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(54) **PROTECTIVE HELMET**

SCHUTZHELM

CASQUE DE PROTECTION

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(73) Proprietor: **Suddaby, Loubert S.**
Orchard Park, NY 14127 (US)

(72) Inventor: **Suddaby, Loubert S.**
Orchard Park, NY 14127 (US)

(74) Representative: **Reichert & Lindner**
Partnerschaft Patentanwälte
Stromerstr. 2A
93049 Regensburg (DE)

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Description

FIELD

[0001] The invention relates generally to a protective helmet, and, more particularly, to a protective helmet having an energy storage mechanism which absorbs linear and rotational forces and slowly releases such forces.

BACKGROUND

[0002] The human brain is an exceedingly delicate structure protected by a series of envelopes to protect it from injury. The innermost layer, the pia mater, covers the surface of the brain. The arachnoid layer, adjacent to the pia mater, is a spidery web-like membrane that acts like a waterproof membrane. Finally, the dura mater, a tough leather-like layer, covers the arachnoid layer and adheres to the bones of the skull.

[0003] While this structure protects against penetrating trauma, the softer inner layers absorb only a small amount of energy before linear forces applied to the head are transmitted to the brain. When an object strikes a human head, both the object and the human head are moving independently and often in different angles thus, angular forces, as well as linear forces, are almost always involved in head injuries. Many surgeons in the field believe the angular or rotational forces applied to the brain are more hazardous than direct linear forces due to the twisting or shear forces they apply to the white matter tracts and the brain stem.

[0004] One type of brain injury that occurs frequently is the mild traumatic brain injury (MTBI), more commonly known as a concussion. Such injury occurs in many settings, such as, construction worksites, manufacturing sites, and athletic endeavors and is particularly problematic in contact sports. While at one time a concussion was viewed as a trivial and reversible brain injury, it has become apparent that repetitive concussions, even without loss of consciousness, are serious deleterious events that contribute to debilitating irreversible diseases, such as dementia and neuro-degenerative diseases including Parkinson's disease, chronic traumatic encephalopathy (CTE), and dementia pugilistica.

[0005] U.S. Patent Application No. 13/841,076, filed March 15, 2013, is a continuation-in-part of U.S. Patent Application No. 13/412,782, filed March 6, 2012, and published as US 2015/143,617 A1. The embodiments of Figures 1 to 29 are known from US 2015/143,617 A1.

[0006] U.S. Patent No. 5,815,846 (Calonge) describes a helmet with fluid filled chambers that dissipate force by squeezing fluid into adjacent equalization pockets when external force is applied. In such a scenario, energy is dissipated only through viscous friction as fluid is restrictively transferred from one pocket to another. Energy dissipation in this scenario is inversely proportional to the size of the hole between the full pocket and the empty pocket. That is to say, the smaller the hole, the greater the energy drop. The problem with this design is that, as the size of the hole is decreased and the energy dissipation increases, the time to dissipate the energy also increases. Because fluid filled chambers react hydraulically, energy transfer is in essence instantaneous. Hence, in the Calonge design, substantial energy is transferred to the brain before viscous fluid can be displaced negating a large portion of the protective function provided by the fluid filled chambers. Viscous friction is too slow an energy dissipating modification to adequately mitigate concussive force. If one were to displace water from a squeeze bottle one can get an idea as to the function of time and force required to displace any fluid when the size of the exit hole is varied. The smaller the transit hole, the greater the force required and the longer the time required for any given force to displace fluid.

[0007] U.S. Patent No. 3,872,511 (Nichols) describes a helmet with hard inner and outer shells with an intermediate zone between the two shells. The zone contains a plurality of fluid-filled bladders that are held to the inner surface of the outer shell by means of a valve. When an impact occurs the outer shell is forced into the zone, squeezing the bladders. The valve closes upon impact causing the air to be retained in the bladders to cushion the impact from the user's head. However, because the movement of the bladders is restricted at impact, the force of the impact, although reduced is still directed into the head. In addition, the Nichols patent makes no provision for mitigation of rotational forces striking the helmet.

[0008] U.S. Patent No. 6,658,671 (Hoist) describes a helmet with inner and outer shells and a sliding layer. The sliding layer allows for the displacement of the outer shell relative to the inner shell to help dissipate some of the angular force during a collision applied to the helmet. However, the force dissipation is confined to the outer shell of the helmet. In addition, the Hoist helmet provides no mechanism for returning the two shells to the resting position relative to each other. A similar shortcoming is shown in the helmets described in U.S. Patent No. 5,956,777 (Popovich) and European patent publication EP 0048442 (Kalman et al.).

[0009] German Patent DE 19544375 (Zhan) describes a construction helmet that includes apertures in the hard outer shell that allows the expansion of cushion material through the apertures to dispel some of the force of a collision. However, because the inner liner rests against a user's head, some force is directed toward rather than away from the head.

[0010] U.S. Patent Application Publication No. 2012/0198604 (Weber et al.) describes a safety helmet for protecting the human head against repetitive impacts as well as moderate and severe impacts to reduce the likelihood of brain injury caused by both translational and rotational forces. The helmet includes isolation dampers that act to separate an outer liner from an inner liner. Gaps are provided between the ends of the outer liner and the inner liner to provide space to enable the outer liner to move without contacting the inner liner upon impact.

[0011] Clearly, to prevent traumatic brain injury, not only must penetrating objects be stopped, but any force, angular or linear, imparted to the exterior of the helmet must also be prevented from simply being transmitted to the enclosed skull and brain. The helmet must not merely play a passive role in dampening such external forces, but must play an active role in dissipating both linear and angular momentum imparted such that they have little or no deleterious effect on the delicate brain.

[0012] To afford maximum protection from linear and angular forces, the outer shell of a helmet mitigating such force must be capable of movement independent from the inner shell of the helmet which covers and encloses the skull and brain, such that any force vector or vectors can be allayed prior to the force getting to the brain.

[0013] To attain these objectives in a helmet design, the inner component (shell) and the outer component (shell or shells) must be capable of appreciable degrees of movement independent of each other. Additionally, the momentum imparted to the outer shell should both be directed away from and/or around the underlying inner shell and brain and sufficiently dissipated or stored so as to negate deleterious effects.

[0014] Thus, there is a long-felt need for a protective helmet having an energy storage mechanism that absorbs linear and rotational forces and slowly releases such forces.

SUMMARY

[0015] According to aspects illustrated herein, there is provided a protective helmet having multiple protective zones, comprising an inner shell having a first inner surface and a first outer surface, a padded inner lining attached to the first inner surface, an outer shell having a second inner surface and a second outer surface, the outer shell functionally attached to the inner shell, an elastomeric zone between the first outer surface and the second inner surface, a plurality of energy dissipation devices arranged between the inner and outer shells, and a plurality of sinusoidal springs positioned in the elastomeric zone, each of the plurality of sinusoidal springs comprising a first end, and a second end connected to one of the plurality of energy dissipation devices.

[0016] According to aspects illustrated herein, there is provided a protective helmet having multiple protective zones, comprising an inner shell having a first inner surface and a first outer surface, a padded inner lining attached to the first inner surface, an outer shell having a second inner surface and a second outer surface, the outer shell functionally attached to the inner shell, an elastomeric zone between the first outer surface and the second inner surface, a plurality of sinusoidal springs positioned in the elastomeric zone, each of the plurality of sinusoidal springs comprising a first end and a second end, and a plurality of locking devices arranged between the inner and outer shells, wherein each of the plurality of locking devices comprises a first portion comprising a first plurality of teeth, the first portion connected to the second end, a second portion comprising a second plurality of teeth, the second portion arranged on the first outer surface, wherein the first plurality of teeth are arranged to engage the second plurality of teeth, and a release device connected to the first portion, the release device is operatively arranged to release the locking device.

