with the spirit and scope of the present invention.

As utilized herein, the term “developable” has a specific definition. A developable surface is a shape that can be made from a thin sheet of material without breaking or stretching. The term “developable mechanism” or “developable actuator” are interchangeable terms as utilized herein and describe a mechanism that conforms to or is created from a developable surface. Developable mechanisms can conform to or emerge from developable surfaces such as aircraft fuselages and wings, submarine hulls, rocket cones, and minimally invasive surgery tools.

FIG. 1 and FIG. 2 depict one embodiment of hollow rod developable actuator tool 100 of the present invention. FIG. 1 show a top down view of the hollow rod developable actuator tool 100 in successive images (a)-(c) showing the actuation of the tool from a first stowed state (a) to a second deployed state (c). FIG. 2 shows a hollow rod actuator in use. In the embodiments of FIG. 1 and FIG. 2, a single hollow rod in the form of a cylindrical hollow tube is provided with two four-bar mechanisms, both fit to the diameter and thickness of the cylinder, so that the individual links of the mechanism have the same curvature as the cylinder (although this is not a requirement for operation).

Both four-bar mechanisms share the first link 102 comprising a cylinder. The rest of the first four-bar mechanism makes up a first tool mechanism 104 including a second link 106, a third link 108, and a fourth link 110. The rest of the second four-bar mechanism makes up a second tool mechanism 112 including a fifth link 114, a sixth link 116, and a seventh link 118. Each of these elements will be described in more detail below.

The cylinder of the first link 102 has a first end 120 having a first aperture, a second end 122 having a second aperture, and a wall 124 extending between the first end 120 and second end 122 defining an outer circumference of the hollow rod developable actuator too 1100 and a central passage 126 therethrough from the first end 120 to the second end 122. A cavity 128 is disposed in the wall 124 having a first joint 130 and a second joint 132 offset from the first joint 130 mounted therein.

The wall 124 of the first link 102 may be formed of plastic, metal, or any other material suitable for forming a developable surface. Examples of suitable materials include stainless steel, titanium, nitinol, tungsten carbide, carbon steels, aluminum, high density polyethylene (HDPE), polypropylene, polylactic acid (PLA), acrylonitrile butadiene styrene (ABS) plastic, polyethylene terephthalate (PET),

and acrylic. Other suitable materials will be apparent to one skilled in the art given the benefit of this disclosure. The outer circumference of the first link 102 as well as the length of the wall 124 between the first end 120 and the second end 122 may vary depending on the intended use or application of the hollow rod developable actuator tool 100.

The cavity 128 in the wall 124 comprises a recess, cut-away, channel, passage, window, or the like that is sized and dimensioned to allow the first tool mechanism 104 and the second tool mechanism 112 to reside or otherwise be stowed in the first cavity when the mechanism of the present device is in a closed position. The first joint 130 is a pin embedded in the wall 124 and spanning the cavity 128 at one end of the cavity 128. The second joint 132 is a pin embedded in the wall 124 and spanning the cavity 128 at the other end of the cavity 128 such that the second joint 132 is offset from the first joint 130 along the circumference of the cylinder of the first link 102. Other suitable joint devices and configurations will be apparent to one skilled in the art given the benefit of this disclosure.

As discussed, the first tool mechanism 104 includes a second link 106, a third link 108, and fourth link 110. These elements in conjunction with the first link 102 make up a first four bar mechanism.

In the example of FIG. 1 and FIG. 2, the second link 106 is in a first plane perpendicular to the central passage 126 and makes up a first tool member. The first tool member of the second link 106 includes a body 134 having a first end and a second end, a contact area 136 on the first end of the body 134, a third joint 138 in proximity to the first end of the body 134, and a fourth joint 140 at the second end of the body 134.

The body 134 that makes up the first tool member of the second link 106 may be formed of plastic, metal, or any other material suitable for forming a developable surface. Examples of suitable materials include stainless steel, titanium, nitinol, tungsten carbide, carbon steels, aluminum, high density polyethylene (HDPE), polypropylene, polylactic acid (PLA), acrylonitrile butadiene styrene (ABS) plastic, polyethylene terephthalate (PET), and acrylic. In certain embodiments, the body 134 of the second link 106 is curved to conform to the curvature of the first link 102 such that the body 134 of the second link 106 can align with and be contained within the outer circumference of the cylinder of the first link 102 when the first tool mechanism 104 is stowed or otherwise docked in the cavity 128 in the wall 124 of the first link 102 when the mechanism is in a closed state as seen in the first image (a) of FIG. 1.

The contact area 136 is configured to engage with objects when the first tool member is extended outside the mechanism is in an open state. In certain embodiments, the contact area 136 is a gripping surface. In other embodiments, the contact area 136 is a blade. In still other embodiments, the contact area 136 is a stabilizing foot. In certain embodiments, the contact area 136 is formed as part of the body 134 from the same material as the body 134. In other embodiments, the contact area 136 can be formed of a material different from the body 134 and attached to the body 134. In certain embodiments, the contact area 136 may extend from the first plane perpendicular to the central passage 126 into the second plane perpendicular to the central passage 126. Other suitable materials and implementations will be apparent to one skilled in the art given the benefit of this disclosure.

In the example of FIG. 1 and FIG. 2, the third link 108 is in a second plane perpendicular to the central passage 126. The third link 108 has a first end 142 pivotably connected to

the first joint 130 of the first link 102, a second end 144 pivotably connected to the third joint 138 of the second link 106, and a body 146 extending between the first end 142 and second end 144. The body 146 of the third link 108 may be formed of plastic, metal, or any other material suitable for forming a developable surface. Examples of suitable materials include stainless steel, titanium, nitinol, tungsten carbide, carbon steels, aluminum, high density polyethylene (HDPE), polypropylene, polylactic acid (PLA), acrylonitrile butadiene styrene (ABS) plastic, polyethylene terephthalate (PET), and acrylic. In certain embodiments, the body 146 of the third link 108 is curved to conform to the curvature of the first link 102 such that the body 146 of the third link 108 can reside within the cavity 128 in the first link 102 and be flush with the outer circumference of the first link 102 when the mechanism is in a closed state as seen in the first image (a) of FIG. 1.

In the example of FIG. 1 and FIG. 2, the fourth link 110 is in the second plane perpendicular to the central passage 126. The fourth link 110 has a first end 148 pivotably connected to the second joint 132 of the first link 102, a second end 150 pivotably connected to the fourth joint 140 of the second link 106, and a body 152 extending between the first end 148 and second end 150. The body 152 of the fourth link 110 may be formed of plastic, metal, or any other material suitable for forming a developable surface. Examples of suitable materials include stainless steel, titanium, nitinol, tungsten carbide, carbon steels, aluminum, high density polyethylene (HDPE), polypropylene, polylactic acid (PLA), acrylonitrile butadiene styrene (ABS) plastic, polyethylene terephthalate (PET), and acrylic. In certain embodiments, the body 152 of the fourth link 110 is curved to conform to the curvature of the first link 102 such that the body 152 of the fourth link 110 can reside within the cavity 128 in the first link 102 and be flush with the outer circumference of the first link 102 when the mechanism is in a closed state as seen in the first image (a) of FIG. 1.