[0017] According to aspects illustrated herein, there is provided a protective helmet having multiple protective zones, comprising an inner shell having a first inner surface and a first outer surface, a padded inner lining attached to the first inner surface, an outer shell having a second inner surface and a second outer surface, the outer shell functionally attached to the inner shell, an elastomeric zone between the first outer surface and the second inner surface, a plurality of sinusoidal springs positioned in the elastomeric zone, each of the plurality of sinusoidal springs comprising a first end and a second end, and a plurality of piston devices arranged between the inner and outer shells, wherein each of the plurality of piston devices comprises a first component connected to the second end and a second component.

[0018] These and other objects, features, and advantages of the present disclosure will become readily apparent upon a review of the following detailed description of the disclosure, in view of the drawings and appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] Various embodiments are disclosed, by way of example only, with reference to the accompanying schematic drawings in which corresponding reference symbols indicate corresponding parts, in which:

Figure 1 is a front view of the double shell helmet ("helmet");

Figure 2 is a side view of the helmet of Figure 1 showing two face protection device attachments on one side of the helmet;

Figure 3A is a cross-sectional view of the helmet of Figure 1 showing an inner shell and elastomeric cords connecting the two shells;

Figure 3B is a cross-sectional view similar to Figure 3 depicting an alternate embodiment of the helmet including an intermediate shell enclosing cushioning pieces;

Figure 3C is a cross-sectional view similar to Figure 3A depicting an alternate embodiment of the elastomeric cords in which some of the elastomeric cords have thin and thick portions;

Figures 4A is an enlarged schematic view of the cords shown in Figure 3C in a neutral position;

Figure 4B is an enlarged schematic view of the cords shown in Figure 3C in compression;

Figures 4C is an enlarged schematic view of the cords shown in Figure 3C in a neutral position;

Figure 4D is an enlarged schematic view of the cords shown in Figure 3C in tension;

Figure 5A is a top perspective view of a section of the outer shell of the helmet showing an alternate embodiment including a liftable lid that protect diaphragms covering apertures in the outer shell of the helmet;

Figure 5B is a top perspective view of a section of the outer shell of the helmet, as shown in Figure 5A, depicting the liftable lid protecting the bulging fluid-filled bladder;

Figure 6A is an exploded view showing the attachment of the cord to both the inner shell and outer shell to enable the outer shell to float around the inner shell;

Figure 6B is a cross-sectional view of the completed attachment fitting with the elastomeric cord attached to two plugs and extending between the outer shell and the inner shell of the helmet;

Figure 7 is a cross-sectional view of an alternate embodiment of the helmet including parabolic leaf springs;

Figure 7A is a cross-sectional view of an alternate embodiment of the helmet including elliptical leaf springs;

Figure 8 is a cross-sectional view of the alternate embodiment of the protective helmet shown in Figure 7 showing the leaf springs with elastomeric cords;

Figure 9 is a cross-sectional view of the helmet illustrating leaf springs anchored on the outer shell of the helmet;

Figure 10A depicts schematically the parabolic leaf springs when the helmet is in a neutral state before being struck by a force;

Figure 10B depicts schematically how the parabolic leaf springs temporarily change their shape when absorbing a force striking the helmet;

Figure 11 is an enlarged schematic cross-sectional view of a crumple zone in a helmet in which a leaf spring is the force absorber/deflector;

Figure 12 is a top view of the crumple zone showing a plurality of elastomeric cords extending between the cones of a visco-elastic material;

Figure 13A is a front view of an articulating helmet, which is divided into at least two parts that are attached by an articulating means such as hinges or pivots;

Figure 13B is a front view of an articulating helmet, which is divided into two parts;

Figure 14A is a front view of an alternate embodiment of the articulating helmet having three articulating sections;

Figure 14B is a front view of the articulating helmet of Figure 14A;

Figure 15 is a side view of a two-section embodiment of an articulating helmet including air vents;

Figure 16 is a side view of a three-section embodiment of an articulating helmet showing two hinges for the articulating means;

Figure 17 is a front view of an additional alternate embodiment of an articulating helmet including pads or cushions attached to the inner surface of the helmet;

Figure 17A is a front view of a user wearing an articulating helmet in a cross-sectional view demonstrating the fit of the helmet on the user;

Figure 18 is a front view of an articulating helmet;

Figure 18A is a front view of the articulating helmet of Figure 18;

Figure 19A depicts an enlarged cross-sectional view of a swivel that enables two articulating sections of an articulating helmet to nest within one another;

Figure 19B depicts an enlarged cross-sectional view showing two articulating sections of an articulating helmet pulled apart prior to being placed into a nesting position;

Figure 19C depicts an enlarged cross-sectional view of two articulating sections in a nested position;

Figure 20 is a side perspective view of an additional embodiment of a protective helmet;

Figure 20A depicts an alternate embodiment of the helmet shown in Figure 20 in which the outer surface comprises overlapping plates that extend over the helmet, the plate being situated or apposed to an adjacent sinusoidal spring;

Figure 21 is a cross-sectional view of a sinusoidal spring of the helmet shown in Figure 20;

Figure 22 shows the same view as the view shown in Figure 21 showing force, such as from a blow or hit, being applied to the helmet;

Figure 23 depicts the same view shown in Figures 21 and 22 after the outer shell and sinusoidal spring have returned to the neutral position;

Figure 24 is a cross-sectional view of the alternate embodiment of the helmet shown in Figure 20A depicting how the overlapping plates are connected to each other and retain the ability to move in response to forces applied to the helmet;

Figure 25 shows the same view of the helmet as shown in Figure 24 showing force, such as from a blow or hit, being applied to the helmet;

Figure 26 depicts the same view shown in Figures 24 and 25 after the outer shell and sinusoidal spring have returned to the neutral position;

Figure 27 is a transverse cross-sectional view illustrating another alternate embodiment of helmet including a tab indicator to measure at least semi-quantitatively rotational force striking the helmet;

Figure 28 is a transverse cross-sectional view of the helmet depicting movement of the outer shell when struck by rotational force represented by the arrow, i.e., force striking from an angle relative to the helmet;

Figure 29 is a transverse cross-sectional view of the helmet representing the outer shell after it is returned to the neutral position after being struck by a rotational force with a tab indicator displayed in a window;

Figure 30 is a cross-sectional view of a helmet according to the claimed invention;

Figure 31 shows the same view as the view shown in Figure 30 showing force, such as from a blow or hit, being applied to the helmet;

Figure 32 depicts the same view shown in Figures 30 and 31 after the outer shell has returned to the neutral position;

Figure 33 shows the disengagement of an energy dissipation device and the return of the sinusoidal spring to the neutral position;

Figure 34 shows the helmet as shown in Figures 31-33 after the energy dissipation device has been completely disengaged;

Figure 35 is a cross-sectional view of a helmet according to the claimed invention;

Figure 36 is a top perspective view of the alternative embodiment of the helmet shown in Figure 35;

Figure 37 is a top perspective view of the embodiment of an energy dissipation device used in the helmet shown in Figure 35;

Figure 38 is a cross-sectional view of the energy dissipation device shown in Figure 37;

Figure 39 is a cross-sectional view of the energy dissipation device shown in Figure 37;

Figure 40 is a cross-sectional view of the energy dissipation device shown in Figure 37;

Figure 41 is a cross-sectional view of the energy dissipation device shown in Figure 37;

Figure 42 is a cross-sectional view of the energy dissipation device shown in Figure 37; and,

Figure 43 is a cross-sectional view of the energy dissipation device shown in Figure 37;

DETAILED DESCRIPTION OF EMBODIMENTS

[0020] At the outset, it should be appreciated that like drawing numbers on different drawing views identify identical, or functionally similar, structural elements. It is to be understood that the claims are not limited to the disclosed aspects.