As discussed, the second tool mechanism 112 includes a fifth link 114, a sixth link 116, and seventh link 118. These elements in conjunction with the first link 102 make up a second four bar mechanism.

In the example of FIG. 1 and FIG. 2, the fifth link 114 is in the second plane perpendicular to the central passage 126 and makes up a second tool member. The second tool member of the fifth link 114 includes a body 154 having a first end and a second end, a contact area 156 on the first end of the body 154, a fifth joint 158 in proximity to the first end of the body 154, and a sixth joint 160 at the second end of the body 154.

The body 154 that makes up the second tool member of the fifth link 114 may be formed of plastic, metal, or any other material suitable for forming a developable surface. Examples of suitable materials include stainless steel, titanium, nitinol, tungsten carbide, carbon steels, aluminum, high density polyethylene (HDPE), polypropylene, polylactic acid (PLA), acrylonitrile butadiene styrene (ABS) plastic, polyethylene terephthalate (PET), and acrylic. In certain embodiments, the body 154 of the fifth link 114 is curved to conform to the curvature of the first link 102 such that the body 154 of the second link 106 can align with and be contained within the outer circumference of the cylinder of the first link 102 when the second tool mechanism 112 is stowed or otherwise docked in the cavity 128 in the wall 124 of the first link 102 when the mechanism is in a closed state as seen in the first image (a) of FIG. 1.

The contact area 156 is configured to engage with objects when the second tool member is extended outside the

mechanism in an open state. In certain embodiments, the contact area **156** is a gripping surface. In other embodiments, the contact area **156** is a blade. In still other embodiments, the contact area **156** is a stabilizing foot. In certain embodiments, the contact area **156** is formed as part of the body **154** from the same material as the body **154**. In other embodiments, the contact area **156** can be formed of a material different from the body **154** and attached to the body **154**. In certain embodiments, the contact area **156** may extend from the second plane perpendicular to the central passage **126** into the first plane perpendicular to the central passage **126**. Other suitable materials and implementations will be apparent to one skilled in the art given the benefit of this disclosure.

In the example of FIG. 1 and FIG. 2, the sixth link **116** is in the first plane perpendicular to the central passage **126**. The sixth link **116** has a first end **162** pivotably connected to the second joint **132** of the first link **102**, a second end **164** pivotably connected to the fifth joint **158** of the fifth link **114**, and a body **166** extending between the first end **162** and second end **164**. The body **166** of the sixth link **116** may be formed of plastic, metal, or any other material suitable for forming a developable surface. Examples of suitable materials include stainless steel, titanium, nitinol, tungsten carbide, carbon steels, aluminum, high density polyethylene (HDPE), polypropylene, polylactic acid (PLA), acrylonitrile butadiene styrene (ABS) plastic, polyethylene terephthalate (PET), and acrylic. In certain embodiments, the body **166** of the sixth link **116** is curved to conform to the curvature of the first link **102** such that the body **166** of the sixth link **116** can reside within the cavity **128** in the first link **102** and be flush with the outer circumference of the first link **102** when the mechanism is in a closed state as seen in the first image (a) of FIG. 1.

In the example of FIG. 1 and FIG. 2, the seventh link **118** is in the first plane perpendicular to the central passage **126**. The seventh link **118** has a first end **168** pivotably connected to the first joint **130** of the first link **102**, a second end **170** pivotably connected to the sixth joint **160** of the fifth link **114**, and a body **172** extending between the first end **168** and second end **170**. The body **172** of the seventh link **118** may be formed of plastic, metal, or any other material suitable for forming a developable surface. Examples of suitable materials include stainless steel, titanium, nitinol, tungsten carbide, carbon steels, aluminum, high density polyethylene (HDPE), polypropylene, polylactic acid (PLA), acrylonitrile butadiene styrene (ABS) plastic, polyethylene terephthalate (PET), and acrylic. In certain embodiments, the body **172** of the seventh link **118** is curved to conform to the curvature of the first link **102** such that the body **172** of the seventh link **118** can reside within the cavity **128** in the first link **102** and be flush with the outer circumference of the first link **102** when the mechanism is in a closed state as seen in the first image (a) of FIG. 1.

The depth (or distance along the length of the cylinder) on the first link **102** of the first tool mechanism **104** and second tool mechanism **112** does not change the function of the mechanism. In certain embodiments, the cavity **128** of the wall **124** is located in proximity to the second end **122** of the first link **102**. Thus, the first tool mechanism **104** and second tool mechanism **112** are also located in proximity to the second end **122**. Typically, the first end **120** would be proximate to a user while the distal second end **122** would be inserted into the workspace.

When actuated, the tool **100** transitions from a first state wherein first tool mechanism **104** and second tool mechanism **112** are contained entirely inside the outer circumfer-

ence of the cylinder of the first link **102** to a second state where the first tool mechanism **104** and second tool mechanism **112** pass through the cavity **128** in the wall **124** of the first link **102** to extend outside the outer circumference of the first link **102**.

Once deployed in the second state, the first tool mechanism **104** and second tool mechanism **112** can be used to interact with an object in the environment outside the outer circumference of the tool. In certain embodiments, such as seen in FIG. 1 and FIG. 2 The first tool member of the second link **106** and the second tool member of the fifth link **114** are configured to engage an object between the contact area **136** of the second link **106** and the contact area **156** of the fifth link **114**. In such embodiments, the contact areas **136**, **156** can extend from the plane of their respective tool member into the plane of the corresponding tool member. Thus, the contact area **136** of the second link extends from the first plane of the first tool member into the second plane of the second tool member and the contact area **156** of the fifth link **114** extends from the second plane of the second tool member into the first plane of the first tool member. As such, the contact areas **136**, **156** meet up when brought together allowing an object to be gripped between the contact areas **136**, **156**. In other embodiments, at least one of the contact areas **136**, **156** is a blade, wherein an object is cut when the contact areas **136**, **156** are brought together.

Similarly, the tool **100** can be transitioned from the second state where the first tool mechanism **104** and second tool mechanism **112** are extended outside the outer circumference of the first link **102** to the first state where the first tool mechanism **104** and second tool mechanism **112** pass through the cavity **128** in the wall **124** of the first link **102** to be contained within the cavity **128** and the outer circumference of the first link **102**.

Actuation of the two four-bar mechanisms can be accomplished by the use of cables, similar to minimally invasive tools. This actuation method can be seen in FIG. 2, where cables **174** extending from the first end **120** of the cylinder of the first link **102** of the tool **100** are used to actuate the first tool mechanism **104** and second tool mechanism **112** located at the second end **122** of the cylinder of the first link **102** of the tool **100**.

FIG. 3 depicts another embodiment of a hollow rod developable actuator tool **200** of the present invention. FIG. 3 show a perspective view of the hollow rod developable actuator tool **200** in successive images (a)-(d) showing the actuation of the tool from a first stowed state (a) to a second deployed state (d).

In the hollow rod developable actuator tool **200** of FIG. 3, a single hollow rod in the form of a concentric cylinders is provided with two four-bar mechanisms, both fit to the diameter and thickness of the cylinder, so that the individual links of the mechanism have the same curvature as the cylinder (although this is not a requirement for operation).

A first link **202** comprising an inner cylinder is shared by both four-bar mechanisms. The first four-bar mechanism also includes a first tool mechanism **204** including a second link **206** and a third link **208**. The final element of the four-bar mechanism is a fourth link **210** comprising an outer cylinder. The fourth link **210** is also shared with the second four-bar mechanism. The rest of the second four-bar mechanism makes includes second tool mechanism **212** including a fifth link **214** and a sixth link **216**. Each of these elements will be described in more detail below.

The cylinder of the first link **202** has a first end **218** having a first aperture, a second end **220** having a second aperture, and a first wall **222** extending between the first end **218** and

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second end **220** defining an inner circumference of the tool **200** and a central passage **224** therethrough from the first end **218** to the second end **220**. A first cavity **226** is disposed in the first wall **222** having a first joint **228** and a second sliding joint **230** mounted therein.

The first wall **222** of the first link **202** may be formed of plastic, metal, or any other material suitable for forming a developable surface. Examples of suitable materials include stainless steel, titanium, nitinol, tungsten carbide, carbon steels, aluminum, high density polyethylene (HDPE), polypropylene, polylactic acid (PLA), acrylonitrile butadiene styrene (ABS) plastic, polyethylene terephthalate (PET), and acrylic. Other suitable materials will be apparent to one skilled in the art given the benefit of this disclosure. The inner circumference of the first link **202** as well as the length of the first wall **222** between the first end **218** and the second end **220** may vary depending on the intended use or application of the hollow rod developable actuator tool **200**.

The first cavity **226** in the first wall **222** comprises a recess, cut-away, channel, passage, window, or the like that is sized and dimensioned to allow the first tool mechanism **204** and the second tool mechanism **212** to reside or otherwise be stowed in the first cavity **226** when the mechanism of the present device is in a stowed state. The first joint **228** is a pin embedded in the first wall **222** and spanning the first cavity **226** at one end of the first cavity **226**. The sliding second joint **230** is a pin fitted in a slot **232** in the first wall **222** and spanning the first cavity **226** at the other end of the first cavity **226**. Other suitable joint devices and configurations will be apparent to one skilled in the art given the benefit of this disclosure.

As discussed, the first tool mechanism **204** includes a second link **206** and a third link **208**. These elements in conjunction with the first link **202** and the fourth link **210** make up a first four bar mechanism.

In the example of FIG. 3, the second link **206** makes up a first tool member. The first tool member of the second link **206** includes a first end **234** pivotably connected to the first wall **222** of the first link **202** at the first joint **228**, a second end **236** having a contact area **238**, a body **240** extending between the first end **234** and second end **236**, and a third joint **242** offset from the second end **236** of the second link **206**.

The body **240** that makes up the first tool member of the second link **206** may be formed of plastic, metal, or any other material suitable for forming a developable surface. Examples of suitable materials include stainless steel, titanium, nitinol, tungsten carbide, carbon steels, aluminum, high density polyethylene (HDPE), polypropylene, polylactic acid (PLA), acrylonitrile butadiene styrene (ABS) plastic, polyethylene terephthalate (PET), and acrylic. In certain embodiments, the body **240** of the second link **206** is curved to conform to the curvature of the first link **202** such that the body **240** of the second link **206** can align with and be contained within the outer circumference of the cylinder of the fourth link **210** when the first tool mechanism **204** is in a stowed state as seen in the first image (a) of FIG. 3.

The contact area **238** is configured to engage with objects when the first tool member is extended outside the mechanism is in a deployed state. In certain embodiments, the contact area **238** is a gripping surface. In other embodiments, the contact area **238** is a blade. In still other embodiments, the contact area **238** is a stabilizing foot. In certain embodiments, the contact area **238** is formed as part of the body **240** from the same material as the body **240**. In other embodiments, the contact area **238** can be formed of a material different from the body **240** and attached to the

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body **240**. Other suitable materials and implementations will be apparent to one skilled in the art given the benefit of this disclosure.

The third link **208** has a first end **244** pivotably connected to the third joint **242** of the second link **206**, a second end **246** pivotably connected to a fourth joint **248**, and a body **250** extending between the first end **244** and second end **246**. The body **250** of the third link **208** may be formed of plastic, metal, or any other material suitable for forming a developable surface. Examples of suitable materials include stainless steel, titanium, nitinol, tungsten carbide, carbon steels, aluminum, high density polyethylene (HDPE), polypropylene, polylactic acid (PLA), acrylonitrile butadiene styrene (ABS) plastic, polyethylene terephthalate (PET), and acrylic. In certain embodiments, the body **250** of the third link **208** is curved to conform to the curvature of the first link **202** such that the body **250** of the third link **208** can reside within the first cavity **226** in the first link **202** and be flush with the inner circumference of the first link **202** when the mechanism is in a stowed state as seen in the first image (a) of FIG. 3.

The outer cylinder of the fourth link **210** has a first end **252** having a first aperture, a second end **254** having a second aperture, and a second wall **256** extending between the first end **252** and the second end **254** defining an outer circumference of the hollow rod and the central passage **224** therethrough from the first end **252** to the second end **254**. A second cavity **258** is disposed in the second wall **256** having the fourth joint **248** mounted and a fifth joint **260** mounted therein.

The second wall **256** of the fourth link **210** may be formed of plastic, metal, or any other material suitable for forming a developable surface. Examples of suitable materials include stainless steel, titanium, nitinol, tungsten carbide, carbon steels, aluminum, high density polyethylene (HDPE), polypropylene, polylactic acid (PLA), acrylonitrile butadiene styrene (ABS) plastic, polyethylene terephthalate (PET), and acrylic. Other suitable materials will be apparent to one skilled in the art given the benefit of this disclosure. The outer circumference of the fourth link **210** as well as the length of the second wall **256** between the first end **252** and the second end **254** may vary depending on the intended use or application of the hollow rod developable actuator tool **200**.

The second cavity **258** in the second wall **256** comprises a recess, cut-away, channel, passage, window, or the like that is sized and dimensioned to allow the first tool mechanism **204** the second tool mechanism **212** to reside or otherwise be stowed in the second cavity **258** when the mechanism of the present device is in a closed position. In the embodiment of FIG. 3 the fourth joint **248** is a pin embedded in the second wall **256** and spanning the second cavity **258** located at one end of the second cavity **258**. The fifth joint **260** is a pin embedded in the second wall **256** and spanning the second cavity **258** at the other end of the second cavity **258**. Other suitable joint devices or mechanism will be apparent to one skilled in the art given the benefit of this disclosure.