[0021] Furthermore, it is understood that this disclosure is not limited to the particular methodology, materials and modifications described and as such may, of course, vary. It is also understood that the terminology used herein is for the purpose of describing particular aspects only, and is not intended to limit the scope of the claims.

[0022] Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood to one of ordinary skill in the art to which this disclosure pertains. It should be understood that any methods, devices or materials similar or equivalent to those described herein can be used in the practice or testing of the example embodiments.

[0023] It should be appreciated that the term "substantially" is synonymous with terms such as "nearly," "very nearly," "about," "approximately," "around," "bordering on," "close to," "essentially," "in the neighborhood of," "in the vicinity of," etc., and such terms may be used interchangeably as appearing in the specification and claims. It should be appreciated that the term "proximate" is synonymous with terms such as "nearby," "close," "adjacent," "neighboring," "immediate," "adjoining," etc., and such terms may be used interchangeably as appearing in the specification and claims.

[0024] In one embodiment, the inner shell and outer shell are connected to each other by elastomeric cords that serve to limit the rotation of the outer shell on the inner shell and to dissipate energy by virtue of elastic deformation rather than passively transferring rotational force to the brain as with existing helmets. In effect, these elastomeric cords function like mini bungee cords that dissipate both angular and linear forces through a mechanism known as hysteretic damping, i.e., when elastomeric cords are deformed, internal friction causes high energy losses to occur. These elastomeric cords are of particular value in preventing so called contrecoup brain injury.

[0025] The outer shell, in turn, floats on the inner shell by virtue of one or more force absorbers or deflectors such as, for example, fluid-filled bladders, leaf springs, or sinusoidal springs, located between the inner shell and the outer shell. To maximize the instantaneous reduction or dissipation of a linear and/or angular force applied to the outer shell, the fluid-filled bladders interposed between the hard inner and outer shells may be intimately associated with, that is located under, one or more apertures in the outer shell with the apertures preferably being covered with elastomeric diaphragms and serving to dissipate energy by bulging outward against the elastomeric diaphragm whenever the outer shell is accelerated, by any force vector, toward the inner shell. Alternatively, the diaphragms could be located internally between inner and outer shells, or at the inferior border of the inner and outer shells, if it is imperative to preserve surface continuity in the outer shell. This iteration would necessitate separation between adjacent bladders to allow adequate movement of associated diaphragms.

[0026] In existing fluid-filled designs, when the outer shell of a helmet receives a linear force that accelerates it toward the inner shell, the interposed gas or fluid is compressed and displaced. Because gas and especially fluid is not readily compressible, it passes the force passively to the inner shell and hence to the skull and the brain. This is indeed the very mechanism by which existing fluid-filled helmets fail. The transfer of force is hydraulic and essentially instantaneous, negating the effectiveness of viscous fluid transfers as a means of dissipating concussive force.

[0027] Because of the elastomeric diaphragms, any force imparted to the outer shell will transfer to the gas or liquid in the bladders, which, in turn, will instantaneously transfer the force to the external elastomeric diaphragms covering the apertures in the outer shell. The elastomeric diaphragms, in turn, will bulge out through the aperture in the outer shell, or at the inferior junction between inner and outer shells thereby dissipating the applied force through elastic deformation at the site of the diaphragm rather than passively transferring it to the padded lining of the inner shell. This process directs energy away from the brain and dissipates it via a combination of elastic deformation and tympanic resonance or oscillation. By oscillating, an elastic diaphragm employs the principle of hysteretic damping over and over, thereby maximizing the conversion of kinetic energy to low-level heat, which, in turn, is dissipated harmlessly to the surrounding air.

[0028] Furthermore, the elastomeric springs or cords that bridge the space holding the fluid-filled bladders (like the arachnoid membrane in the brain) serve to stabilize the spatial relationship of the inner and outer shells and provide additional dissipation of concussive force via the same principle of elastic deformation via the mechanism of stretching, torsion, and even compression of the elastic cords.

[0029] By combining the bridging effects of the elastic springs or cords as well as the elastomeric diaphragms strategically placed at external apertures, both linear and rotational forces can be effectively dissipated.

[0030] In an alternate embodiment, leaf springs may replace fluid-filled bladders as a force absorber/deflector. Leaf springs may be structured as a fully elliptical spring or, preferably, formed in a parabolic shape. In both forms, the leaf spring is anchored at a single point to either the outer shell or, preferably, the hard inner shell and extends into the zone between the outer shell and inner shell. The springs may have a single leaf (or arm) or comprise a plurality of arms arrayed radially around a common anchor point. Preferably, each arm tapers from a thicker center to thinner outer portions toward each end of the arm. Further, the ends of each arm may include a curve to allow the end to more easily slide on the shell opposite the anchoring shell. In contrast to the use of leaf springs in vehicles, the distal end of the spring arms are not attached to the nonanchoring or opposite shell. This allows the ends to slide on the shell to allow independent movement of each shell when the helmet is struck by rotational forces. This also enables the frictional dissipation of energy. Preferably, the distal ends contact the opposite shell in the neutral condition, that is, when the helmet is not in the process of being struck.

[0031] Adverting to the drawings and as mentioned above, the embodiments of Figures 1 to 29 are known from US 2015/143,617 A1. Figure 1 is a front view of multiple protective zone helmet **10** ("helmet **10"**). The outer protective zone is formed by outer shell **12** and is preferably manufactured from rigid, impact resistant materials such as metals, plastics, polycarbonates, ceramics, composites, and similar materials well known to those having skill in the art. Outer shell **12** defines at least one and preferably a plurality of apertures **14** (or aperture **14**). Apertures **14** may be open but are preferably covered by a flexible elastomeric material in the form of diaphragms **16** (or diaphragm **16**). In a preferred embodiment, helmet **10** also includes several face protection device attachments. Figure 1 shows face protection device attachments **18a** and **18b;** however, helmet **10** can have any suitable number of face protection device attachments. In a more preferred embodiment, face protection device attachments are fabricated from a flexible elastomeric material to provide flexibility to the attachment. The elastomeric material reduces the rotational pull on helmet **10** if the attached face protection device (not shown in Figure 1) is pulled. By "elastomeric" it is meant any of various substances resembling rubber in properties, such as resilience and flexibility. Such elastomeric materials are well known to those having skill in the art. Figure 2 is a side view of helmet **10** showing two face protection device attachments **18a** and **18b** on one side of the helmet. Examples of face protection devices are visors and face masks. Such attachments can also be used for chin straps releasably attached to the helmet in a known manner.