As discussed, the second tool mechanism **212** includes a fifth link **214** and a sixth link **216**. These elements in conjunction with the first link **202** and the fourth link **210** make up the second four-bar mechanism.

In the example of FIG. 3, the fifth link **214** makes up a second tool member. The second tool member of the fifth link **214** includes a first end **262** pivotably connected to the second wall **256** of the fourth link **210** at the fifth joint **260**, a second end **264** having a contact area **266**, a body **268**

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extending between the first end **262** and second end **264**, and a sixth joint **270** offset from the second end **264** of the fifth link **214**.

The body **268** that makes up the second tool member of the fifth link **214** may be formed of plastic, metal, or any other material suitable for forming a developable surface. Examples of suitable materials include stainless steel, titanium, nitinol, tungsten carbide, carbon steels, aluminum, high density polyethylene (HDPE), polypropylene, polylactic acid (PLA), acrylonitrile butadiene styrene (ABS) plastic, polyethylene terephthalate (PET), and acrylic. In certain embodiments, the body **268** of the fifth link **214** is curved to conform to the curvature of the fourth link **210** such that the body **268** of the fifth link **214** can align with and be contained within the outer circumference of the cylinder of the fourth link **210** when the second tool mechanism **212** is in a stowed state as seen in the first image (a) of FIG. 3.

The contact area **266** is configured to engage with objects when the second tool member is extended outside the mechanism in a deployed state. In certain embodiments, the contact area **266** is a gripping surface. In other embodiments, the contact area **266** is a blade. In still other embodiments, the contact area **266** is a stabilizing foot. In certain embodiments, the contact area **266** is formed as part of the body **268** from the same material as the body **268**. In other embodiments, the contact area **266** can be formed of a material different from the body **268** and attached to the body **268**. Other suitable materials and implementations will be apparent to one skilled in the art given the benefit of this disclosure.

The sixth link **216** has a first end **272** pivotably connected to the sliding second joint **230** of the first link **202**, a second end **274** pivotably connected to a sixth joint **270** of the fifth link **214**, and a body **276** extending between the first end **272** and second end **274**. The body **276** of the sixth link **216** may be formed of plastic, metal, or any other material suitable for forming a developable surface. Examples of suitable materials include stainless steel, titanium, nitinol, tungsten carbide, carbon steels, aluminum, high density polyethylene (HDPE), polypropylene, polylactic acid (PLA), acrylonitrile butadiene styrene (ABS) plastic, polyethylene terephthalate (PET), and acrylic. In certain embodiments, the body **250** of the sixth link **216** is curved to conform to the curvature of the first link **202** such that the body **250** of the sixth link **216** can reside within the first cavity **226** in the first link **202** and be flush with the inner circumference of the first link **202** when the mechanism is in a stowed state as seen in the first image (a) of FIG. 3.

The depth (or distance along the length of the cylinder) on the fourth link **210** of the first link **202**, first tool mechanism **204**, and second tool mechanism **212** does not change the function of the mechanism. In certain embodiments, the first link **202** extends the full length of the fourth link. In certain embodiments, the first cavity **226** of the first wall **222** and the second cavity **258** of the second wall **256** are located in proximity to the second end **254** of the fourth link **210** and the second end **220** of the first link **202**. Thus, the first tool mechanism **204** and second tool mechanism **212** are also located proximity to the second ends **220**, **254**. Typically, the first ends **218**, **252** would be proximate to a user while the distal second ends **220**, **254** would be inserted into the workspace.

When the inner cylinder of the first link **202** is rotated in relation to the outer cylinder of the fourth link **210** such as indicated by arrow **280**, the tool **200** transitions from a first state wherein first tool mechanism **204** and second tool mechanism **212** are contained within the first cavity **226** of

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the first wall **222** of the first link **202** and the second cavity **258** of the second wall **256** of the fourth link **210** as seen in the first image (a) of FIG. 3 to a second state where the first tool mechanism **204** and second tool mechanism **212** pass through the second cavity **258** in the second wall **256** of the fourth link **210** to extend outside the outer circumference of the fourth link **210** where the first tool mechanism **204** and second tool mechanism **212** can interact with an object outside the tool **200** as seen in the last image (d) of FIG. 3. In the second image (b) of FIG. 3 the first tool mechanism **204** is extended at the inner cylinder of the first link **202** is rotated in relation to the outer cylinder of the fourth link **210** as indicated by arrow **280** moving the first joint **228** on the first link **202** toward the fourth joint **248** on the fourth link **210** swinging the third link **208** outward which in turn moves the first tool member of the second link **206** outside the tool **200**. The pin of sliding second joint **230** sliding through slot **232** prevents the second tool mechanism **212** from being deployed. In the third image (c) of FIG. 3, the pin of the sliding second joint **230** reaches the end of the slot **232** and the sixth link **216** swings outward which in turn moves the second tool member of the fifth link **214** outside the tool **200**. In the final image (d) of FIG. 3 the first tool mechanism **204** and second tool mechanism **212** are in the extended in the second deployed state.

Once deployed in the second state, the first tool mechanism **204** and second tool mechanism **212** can be used to interact with an object in the environment outside the outer circumference of the tool. In certain embodiments, such as seen in FIG. 3, the first tool member of the second link **206** and the second tool member of the fifth link **214** are configured to engage an object between the contact area **238** of the second link **206** and the contact area **266** of the fifth link **214**.

Similarly, the tool **200** can be transitioned from the second state where the first tool mechanism **204** and second tool mechanism **212** are extended outside the outer circumference of the fourth link **210** to the first state where the first tool mechanism **204** and second tool mechanism **212** pass through the second cavity **258** in the second wall **256** of the fourth link **210** to be contained within the inner and outer circumferences of the tool **200**. This is achieved by rotating the inner cylinder of the first link **202** in relation to the outer cylinder of the fourth link **210** in the reverse direction that was used to actuate the tool **200**.

In accordance with another embodiment of the present invention, and turning to FIGS. 4A through 4C, two four-bar mechanisms share two common joints located on two concentric cylinders. Actuation is achieved by the rotation of the inner cylinder and the mechanism. These features allow for the gripping surfaces to meet at two different locations based on the direction of rotation.

FIG. 4A and FIG. 4B depicts another embodiment of a hollow rod developable actuator tool **400** of the present invention. FIG. 4A show a top-down view of the hollow rod developable actuator tool **300** in successive images showing the actuation of the tool **300** from a first stowed state to a second deployed state. FIG. 4B shows an isometric view of the hollow rod developable actuator tool **300** in successive images.

In the hollow rod developable actuator tool **200** of FIG. 4A and FIG. 4B, a single hollow rod in the form of a concentric cylinders is provided with two four-bar mechanisms, both fit to the diameter and thickness of the cylinder, so that the individual links of the mechanism have the same curvature as the cylinder (although this is not a requirement for operation).

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A first link **302** comprising an inner cylinder is shared by both four-bar mechanisms. The first four-bar mechanism also includes a first tool mechanism including a second link **304** and a third link **306**. The final element of the four-bar mechanism is a fourth link **308** comprising an outer cylinder. The fourth link **308** is also shared with the second four-bar mechanism. The rest of the second four-bar mechanism is second tool mechanism including a fifth link **310** and a sixth link **312**. Each of these elements will be described in more detail below.

The cylinder of the first link **302** has a first end **314** having a first aperture, a second end **316** having a second aperture, and a first wall **318** extending between the first end **314** and second end **316** defining an inner circumference of the tool **300** and a central passage **320** therethrough from the first end **314** to the second end **316**. A first cavity **322** is disposed in the first wall **318** having a first joint **324** mounted therein.

The first wall **318** of the first link **302** may be formed of plastic, metal, or any other material suitable for forming a developable surface. Examples of suitable materials include stainless steel, titanium, nitinol, tungsten carbide, carbon steels, aluminum, high density polyethylene (HDPE), polypropylene, polylactic acid (PLA), acrylonitrile butadiene styrene (ABS) plastic, polyethylene terephthalate (PET), and acrylic. Other suitable materials will be apparent to one skilled in the art given the benefit of this disclosure. The inner circumference of the first link **302** as well as the length of the first wall **318** between the first end **314** and the second end **316** may vary depending on the intended use or application of the hollow rod developable actuator tool **300**.

The first cavity **322** in the first wall **318** comprises a recess, cut-away, channel, passage, window, or the like that is sized and dimensioned to allow the second link **304** and third link **306** of the first tool mechanism as well as the fifth link **310** and sixth link of the second tool mechanism to reside or otherwise be stowed in the first cavity **322** when the mechanism of the present device is in a stowed state. The first joint **324** is a pin embedded in the first wall **318** and spanning the first cavity **322**. Other suitable joint devices and configurations will be apparent to one skilled in the art given the benefit of this disclosure.

As discussed, the first tool mechanism includes a second link **304** and a third link **306**. These elements in conjunction with the first link **302** and the fourth link **308** make up a first four bar mechanism.

The second link **304** includes a first end **326** pivotably connected to the first wall **318** of the first link **302** at the first joint **324**, a second end **328** having a contact area **330**, a body **332** extending between the first end **326** and second end **328**, and a second joint **334** offset from the second end **328** of the second link **304**.

The body **332** of the second link **304** may be formed of plastic, metal, or any other material suitable for forming a developable surface. Examples of suitable materials include stainless steel, titanium, nitinol, tungsten carbide, carbon steels, aluminum, high density polyethylene (HDPE), polypropylene, polylactic acid (PLA), acrylonitrile butadiene styrene (ABS) plastic, polyethylene terephthalate (PET), and acrylic. In certain embodiments, the body **332** of the second link **304** is curved to conform to the curvature of the first link **302** such that the body **332** of the second link **304** can align with and be contained within the outer circumference of the cylinder of the fourth link **308** when the tool **300** is in a stowed state as seen in the left-most images of FIG. 4A and FIG. 4B.

The contact area **330** is configured to engage with objects when the first tool mechanism is extended outside the

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mechanism is in a deployed state. In certain embodiments, the contact area **330** is a gripping surface. In other embodiments, the contact area **330** is a blade. In still other embodiments, the contact area **330** is a stabilizing foot. In certain embodiments, the contact area **330** is formed as part of the body **332** from the same material as the body **332**. In other embodiments, the contact area **330** can be formed of a material different from the body **332** and attached to the body **332**. Other suitable materials and implementations will be apparent to one skilled in the art given the benefit of this disclosure.

The third link **306** has a first end **336** pivotably connected to the second joint **334** of the second link **304**, a second end **338** pivotably connected to a third joint **340**, and a body **342** extending between the first end **336** and second end **338**. The body **342** of the third link **306** may be formed of plastic, metal, or any other material suitable for forming a developable surface. Examples of suitable materials include stainless steel, titanium, nitinol, tungsten carbide, carbon steels, aluminum, high density polyethylene (HDPE), polypropylene, polylactic acid (PLA), acrylonitrile butadiene styrene (ABS) plastic, polyethylene terephthalate (PET), and acrylic. In certain embodiments, the body **342** of the third link **306** is curved to conform to the curvature of the first link **302** such that the body **342** of the third link **306** can reside within the first cavity **322** in the first link **302** and be flush with the inner circumference of the first link **302** when the mechanism is in a stowed state as seen in the left-most images of FIG. 4A and FIG. 4B.

The outer cylinder of the fourth link **308** has a first end **344** having a first aperture, a second end **346** having a second aperture, and a second wall **348** extending between the first end **344** and the second end **346** defining an outer circumference of the hollow rod and the central passage **320** therethrough from the first end **344** to the second end **346**. A second cavity **350** is disposed in the second wall **348** having the third joint **340** mounted therein.

The second wall **348** of the fourth link **308** may be formed of plastic, metal, or any other material suitable for forming a developable surface. Examples of suitable materials include stainless steel, titanium, nitinol, tungsten carbide, carbon steels, aluminum, high density polyethylene (HDPE), polypropylene, polylactic acid (PLA), acrylonitrile butadiene styrene (ABS) plastic, polyethylene terephthalate (PET), and acrylic. Other suitable materials will be apparent to one skilled in the art given the benefit of this disclosure. The outer circumference of the fourth link **308** as well as the length of the second wall **348** between the first end **344** and the second end **346** may vary depending on the intended use or application of the hollow rod developable actuator tool **300**.

The second cavity **350** in the second wall **348** comprises a recess, cut-away, channel, passage, window, or the like that is sized and dimensioned to allow the second link **304** and third link **306** of the first tool mechanism and the fifth link **310** and sixth link **312** of the second tool mechanism to reside or otherwise be stowed in the second cavity **350** when the mechanism of the present device is in a closed position. In the embodiment of FIG. 4A and FIG. 4B the third joint **340** is a pin embedded in the second wall **348** and spanning the second cavity **350**. Other suitable joint devices or mechanism will be apparent to one skilled in the art given the benefit of this disclosure.

As discussed, the second tool mechanism includes a fifth link **310** and a sixth link **312**. These elements in conjunction with the first link **302** and the fourth link **308** make up the second four-bar mechanism. In addition, the fifth link **310**

shares the first joint **324** with the second link **304** and the sixth link **312** shares the third joint **340** with the third link **306**.

The fifth link **310** includes a first end **352** pivotably connected to the first wall **318** of the first link **302** at the first joint **324**, a second end **354** having a contact area **356**, a body **358** extending between the first end **352** and second end **354**, and a fourth joint **360** offset from the second end **354** of the fifth link **310**.