[0032] Figure 3A is a cross-sectional view of helmet **10** showing the hard inner shell **20** and the elastomeric springs or cords **30** (or cords **30**) that extend through an elastomeric zone connecting the two shells. Inner shell **20** forms an anchor zone and is preferably manufactured from rigid, impact resistant materials such as metals, plastics such as polycarbonates, ceramics, composites, and similar materials well known to those having skill in the art. Inner shell **20** and outer shell **12** are slidingly connected at sliding connection **22.** By "slidingly connected" it is meant that the edges of inner shell **20** and outer shell **12,** respectively, slide against or over each other at connection **22.** In an alternate embodiment, outer shell **12** and inner shell **20** are connected by an elastomeric element, for example, a u-shaped elastomeric connector **22a** ("connector **22a"**). Sliding connection **22** and connector **22a** each serve to both dissipate energy and maintain the spatial relationship between outer shell **12** and inner shell **20.**

[0033] Cords **30** are flexible cords, such as bungee cords or elastic "hold down" cords, or their equivalents, used, for example, to hold articles on car or bike carriers. This flexibility allows outer shell **12** to move or "float" relative to inner shell **20** while remaining connected to inner shell **20.** This floating capability is also enabled by the sliding connection **22** between outer shell **12** and inner shell **20.** In an alternate embodiment, sliding connection **22** may also include elastomeric connection **22a** between outer shell **12** and inner shell **20.** Padding **24** forms an inner zone and lines the inner surface of inner shell **20** to provide a comfortable material to support helmet **10** on the user's head. In one embodiment, padding **24** may enclose loose cushioning pieces **24a** such as STYROFOAM® beads or "peanuts," or loose oatmeal.

[0034] Also shown in Figure 3A is a cross-sectional view of bladders **40** (or bladder **40**) situated in the elastomeric zone between outer shell **12** and inner shell **20.** Helmet **10** includes at least one, but preferably a plurality of bladders **40.** Bladders **40** are filled with fluid, either a liquid such as water, or a gas such as helium or air. In one preferred embodiment, the fluid is helium as it is light and its use would reduce the total weight of helmet **10.** In an alternate embodiment, bladders **40** may also include compressible beads or pieces such as STYROFOAM® beads. Bladders **40** are preferably located under apertures **14** of outer shell **12** and are in contact with both inner shell **20** and outer shell **12.** Thus, when outer shell **12** is pressed in toward inner shell **20** (and thus the user's skull) during a collision, bladder **40** is squeezed and the fluid therein is compressed, similar to squeezing a balloon. Bladder **40** will bulge toward aperture **14** and displace elastomeric diaphragm **16.** This bulging-displacement action diverts the force of the blow from radially inward (i.e., toward the user's skull and brain) to radially outward (i.e., up toward the apertures) providing a new direction for the force vector. Bladders **40** may also be divided internally into compartments **40a** by bladder wall **44** such that, if the integrity of one of compartments **40a** is breached, another compartment will still function to dissipate linear and rotational forces. Bladders **40** may additionally comprise valve(s) **46** arranged between compartments **40a** to control the fluid movement. In the example embodiment shown in Figure 3A, bladders **40** include two compartments. It should be appreciated, however, that any number of compartments suitable to control the fluid movement can be used.

[0035] Figure 3B is a cross-sectional view, similar to Figure 3A discussed above, depicting an alternate embodiment of helmet **10.** Helmet **10** shown in Figure 3B includes crumple zone or intermediate shell **50** located between outer shell **12** and inner shell **20.** In the embodiment shown, intermediate shell **50** is close, or adjacent, to inner shell **20.** Intermediate shell **50** encloses filler **52.** Preferably, filler **52** is a compressible material that is packed to deflect the energy of a blow and protect the skull, similar to a "crumple zone" in an automobile. Filler **52** is designed to crumple or deform, thereby absorbing the force of the collision before it reaches inner pad **24** and the braincase. In this embodiment, cords **30** extend from inner shell **20** to outer shell **12** through intermediate shell **50.** One suitable material for filler **52** is STYROFOAM® beads or "peanuts," or an equivalent material such as materials used for packing objects. Because of its "crumpling" function, intermediate shell **50** is preferably constructed with a softer or more deformable material than outer shell **12** and/or inner shell **20.** Typical fabrication material for intermediate shell **50** is a stretchable material such as latex or spandex or other similar elastomeric fabric that preferably encloses filler **52.**

[0036] Figure 3C is a cross-sectional view similar to Figure 3A depicting an alternate embodiment of helmet **10** comprising elastomeric cords **30** and **31.** Elastomeric cords **31** (or cord **31**) include thick elastomeric portions **31a** and thin nonelastomeric portions **31b.** In the embodiment shown, thick elastomeric portions **31a** are connected to the outer surface of inner shell **20,** but alternatively may be connected to the inner surface of outer shell **12.** Thin nonelastomeric portions **31b** of cords **31** are connected to the inner surface of outer shell **12,** but alternatively may be attached to the outer surface of inner shell **20.** Thin nonelastomeric portions **31b** may comprise a single cord or multiple cords. In this exemplary embodiment, thick elastomeric portions **31a** of cords **31** are thicker than uniform elastomeric cords **30.** For example, the diameter of elastomeric portions **31a** is greater than the diameter of cords **30.** It should be appreciated, however, that elastomeric portions **31a** and cords **30** may have any suitable diameter that allows cords **31** to act as a backup to prevent cords **30** from being stretched beyond their elastic limit. Also shown in Figure 3C is force **F** located to the left of helmet **10.** Force **F** is directed radially inward relative to helmet **10** and represents a blow to outer shell **12** as will be discussed with respect to Figures 4A-D.

[0037] Figures 4A-D are enlarged schematic views of cords **30** and **31** as shown in Figure 3C. Figures 4A and 4B are enlarged views of detail 4A,B in Figure 3C. Figure 4A shows cords **30,** which have uniform thickness throughout their lengths, and cords **31** in the neutral position. In the neutral position, cords **30** are under slight tension while cords **31** are under no tension. In the neutral position, the distance between inner shell **20** and outer shell **12** and thus the length of cords **30** and **31** is length **LI.** Figure 4B shows cords **30** and **31** as shown in Figure 4A, but under maximum compression as a result of force **F** impacting helmet **10** (as directed in Figure 3C). When force **F,** a greater than normal force, is applied, outer shell **12** displaces radially inward relative to inner shell **20** (i.e., the radially distance between inner shell **20** and outer shell **12** decreases). In this case, significant compression occurs in elastomeric cord **30;** however, only nominal compression occurs in cord **31.** As shown, nonelastomeric portions **31b** loosens and elastomeric portions **31a** exhibits only nominal or no compression. In the compressed state, the distance between inner shell **20** and outer shell **12** and thus the length of cords **30** and **31** is length **L2,** which is less than length **LI.** Figures 4C and 4D are enlarged views of detail 4C,D in Figure 3C. Figure 4C shows cords **30,** which have uniform thickness throughout their lengths, and cords **31** in the neutral position. In the neutral position, cords **30** are under slight tension while cords **31** are under no tension. In the neutral position, the distance between inner shell **20** and outer shell **12** and thus the length of cords **30** and **31** is length **L3,** which is substantially equal to **LI.** Figure 4D shows cords **30** and **31** as shown in Figure 4C, but under maximum tension as a result of force **F** impacting helmet **10** (as directed in Figure 3C). When force **F** is applied, outer shell **12** displaces radially outward relative to inner shell **20** (i.e., the radial distance between inner shell **20** and outer shell **12** increases). In this case, significant expansion occurs in elastomeric cord **30,** and moderate expansion occurs in cord **31.** As shown, nonelastomeric portions **31b** are tightly drawn and elastomeric portions **31a** are moderately expanded. Under maximal displacement of outer shell **12** relative to inner shell **20,** cords **30** may be stretched close or up to their elastic limit. However, when this occurs, nonelastomeric portion **31b** of cord **31** engages elastomeric portion **31a** to mitigate the large force striking helmet **10** and to prevent any loss of elasticity in cord **30.** By using cord **31** as a backup for blows struck with severe force, greater protection can be achieved even after cord **30** reaches its elastic limit and does not interfere with absorbing any rotational forces striking helmet **10.** For this reason, cords **31** preserve the integrity of the cord system of helmet **10.** In the expanded state, the distance between inner shell **20** and outer shell **12** and thus the length of cords **30** and **31** is length **L4,** which is greater than length **LI.**

[0038] Figure 5A is a top view of one section of outer shell **12** of helmet **10** showing an alternate embodiment in which liftable lids **60** (or lid **60**) are used to cover aperture **14** to shield diaphragm **16** and/or bladder **40** from punctures, rips, or similar incidents that may destroy their integrity. Lids **60** are attached to outer shell **12** by lid connectors **62** (or connector **62).** Lids **60** are operatively arranged to lift or raise up if a particular diaphragm **16** bulges outside of aperture **14** due to the expansion of one or more bladders **40.** Because it is liftable, lid **60** allows diaphragm **16** to freely elastically bulge through aperture **14** above the surface of outer shell **12** (i.e., radially outward from outer shell **12**) to absorb and redirect the force of a collision, and also protects diaphragm **16** from damage due to external forces. In an alternate embodiment, diaphragm **16** is not used and lid **60** directly shields and protects bladder **40.** In an example embodiment, connectors **62** are hinges. In an example embodiment, connectors **62** are flexible plastic attachments. Figure 5B depicts liftable lid **60** protecting bladder **40** as it bulges through aperture **14** and radially outward from outer shell **12.**

[0039] Figure 6A is an exploded view showing one method of attaching cord **30** to helmet **10,** such that outer shell **12** floats over inner shell **20.** Cavities **36** (or cavity **36**), preferably comprising concave sides **36a,** are drilled or otherwise arranged in outer shell **12** and inner shell **20** such that they are aligned. Each end of cord **30** is attached to plugs **32** which are arranged in the aligned cavities **36**. In one embodiment, plugs **32** are secured in cavities **36** using a suitable adhesive known to those having ordinary skill in the art. In an alternate embodiment, plugs **32** are secured in cavities **36** with an interference fit (i.e., press fit or friction fit) or a snap fit.

[0040] Figure 6B is a cross-section of helmet 10 with plugs **32** secured in cavities **36.** Cord **30** is attached to two plugs **32** at either end and extends between outer shell **12** and inner shell **20.** Also shown is intermediate shell **50** enclosing filler **52.** Not shown are bladders **40,** which would be arranged between intermediate shell **50** and outer shell **12.** Persons of ordinary skill in the art will recognize that cords **31** may be attached between outer shell **12** and inner shell **20** in a similar manner.

[0041] Figure 7 is a cross-sectional view of an alternate embodiment of helmet **10** wherein bladders **40** are replaced with force absorbers/deflectors comprising parabolic leaf springs **41** (or springs **41**). In the embodiment shown, springs **41** are fixedly secured to inner shell **20** at anchor points **42** (or anchor point **42**). Each of springs **41** comprise at least one arm **43** (or arms **43**) with two ends **43a,** which are preferably curvedly shaped as shown. Arms **43** are preferably tapered having a thicker center portion near anchor point **42** and gradually thinning in width and/or thickness towards ends **43a.** In addition, arms **43** may be laminated with gradually fewer applied elastic layers as distance from anchor point **42** increases. A plurality of arms **43** may be arrayed radially around, and attached to, a single anchor point **42.** As shown in Figure 7, arms **43** extend to crumple zone or intermediate shell **50,** if present, and anchor points **42** extend through crumple zone **50.** Leaf springs **41** may also be used in conjunction with elastomeric cords **30.** Figure 7A is an alternate embodiment comprising elliptical leaf springs **41a** (or spring **41a**) instead of parabolic leaf springs **41.** Like springs **41,** each of springs **41a** is attached at single anchor points **42.**

[0042] Figure 8 is a cross-section of the embodiment of helmet **10** shown in Figure 7, wherein leaf springs **41** are used in conjunction with both elastomeric cords **30** and cords **31.** As described above, cords **31** act as a backup to prevent cords **30** from being stretched beyond their elastic limit. Elastomeric portions **31a** of cords **31**comprise a diameter larger than the diameter of uniform elastomeric cords **30.** As shown in Figure 8, the thick portions may be attached to either outer shell **12** or inner shell **20.**

[0043] Figure 9 is a cross-sectional view of helmet **10** comprising leaf springs **41,** fixedly secured to outer shell **12,** as well as cords **30.** It should be appreciated that the embodiment of helmet **10** shown may further comprise cords **31.**

[0044] Figures 10A and 10B schematically depict the action of leaf springs **41** when helmet **10** is struck by a force. In Figure 10A, helmet **10** is in the neutral state. In the neutral state, springs **41** are under relatively slight tension on all circumferential locations about helmet **10.** In Figure 10B, force **F** strikes helmet **10,** specifically outer shell **12,** the right hand side (i.e., radially inward relative to helmet **10).** Ends **43a** are separated further from each other as arms **43** are pushed toward inner shell **20** (i.e., the radial distance between inner shell **20** and outer shell **12** decreases) to absorb the translational force vector created by force **F.** Simultaneously, ends **43a'** of arms **43'** of springs **41'** located on the opposite side of helmet **10** move closer together as the tension on arms **43'** is reduced (i.e., the radial distance between inner shell **20** and outer shell **12** increases). After force **F** is exhausted, the increased tension created on the arms **43** on the right hand or contact side of helmet **10** act to return outer shell

12 radially outward toward the neutral position. The relaxed tension of arms **43'** on the noncontact side of helmet **10** allows outer shell **12** to move radially inward, closer to inner shell **20,** toward the neutral position. Although not shown in Figures 10A and 10B, it will be understood that cords **30** and/or cords **31** will act to absorb any rotational or torsional forces generated on helmet **10** by force **F.**

[0045] Figure 11 is an enlarged schematic cross section of crumple zone or intermediate zone **50** in helmet **10** wherein leaf spring **41** is the force absorber/deflector. Elastomeric cords **30** extend from inner shell **20** to outer shell **12.** Crumple zone **50** is arranged circumferentially between cords **30** and comprises filler **52.** In the embodiment shown, filler **52** material is in the shape of a plurality of cones **54.** In an example embodiment, filler **52** comprises viscoelastic materials, such as, SORBOTHANE® material, or a combination of viscoelastic materials. Viscoelastic materials provide the advantage of behaving like a quasi-liquid, being readily deformed by an applied force and recovering slowly, although, in the absence of such a force, it takes up a defined shape and volume. An unusually high amount of the energy from an object dropped onto SORBOTHANE® material is absorbed. Leaf spring **41** pivotably connected to inner shell **20** by anchor point **42,** extends up through crumple zone **50,** and contacts outer shell **12.** In this embodiment, cones **54** in crumple zone **50** act to absorb a blow having much greater than normal force so that springs **41** are deflected to such a degree that outer shell **12** reaches crumple zone **50.** Figure 12 is a top view of crumple zone **50** showing a plurality of cords **30** arranged between cones **54** comprising viscoelastic material. It should be appreciated that a helmet employing fluid-filled bladders may include a crumple zone having viscoelastic materials as a filler such as SORBOTHANE® material or STYROFOAM® peanuts.