The body **358** that makes up the second tool member of the fifth link **310** may be formed of plastic, metal, or any other material suitable for forming a developable surface. Examples of suitable materials include stainless steel, titanium, nitinol, tungsten carbide, carbon steels, aluminum, high density polyethylene (HDPE), polypropylene, polylactic acid (PLA), acrylonitrile butadiene styrene (ABS) plastic, polyethylene terephthalate (PET), and acrylic. In certain embodiments, the body **358** of the fifth link **310** is curved to conform to the curvature of the fourth link **308** such that the body **358** of the fifth link **310** can align with and be contained within the outer circumference of the cylinder of the fourth link **308** when the second tool mechanism is in a stowed state as seen in the left-most images of FIG. 4A and FIG. 4B.

The contact area **356** is configured to engage with objects when the second tool mechanism is extended outside the tool **300** in a deployed state. In certain embodiments, the contact area **356** is a gripping surface. In other embodiments, the contact area **356** is a blade. In still other embodiments, the contact area **356** is a stabilizing foot. In certain embodiments, the contact area **356** is formed as part of the body **358** from the same material as the body **358**. In other embodiments, the contact area **356** can be formed of a material different from the body **358** and attached to the body **358**. Other suitable materials and implementations will be apparent to one skilled in the art given the benefit of this disclosure.

The sixth link **312** has a first end **362** pivotably connected to the fourth joint **360** of the fifth link **310**, a second end **364** pivotably connected to a third joint **340** of the fourth link **308**, and a body **366** extending between the first end **362** and second end **364**. The body **366** of the sixth link **312** may be formed of plastic, metal, or any other material suitable for forming a developable surface. Examples of suitable materials include stainless steel, titanium, nitinol, tungsten carbide, carbon steels, aluminum, high density polyethylene (HDPE), polypropylene, polylactic acid (PLA), acrylonitrile butadiene styrene (ABS) plastic, polyethylene terephthalate (PET), and acrylic. In certain embodiments, the body **366** of the sixth link **312** is curved to conform to the curvature of the first link **302** such that the body **366** of the sixth link **312** can reside within the first cavity **322** in the first link **302** and be flush with the inner circumference of the first link **302** when the mechanism is in a stowed state as seen in the left-most images of FIG. 4A and FIG. 4B.

The depth (or distance along the length of the cylinder) on the fourth link **308** of the first link **302**, first tool mechanism, and second tool mechanism does not change the function of the mechanisms. In certain embodiments, the first link **302** extends the full length of the fourth link **308**. In certain embodiments, the first cavity **322** of the first wall **318** and the second cavity **350** of the second wall **348** are located in proximity to the second end **346** of the fourth link **308** and the second end **316** of the first link **302**. Thus, the first tool mechanism and second tool mechanism are also located in proximity to the second ends **316**, **346**. Typically, the first

ends **314**, **344** would be proximate to a user while the distal second ends **316**, **346** would be inserted into the workspace.

When the inner cylinder of the first link **302** is rotated in relation to the outer cylinder of the fourth link **308** such as indicated by arrow **370**, the tool **300** transitions from a first state wherein the second link **304** and third link **306** of the first tool mechanism and the fifth link **310** and sixth link **312** of the second tool mechanism are contained within the first cavity **322** of the first wall **318** of the first link **302** and the second cavity **350** of the second wall **348** of the fourth link **308** as seen in the left-most images of FIG. 4A and FIG. 4B to a second state where the second link **304** and third link **306** of the first tool mechanism and the fifth link **310** and sixth link **312** of the second tool mechanism pass through the second cavity **350** in the second wall **348** of the fourth link **308** to extend outside the outer circumference of the fourth link **308** where the contact area **330** of the second link **304** and the contact area **356** of the fifth link **310** can interact with an object outside the tool **300** as seen in the right-most images of FIG. 4A and FIG. 4B. Once deployed in the second state, the first tool mechanism **204** and second tool mechanism **212** can be used to interact with an object in the environment outside the outer circumference of the tool.

Similarly, the tool **300** can be transitioned from the second state where the second link **304** and third link **306** of the first tool mechanism and the fifth link **310** and sixth link **312** of the second tool mechanism are extended outside the outer circumference of the fourth link **308** to the first state where the second link **304** and third link **306** of the first tool mechanism and the fifth link **310** and sixth link **312** of the second tool mechanism pass through the second cavity **350** in the second wall **348** of the fourth link **308** to be contained within the inner and outer circumferences of the tool **300**. This is achieved by rotating the inner cylinder of the first link **302** in relation to the outer cylinder of the fourth link **308** in the reverse direction that was used to actuate the tool **300**.

In certain embodiments it is possible to further simplify the manufacture, assembly, and overall complexity of the tool **300** through the use of compliant mechanism. By applying principles of compliant mechanisms, the pin joints can be replaced by compliant segments and provide the same motion. FIG. 4C shows a compliant version of the mechanism illustrated in FIG. 4A and FIG. 4B. These compliant configurations allow for more manufacturing methods such as planar CNC routing and die cutting.

FIG. 4C shows a perspective view of the hollow rod developable actuator tool **300** in successive images. The left-most image shows the tool in a closed or stowed state while the right-most image shows the tool **300** in an open or deployed state.

In this embodiment, one or more of the shared first joint **324** or shared third joint **340** is replaced with a compliant mechanism. The compliant mechanism take advantage of the flexible nature of the materials forming the joint to allow to material to flex replicating the degree of motion provided by the conventional pin joint. By using compliant mechanisms, the second link **304** and fifth link **310** can be formed of one piece of material. In a similar manner, the third link **306** and sixth link **312** and also be formed of one piece of material.

The two mechanisms share one single piece, and through the compliance of the piece, achieve motion similar to two separate links. The compliance also makes the system bistable.

It is stressed that the shape of the links is arbitrary for mechanism motion. As long as the distance between the pins

remains the same and the links do not self-interfere, the mechanism will have the same motion. To completely conceal the moving links when the mechanism is closed, the links are constrained to a radius of curvature of the cylindrical tube of the hollow rod and to a shape that will fit inside the hollow rod when fully collapsed.

As mentioned previously, in certain embodiments, the contact areas **136, 156, 238, 266** of the first tool mechanisms **104, 204** and second tool mechanisms **112, 212** are configured as stabilizing feet. FIGS. **5A** and **5B** show a non-gripping application, such as using the first tool mechanisms **104, 204** and second tool mechanism **112, 212** as a landing gear or stabilizing feet for the tool **100, 200**. FIG. **5A** shows the tool **100** of FIG. **1** and FIG. **2** where contact areas **136, 156** are configured as stabilizing feet **400, 402** and are in a first stowed state. FIG. **5B** shows the tool **100** wherein the stabilizing feet **400, 402** and are in a second deployed state.

FIG. **6** depicts a methodology **500** for using the hollow rod developable actuator tools **100, 200** of the present invention. First a hollow rod developable actuator tool **100, 200** as described herein is provided (Step **502**). This tool **100, 200** can be deployed in the particular workspace where hollow rod actuator tools are typically used such as drill site or surgical environment. The tool **100, 200** can then be actuated in the workspace (Step **504**) to transition from a first closed state to a second open state wherein the mechanism can be used to interact with an item in the outside the circumference of the tool **100, 200** (step **506**). In certain embodiments, the tool **100, 200** may also be transitioned from the second open state back to the first closed state to disengage the tool **100, 200** (Step **508**) wherein the tool **100** can be withdrawn from the workspace.