[0046] Figures 13A and 13B are front views of articulating helmet **100** ("helmet **100"**), which is divided into at least two parts that are attached by an articulating means. By articulating, it is meant that the helmet comprises parts or sections joined by an articulating means such as hinge or pivot connections, swivels, or other devices that allow the separate parts of the helmet to be opened and closed together. Each section includes hard outer shell **101.** Figure 13A shows helmet **100** in the closed and locked orientation. Sections **102a** and **102b** are connected through articulating means **104.** In this embodiment, articulating means **104** is a hinge. It should be appreciated that any number of articulating means **104** suitable to open and close helmet **100** may be used, and that the protective helmet **100** is not limited to the use of one articulating means. Preferably, helmet **100** comprises one or more locks **106** (or lock **106**) to secure helmet **100** in the closed position. Helmet **100** further comprises ear apertures **108** and inner surface **101a.** Figure 13B shows helmet **100** in the open orientation. Lock **106** is disengaged allowing articulating means **104** to open and separate sections **102a** and **102b.**

[0047] Figures 14A and 14B depict front views of an alternate embodiment of helmet **100** comprising sections **103a, 103b,** and **103c.** In this embodiment, helmet **100** includes air vents **110,** which are openings defined by helmet **100** that extend from outer surface **101** through to inner surface **101a.** Articulating means **104** allows sections **103b** and **103c** to pivot with respect to section **103a.** One or more locks **106** hold sections **103b** and **103c** in the closed position. It should be appreciated that air vents **110** may be arranged in helmets having any number of sections, for example, a helmet having two sections (as shown in Figures 13A and 13B). Figure 14B shows helmet **100** in the open position in which both articulating means **104** open to separate sections **103b** and **103c** from section **103a.** Figure 15 is a side view of the two-section embodiment of helmet **100,** as shown in Figures 13A and 13B, further comprising air vents **110** and two articulating means **104.** Similarly, Figure 16 is a side view of the three-section embodiment of helmet **100,** as shown in Figures 14A and 14B, showing two articulating means **104** for section **103c.**

[0048] Figure 17 is a front view of another alternate embodiment of articulating helmet **100** wherein pads or cushions **112** are attached to inner surface **101a** of helmet **100.** Pads **112** may be permanently attached to inner surface **101a** with suitable attachment devices such as rivets, screws, or adhesives. Alternatively, pads **112** may be releasably attached to inner surface **101a** using attachment devices such as VELCRO® hook and loop material, suction cups, snap buttons, or other releasable coupling device. Releasably attached pads **112** provides the advantage of allowing a user to customize helmet **100** with cushions **112** of various sizes, materials, and arrangements that provide a snug fit when helmet **110** is worn. Pads **112** comprise any suitable foam materials known to those having ordinary skill in the art. In both embodiments, pads **112** are attached to inner surface **101a** between vents **110** to ensure maximum air flow to the user.

[0049] Figure 17A is a front view of a user showing a cross-section of articulating helmet **100** as worn by user **U,** with outer shell **120** removed. When helmet **100** is worn, pads **112** contact the top of the head of user U to provide a snug fit. It should be appreciated that pads **112** are arranged on inner surface **101a** such that air vents **110** are unimpeded and provide air flow to user **U.** In this embodiment, ear apertures **108** are covered with a membrane or diaphragm **108a.** In one embodiment, diaphragm **108a** is fabricated from KEVLAR® fabric.

[0050] Figures 18 and 18A are front views of articulating helmet **100** showing an embodiment wherein one section of helmet **100** may nest inside the other. In Figure 18A, section **102b** is nested inside section **102a** and helmet **100** is in the open position. Articulating means **104a** is a swivel operatively arranged to hold sections **102a** and **102b** together and allow sections **102a** and **102b** to open and turn relative to each other such that outer surface **101** of one section radially faces inner surface **101a** of the other section. For example, section **102b** is rotated 90 degrees radially inside of section **102a,** or vice versa. This embodiment decreases the overall volume of helmet **100** in the open position making it easier to store.

[0051] Figure 19A depicts an enlarged cross-sectional view of one embodiment of swivel means **104a** that enables sections **102a** and **102b** to turn and nest within one another. Cable **105** is attached to section **102b** at one end and universal joint **107** at another end. Spring **109** is connected to universal joint **107** at a first end and section **102b** at a second end. Universal joint **107** is rotatably connected to section **102a** (e.g., embedded therein) such that cable **105** and section **102b** are rotatabeable relative to section **102a,** and vice versa. Spring **109** pulls attached section **102b** (and cable **105)** toward section **102a.** Figure 19B shows sections **102a** and **102b** pulled apart with stretched spring **105** holding the two sections together. In addition, male prongs or tubes **120** can be arranged on section **102a** which slide into ports **122** arranged on section **102b** to stabilize the helmet when sections **102a** and **102b** are joined together. Alternatively, male prongs or tubes **120** can be arranged on section **102b** and ports **122** can be arranged on section **102a** (this embodiment is not shown). As shown in Figure 19C, universal joint **107** enables section **102b** to rotate relative to section **102a** after which section **102b** is pulled back toward section **102a.** Because section **102b** has been rotated, outer surface **101** of section **102b** nests against inner surface **101a** of section **102a.**

[0052] Figure 20 is a side perspective view of a further additional embodiment of the helmet with outer shell **202** removed. Helmet **200** includes an integral or continuous outer shell **202** (not shown in Figure 20) and inner shell **204** functionally connected. By integral or continuous is meant that shell **202** is formed as a single unit. By functionally connected, it is meant that outer shell **202** and inner shell **204** are connected such that outer shell **202** may move, such as rotate, relative to inner shell **204** such as, for example, the sliding connection **22** discussed above. Elastomeric zone **203** ("zone **203"**) lies between outer shell **202** and inner shell **204.** At least one sinusoidal spring **208** (spring(s) **208"**) is positioned in zone **203.** Figure 20 depicts a preferred embodiment in which a plurality of springs **208** are positioned in zone **203.** In a more preferred embodiment shown here, springs **208** are sinusoidal springs **208** having a shape similar to or identical with a series of sine waves and can be manufactured as described in U.S. Patent Application Publication No. 2012/00773884 and U.S. Patent No. 4,708,757 both to Guthrie.

[0053] Although not necessary for the protective function of helmet **200,** in a further embodiment, the distal end of at least one of springs **208** is in operative contact with force indicator tab **216** ("tab **216"**). By "operative contact" it is meant that a component or device contacts but is not connected to a second component and causes that second component to function. For example, as described below, the operative contact end of spring **208** contacts the proximal edge of tab **216** so that when spring **208** is extended, it pushes tab **216** to an outer position toward the outer perimeter of helmet **200.** When spring **208** retracts, tab **216** remains in its displaced position. Tab **216** preferably is a multi-color panel as represented by the different cross hatching patterns on the surface of tab **216,** shown in Figure 20.