The actuating of the tool **100, 200** (step **504**) is shown in the successive images of FIG. **1** and FIG. **3** moving left to right with the left-most image being the tool **100, 200** in a first stowed state and the right most image being the tool **100** in a deployed second state wherein the tool **100, 200** engages an object in the outside the circumference of the tool **100, 200**.

In the embodiment of FIG. **1** and FIG. **2**, the tool **100** is actuated through the use of actuation cables **174** shown in FIG. **2**. In the embodiment of FIG. **3**, the tool **200** is actuated by rotating the inner cylinder of the first link **202** in relation to the outer cylinder of the fourth link **210**.

In some embodiments, the engagement of an object (step **506**) by the contact areas **136, 238** of the first tool mechanism **104, 204** and the contact area **156, 266** of the second tool mechanism **112, 212** involves grasping the object between the contact areas **136, 238** of the first tool mechanism **104, 204** and the contact area **156, 266** of the second tool mechanism **112, 212**. In other embodiments, such as when at least one of the contact areas **136, 156, 238, 266** are a blade, the engagement of an object by the contact areas **136, 238** of the first tool mechanism **104, 204** and the contact area **156, 266** of the second tool mechanism **112, 212** involves cutting the object between the contact areas **136, 238** of the first tool mechanism **104, 204** and the contact area **156, 266** of the second tool mechanism **112, 212**. In still other embodiments, such as seen in FIG. **5A** and FIG. **5B**, the contact areas **136, 156** stabilizing feet **400, 402** that when deployed, served to stabilize, balance or otherwise situate the tool **100** on the object.

In a similar manner, the tool **100, 200** can be disengaged (step **508**), by transitioning the tool **100, 200** from the deployed second state to the first stowed state. At such time, the tool **100, 200** can be withdrawn from the environment.

Conventional cylindrical shaft or tube tools often allow only one tool to operate at the end of the shaft, especially when the tubes are small. The present invention enables an instrument or mechanism to be included in the cylindrical tube and to enter a workspace through a single entrance in combination with other instruments on the end of the shaft. This can i) lower the time required to perform a task in a confined/remote workspace by reducing the number of tooling changes required; ii) reduce the trauma/damage to the boundary of the workspace by reducing the number of entrance holes/points required; iii) reduce trauma/damage to the workspace by limiting interface between the blades/grippers and body tissue, since the only tissue interacting with the blades/grippers is that which is drawn into the inner diameter of the cylindrical shaft; iv) reduce the complexity of the control system used in conjunction with the tooling setup, as fewer shafts would be required to enter the space, and v) reduce the cost of the procedure.

To any extent utilized herein, the terms “comprises” and “comprising” are intended to be construed as being inclusive, not exclusive. As utilized herein, the terms “exemplary”, “example”, and “illustrative”, are intended to mean “serving as an example, instance, or illustration” and should not be construed as indicating, or not indicating, a preferred or advantageous configuration relative to other configurations. As utilized herein, the terms “about” and “approximately” are intended to cover variations that may existing in the upper and lower limits of the ranges of subjective or objective values, such as variations in properties, parameters, sizes, and dimensions. In one non-limiting example, the terms “about” and “approximately” mean at, or plus 10 percent or less, or minus 10 percent or less. In one non-limiting example, the terms “about” and “approximately” mean sufficiently close to be deemed by one of skill in the art in the relevant field to be included. As utilized herein, the term “substantially” refers to the complete or nearly complete extend or degree of an action, characteristic, property, state, structure, item, or result, as would be appreciated by one of skill in the art. For example, an object that is “substantially” circular would mean that the object is either completely a circle to mathematically determinable limits, or nearly a circle as would be recognized or understood by one of skill in the art. The exact allowable degree of deviation from absolute completeness may in some instances depend on the specific context. However, in general, the nearness of completion will be so as to have the same overall result as if absolute and total completion were achieved or obtained. The use of “substantially” is equally applicable when utilized in a negative connotation to refer to the complete or near complete lack of an action, characteristic, property, state, structure, item, or result, as would be appreciated by one of skill in the art.

Numerous modifications and alternative embodiments of the present invention will be apparent to those skilled in the art in view of the foregoing description. Accordingly, this description is to be construed as illustrative only and is for the purpose of teaching those skilled in the art the best mode for carrying out the present invention. Details of the structure may vary substantially without departing from the spirit of the present invention, and exclusive use of all modifications that come within the scope of the appended claims is reserved. Within this specification embodiments have been described in a way which enables a clear and concise specification to be written, but it is intended and will be appreciated that embodiments may be variously combined or separated without parting from the invention. It is

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intended that the present invention be limited only to the extent required by the appended claims and the applicable rules of law.

It is also to be understood that the following claims are to cover all generic and specific features of the invention described herein, and all statements of the scope of the invention which, as a matter of language, might be said to fall therebetween.

What is claimed is:

1. A hollow rod developable actuator tool, the tool comprising:

a first link comprising a cylinder comprising:

a first end having a first aperture;

a second end having a second aperture;

a wall extending between the first end and second end defining an outer circumference of the hollow rod and a central passage therethrough from the first end to the second end; and

a cavity in the wall having a first joint and a second joint offset from the first joint mounted therein;

a first tool mechanism comprising:

second link in a first plane perpendicular to the central passage comprising a first tool member, the first tool member comprising:

a body having a first end and a second end;

a contact area on the first end of the body;

a third joint in proximity to the first end of the body; and

a fourth joint at the second end of the body;

a third link in a second plane perpendicular to the central passage, the third link comprising:

a first end pivotably connected to a first joint on the first link;

a second end pivotably connected to the third joint of the second link; and

a body extending between the first end and second end; and

a fourth link in the second plane perpendicular to the central passage, the fourth link comprising:

a first end pivotably connected to a second joint on the first link;

a second end pivotably connected to the fourth joint of the second link; and

a body extending between the first end and second end;

a second tool mechanism comprising:

a fifth link in the second plane perpendicular to the central passage comprising a second tool member, the second tool member comprising:

a body having a first end and a second end;

a contact area on the first end of the body;

a fifth joint in proximity to the first end of the body; and

a sixth joint at the second end of the body;

a sixth link in the first plane perpendicular to the central passage, the sixth link comprising:

a first end pivotably connected to a second joint on the first link;

a second end pivotably connected to the fifth joint of the fifth link; and

a body extending between the first end and second end; and

a seventh link in the first plane perpendicular to the central passage, the seventh link comprising:

a first end pivotably connected to a first joint on the first link;

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a second end pivotably connected to the sixth joint of the fifth link; and

a body extending between the first end and second end;

wherein, the actuator tool transitions from a first state wherein first tool mechanism and second tool mechanism are contained entirely inside the outer circumference of the hollow rod to a second state where the first tool mechanism and second tool mechanism pass through the cavity in the wall of the first link to extend outside the outer circumference of the hollow rod.