[0054] Tab **216** is positioned within channel **212,** which is positioned on outer surface **205** of inner shell **204.** Channel **212** includes parallel rails **214** with tab **216** positioned between rails **214.** In this way, tab **216** is always pushed in the same direction when spring **208** is extended. Outer shell **202** defines at least one window **210,** shown in shadow, positioned so that tab **216** can be viewed through window **210** if spring **208** is extended sufficiently to push tab **216** into channel **212.** In the embodiment shown, rivet **218** forms the attachment of the plurality of springs **208** to outer shell **202** to form a radial or "spider-like" array of springs **208.** In the preferred embodiment, outer shell **202** is functionally connected to inner shell **204** such that window **210** remains at a constant location relative to inner shell **204.** The disclosure described herein refers to this embodiment. It should be appreciated that outer shell **202** is functionally attached to inner shell **204** such that movement of outer shell **202** relative to inner shell **204** does not affect the location of tab **216** (i.e., outer shell **202** does not contact tab **216).** In another embodiment (not shown), outer shell **202** is functionally attached to inner shell **204** such that window **210** varies in location. For example, in a resting or neutral position, window **210** is arranged on outer shell **202** and located in a first location relative to inner shell **204.** During (or just after) impact, when outer shell **202** moves relative to inner shell **204,** window **210** can be located in a second location, different than the first location. However, outer shell **202** is arranged to always return to its resting or neutral position at a period of time after impact. Thus, window **210** will always return to the first location. Readings of tab **216** should always be conducted when outer shell **202** is in the resting or neutral position and window **210** is located in the first location.

[0055] Figure 20A depicts an alternate embodiment of the helmet labeled helmet **200A** in which outer shell **202** comprises overlapping plates **202a** ("plates **202a"**) which extend over helmet **200A** and forms the outer wall or cover of elastomeric zone **203.** Plates **202a** may be arranged in rows. Figure 20A also depicts a preferred arrangement of sinusoidal springs **208** in which three springs **208** extend along inner shell **204** with the at least one end of at least one of springs **208** in operative contact with tabs **216.** As shown, springs **208** may be arranged separately under rows of plates **202a.** Although not shown in Figure 20A, the opposing ends of each of springs **208** may also be in operative contact with tab **216.** Also shown in Figure 20A, tab **216** is positioned within rails **214** of channel **212.** Outer shell **202** defines at least one window **210** in one of plates **202a** positioned so that tab **216** can be viewed through window **210** if spring **208** is extended sufficiently through channel **212.**

[0056] Figure 21 is a cross-sectional view of helmet **200** through a sinusoidal spring **208.** Spring **208** is positioned in elastomeric zone **203** resting on outer surface **205.** One end of spring **208** is either close to or in contact with tab **216,** which is positioned between rails **214.** In the resting or neutral position shown, tab **216** is arranged under outer shell **202** and not exposed in window **210.** Spring(s) **208** may be attached to outer shell **202,** inner shell **204,** or both outer shell **202** and inner shell **204.** Helmet **200** may also comprise substrate **210a** arranged over window **210.**

[0057] Figure 22 shows the same view of helmet **200** as shown in Figure 21 in which force **A,** represented by arrow **A,** is applied to helmet **200.** The force may be a blow impacting helmet **200.** The dotted lines of outer shell **202** and spring **208** show those components in the neutral state. The solid lines show outer shell **202** pressed into elastomeric zone **203** by force **A.** When force **A** strikes outer shell **202,** one or more of springs **208** are pushed into a compressed mode as shown by the reduced amplitude of the sine wave formed in sinusoidal spring **208** as well as the expanded length of spring **208.** As spring **208** lengthens, as represented by arrow **B,** it pushes tab **216** toward and/or into window **210.** Persons of ordinary skill in the art will recognize that the increase in the length of spring **208** is a function of the amount of force striking helmet **200.** Thus, the amount of exposure of tab **216** in window **210** depends on the amount of force striking helmet **200.** Preferably, tab **216** includes different colors, such as green, yellow, and red, or other indicators, each of which may appear in window **210** depending on the force of the blow. It will be recognized that more than one spring **208** may be extended when helmet **200** is struck.

[0058] Figure 23 depicts the same view shown in Figures 21 and 22 after outer shell **202** and sinusoidal spring **208** have returned to the neutral position. The return movement of outer shell **202** is shown by arrow **C** while the return of spring **208** is shown by arrow **D.** Tab **216** remains under window **210** after spring **208** retracts back to its normal state.

[0059] Figure 24 is a cross-section of helmet **200a** shown in Figure 20A depicting how overlapping plates **202a** are connected to each other and still retain the ability to move in response to forces applied to helmet **200a.** Sinusoidal spring **208** is confined between plates **202a** and outer surface **205** of inner shell **204.** Also shown is the distal end of spring **216** in operative contact with force indicator tab **216.** Window **210** is defined by an edge portion **211** of helmet **200a.** It may also be defined by one of plates **202a.** In one embodiment, articulating plates **202a** are attached using a male-female connection in which a round pin **220** is inserted into round socket **222.** This connection enables the individual plates to pivot on pin **220** transversely or side-to-side and up and down to deflect some of the force away from the user's head while still preserving the integrity of the entire outer shell. Also shown is cover **207** which may overlay articulating plates **202a.** Preferably, cover **207** is made from KEVLAR® fabric that provides an integral cover over the individual plates **202a** but allows movement of individual plates. It should be appreciated that those having ordinary skill in the art will recognize that articulating plates **202a** can be replaced by an integral hard outer shell **202,** as shown in Figure 20 above.

[0060] Figures 25 and 26 are similar to Figures 22 and 23, respectively, in showing outer shell **202a** compressed by force **A** and returning to the neutral state as represented by arrow **C.** As with helmet **200** discussed above, tab **216** remains displayed in window **210** indicating at least semi-quantitatively, the amount of force that struck helmet **202a,** after spring **208** retracts (arrow **D**). By semi-quantitatively, it is meant that the degree of exposure of tab **216** under window **210** indicates if a first impact hits helmet **200** with greater force than a second impact, the measurement recorded is the more severe of the two impacts.

[0061] The indicator(s) on tab **216** displayed in window **210** can be used to show how far spring **208** has moved and thus indicates the amount of force that has struck helmets **200** and **200a.** Springs **208** may be fabricated with suitable calibrated or measured tension using known methods to extend to appropriate lengths depending on the force of the impact to indicate, in at least a semi-quantitative manner, the amount of force striking helmet **200** (or helmet **200a)** and thus possibly affecting the user. Tab **216** may be returned to its neutral position using a screwdriver or other instrument to move it back into operative contact with spring **208.** In some embodiments, a minimum or sufficient amount of force may be necessary to move tab **216** into window **210.** If the striking force is below this minimum, spring **208** will not lengthen sufficiently to move tab **216** into window **210** indicating the striking force was insufficient to cause injury to the user.

[0062] Figure 27 is a transverse cross-sectional view illustrating another alternate embodiment of helmet **200** to include a tab indicator to measure, at least semi-quantitatively, rotational force striking helmet **200.** In this view, sinusoidal springs **208** are removed for clarity, but persons of ordinary skill in the art will recognize that at least one spring **208** may be used in helmets **200** and **200a** with this embodiment. Support **230** is fixedly attached to inner shell **204** on outer surface **205.** Support **230** extends across zone **203** and contacts inner surface **213** of outer shell **202.** Arms **230a** extend from support **230** generally transversely along inner surface **213** of outer shell **202.** Arms **230a** are in operative contact with tab indicators **216a,** which are positioned in rails **214** (not shown).