2. The hollow rod developable actuator tool of claim 1, wherein the first tool mechanism and second tool mechanism engage an object between the contact area of the first and second tool members.

3. The hollow rod developable actuator tool of claim 2, wherein at least one of the contact area of the first tool mechanism and the contact area of the second tool mechanism is a blade.

4. The hollow rod developable actuator tool of claim 1, wherein at least one of the contact area of the first tool mechanism and the contact area of the second tool mechanism is a stabilizing foot.

5. The hollow rod developable actuator tool of claim 1, wherein at least one of the body of the second link, the body of the third link, the body of the fourth link, the body of the fifth link, the body of the sixth link, and the body of the seventh link is curved to match the curvature of the first link making the second link, third link, fourth link, fifth link, sixth link, and seventh link flush with the outer circumference when the actuator tool is in the first state.

6. The hollow rod developable actuator tool of claim 1, wherein the cavity of the first link is disposed in proximity to the second end of the first link.

7. The hollow rod developable actuator of claim 1, wherein the transition from the first state to the second state is actuated by cables extending the length of the cylinder of the first link.

8. A hollow rod developable actuator tool, the tool comprising:

a first link comprising an inner cylinder, the inner cylinder comprising:

a first end having a first aperture;

a second end having a second aperture;

a first wall extending between the first end and second end defining an inner circumference of the hollow rod and a central passage therethrough from first end to the second end; and

a first cavity in the first wall having a first joint and a second sliding joint;

a first tool mechanism comprising:

a second link comprising a first tool member, the first tool member comprising:

a first end pivotably connected to the wall of the first link at the first joint;

a second end having a contact area;

a body extending between first end and second end; and

a third joint offset from the second end of the body of the second link;

a third link comprising:

a first end pivotably connected to the third joint of the second link;

a second end pivotably connected to a fourth joint; and

a body extending between the first end and second end;

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- a fourth link comprising an outer cylinder, the outer cylinder comprising:
 - a first end having a first aperture;
 - a second end having a second aperture,
 - a second wall extending between the first end and second end defining an outer circumference of the hollow rod and a central passage therethrough from first end to the second end; and
 - a second cavity in the second wall having the fourth joint and a fifth joint;
- a second tool mechanism comprising:
 - a fifth link comprising a second tool member, the second tool member comprising:
 - a first end pivotably connected to the wall of the fourth link at the fifth joint;
 - a second end having a contact area;
 - a body extending between first end and second end; and
 - a sixth joint offset from the second end of the body of the fifth link; and
 - a sixth link comprising:
 - a first end pivotably connected to the sliding second joint on the first link;
 - a second end pivotably connected to the sixth joint of the fifth link; and
 - a body extending between the first end and second end;

wherein, when the inner cylinder the first link is rotated in relation to the outer ring of the fourth link, the actuator tool transitions from a first state wherein first tool mechanism and second tool mechanism are contained within the cavities of the walls to a second state where the first tool mechanism and second tool mechanism extend outside the outer circumference of the hollow rod.

9. The hollow rod developable actuator tool of claim 8, wherein the first tool mechanism and second tool mechanism are configured to engage an object between the contact areas of the first and second tool mechanisms.

10. The hollow rod developable actuator tool of claim 9, wherein at least one of the contact area of the first tool mechanism and the contact area of the second tool mechanism is a blade.

11. The hollow rod developable actuator tool of claim 8, wherein at least one of the contact area of the first tool mechanism and the contact area of the second tool mechanism is a stabilizing foot.

12. The hollow rod developable actuator tool of claim 8, wherein of the body of the second link, and the body of the fifth link are curved to match the curvature of the fourth link, and the body of the third link and the body of the sixth link are curved to match the curvature of the first link making the second link, third link, fifth link, and sixth link flush with the inner and outer circumference when the actuator tool is in the first state.

13. The hollow rod developable actuator tool of claim 8, wherein the cavity of the first link and the cavity of the fourth link are disposed in proximity to the second end of the first link and the second end of the fourth link.

14. A hollow rod developable actuator tool, the tool comprising:

- a first link comprising an inner cylinder, the inner cylinder comprising:
 - a first end having a first aperture;
 - a second end having a second aperture;

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- a first wall extending between the first end and second end defining an inner circumference of the hollow rod and a central passage therethrough from first end to the second end; and
- a first cavity in the first wall having a first joint;
- a first tool mechanism comprising:
 - a second link comprising:
 - a first end pivotably connected to the wall of the first link at the first joint;
 - a second end having a contact area;
 - a body extending between first end and second end; and
 - a second joint offset from the second end of the body of the second link;
 - a third link comprising:
 - a first end pivotably connected to the second joint of the second link;
 - a second end pivotably connected to a third joint; and
 - a body extending between the first end and second end;

- a fourth link comprising an outer cylinder, the outer cylinder comprising:
 - a first end having a first aperture;
 - a second end having a second aperture,
 - a second wall extending between the first end and second end defining an outer circumference of the hollow rod and a central passage therethrough from first end to the second end; and
 - a second cavity in the second wall having the third joint;

- a second tool mechanism comprising:
 - a fifth link comprising:
 - a first end pivotably connected to the wall of the first link at the first joint;
 - a second end having a contact area;
 - a body extending between first end and second end; and
 - a fourth joint offset from the second end of the body of the fifth link; and
 - a sixth link comprising:
 - a first end pivotably connected to the fourth joint on the fifth link;
 - a second end pivotably connected to the third joint of the fourth link; and
 - a body extending between the first end and second end;

wherein, when the inner cylinder the first link is rotated in relation to the outer ring of the fourth link, the actuator tool transitions from a first state wherein first tool mechanism and second tool mechanism are contained within the cavities of the walls to a second state where the first tool mechanism and second tool mechanism extend outside the outer circumference of the hollow rod.

15. The hollow rod developable actuator tool of claim 14, wherein the first tool mechanism and second tool mechanism are configured to engage an object between the contact areas of the first and second tool mechanisms.

16. The hollow rod developable actuator tool of claim 15, wherein at least one of the contact area of the first tool mechanism and the contact area of the second tool mechanism is a blade.

17. The hollow rod developable actuator tool of claim 14, wherein at least one of the contact area of the first tool mechanism and the contact area of the second tool mechanism is a stabilizing foot.

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18. The hollow rod developable actuator tool of claim 14, wherein of the body of the second link, and the body of the fifth link are curved to match the curvature of the fourth link, and the body of the third link and the body of the sixth link are curved to match the curvature of the first link making the 5 second link, third link, fifth link, and sixth link flush with the inner and outer circumference when the actuator tool is in the first state.

19. The hollow rod developable actuator tool of claim 14, wherein the cavity of the first link and the cavity of the 10 fourth link are disposed in proximity to the second end of the first link and the second end of the fourth link.

20. The hollow rod developable actuator tool of claim 14, wherein at least one of the first joint and the third joint is s 15 compliant mechanism.

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