[0063] In Figure 28, arrow **E** represents rotational force, e.g., force striking from an angle relative to helmet **200** (or helmet **200a**). Because inner shell **204** is stationary relative to the rotational motion of outer shell **202,** which is suspended on inner shell **204** by springs **208,** support **230** and attached arms **230a** remain stationary relative to outer shell **202.** Tab indicators **216a** rotate with outer shell **202** against stationary arms **230a,** which forces them to move along rails **214.** As shown in Figure 29, when outer shell **202** returns to the neutral position after the hit, tab indicator **216a** remains in rails **214** where they have been pushed. If the rotational force is sufficient, tab indicators **216a** will be displayed in window **210** indicating helmet **200** was hit with sufficient rotational force to display indicator **216a,** thus indicating a possible injury to the user.

[0064] In the following, Figures 30 to 43 refer to embodiments of the invention, wherein a plurality of energy dissipation devices 215, 300 is arranged between the inner shells 20, 204 and outer shells 12, 202, and wherein a second end of each of the plurality of sinusoidal springs 208, 308 is connected to one of said plurality of energy dissipation devices 215, 300. Figure 30 is a cross-sectional view of an alternative embodiment of the helmet shown in Figure 20. In the alternative embodiment shown, helmet **200** further comprises energy dissipation device **215** arranged radially between outer shell **202** and inner shell **204.** Energy dissipation device **215** comprises first portion **215A** and second portion **215B,** which are arranged to engage, and lock, with each other. In this exemplary embodiment, first portion **215A** is connected to spring **208** and comprises plurality of teeth **215A'** facing radially inward in direction **RD1.** Second portion **215B** is connected to inner shell **204** and comprises plurality of teeth **215B'** facing radially outward in direction **RD2.** Energy dissipation device **215** further comprises release **217** for disengaging first portion **215A** and second portion **215B.** For example, pressing release **217** displaces first portion **215A** radially outward in direction **RD2** and disengages teeth **215A'** of first portion **215A** from teeth **215B'** of second portion **215B.** Indicator tab **216** comprises return tab **219** connected thereto. Return tab **219** is arranged radially inward of indicator tab **216** such that the user can return indicator tab **216** to the position shown in Figure 30. Helmet **200** may also comprise substrate **210a** arranged over window **210** such that indicator tab **216** can only be accessed using return tab **219** inside helmet **200** (i.e., indicator tab **216** cannot be accessed through window **210**).

[0065] Figure 31 shows the same view of helmet **200** as shown in Figure 30 in which force **A,** represented by arrow **A,** is applied to helmet **200.** The effect of the force is the same as that shown and described with respect to Figure 22 above. However, as spring **208** extends in direction **B,** first portion **215A** displaces in direction **B** relative to second portion **215B,** which displaces indicator tab **216.** First portion **215A** engages with second portion **215B,** for example, via teeth **215A'** and **215B'.** In this exemplary embodiment, outer shell **202** is functionally connected to inner shell **204** such that window **210** remains in a constant location and does not vary in size (i.e., outer shell **202** does not displace circumferentially relative to inner shell **204** at or around the location of window **210).**

[0066] Figure 32 depicts the same view shown in Figures 30 and 31 after outer shell **202** has returned to the neutral position. The return movement of outer shell **202** is shown by arrow **C.** Unlike the embodiment shown in Figure 23, however, spring **208** does not return to its neutral position because of energy dissipation device **215.** First portion **215A** is still engaged, and thus locked, with second portion **215B.** Figure 33 shows the disengagement of energy dissipation device **215,** wherein release **217** is activated. In an example embodiment, release **217** is connected to first portion **215A** and is displaced in direction **G** to disengage energy dissipation device **215.** For example, pressing release **217** displaces first portion **215A** radially outward in direction **RD2** (or **G**) and disengages teeth **215A'** from teeth **215B'.** The return of first portion **215A** is shown by arrow **D** while the return of spring **208** is shown by arrows **D** and **E.** In another example embodiment, Bluetooth® technology or radio communication can be used to send a signal indicating when tab **216** is displaced into window **210,** so that another party (e.g., coach, doctor, medical professional, etc.) is aware that a significant impact has occurred from a remote location (i.e., without having to be within viewing distance of window **210).** In addition, Bluetooth® technology or radio communication can be used to send a signal indicating the position of tab **216** in window **210,** so that the party is aware of the magnitude of impact that occurred from the remote location. Figure 34 shows helmet **200** after energy dissipation device **215** has been completely disengaged. The position of tab **216** remains in window **210** after spring **208** retracts back to its normal state.

[0067] Figure 35 is a cross-sectional view of an alternative embodiment of the helmet shown in Figure 20. In the alternative embodiment shown, helmet **200** further comprises piston device **221** arranged in inner shell **204.** In another embodiment, piston device **221** is arranged at any suitable location radially between inner shell **204** and outer shell **205.** Piston device **221** is an energy dissipation device comprising first rod **221a,** second rod **221b,** cylinder **221c,** and flange **221d.** First rod **221a** is connected to spring **208** at a first end and flange **221d** at a second end. Second rod **221b** is connected to flange **221d** at a first end and abuts against indicator tab **216** at a second end. Flange **221d** is arranged in cylinder **221c.** In an example embodiment, piston device **221** acts similar to a dashpot or any other suitable device such that displacement of spring **208** in direction **B** is not inhibited and the return of spring **208** in direction **D** occurs at a controlled rate, preferably slowly. In this embodiment, there is no need for a release because spring **208** always returns to its neutral position. Piston device **221** can be a hydraulic piston, a pneumatic piston, or any other suitable device capable of performing the above-identified function.

[0068] Figure 36 is a top perspective view of an alternative embodiment of the helmet shown in Figure 20. In this embodiment, helmet **200** comprises a plurality of brackets **240.** Brackets **240** are connected to inner shell **204** and arranged adjacent to springs **208.** Brackets **240** prevent and/or limit springs **208** from moving laterally. This system provides torsional damping as well as linear damping. Brackets **240** allow spring **208** to function as a torsion bar thereby mitigating rotational or angular force applied to helmet **200.**

[0069] Figure 37 is a top perspective view of an alternative embodiment of energy dissipation device **300** used in helmet **200** shown in Figure 20. Energy dissipation device **300** comprises dashpot **301,** arm **302,** cylinder **306,** and barrier **314.** Dashpot **301** is a linear mechanical device, a damper which resists motion via viscous friction. Arm **302** comprises a plurality of notches and is slidingly engaged within dashpot **301.** Cylinder **306** is connected to sinusoidal spring **308** and is arranged to slide in levels **310** and **312.** Levels **310** and **312** are separated by barrier **314.** Barrier **314** comprises a plurality of doors **316,** which are operatively arranged to allow cylinder **306** to pass from level **310** to level **312.** Barrier **314** also comprises door **318,** which is operatively arranged to allow cylinder **306** to pass from level **312** to level **310.**

[0070] Figures 38-43 are cross-sectional views of energy dissipation device **300** shown in Figure 37. Figure 38 shows energy dissipation device **300** in a neutral position. Cylinder **306** is arranged in level **310** and arm **302** is fully extended from dashpot **301.** Figure 39 shows energy dissipation device **300** during an impact in direction **H.** Sinusoidal spring **308,** and thus cylinder **306,** extends along level **310** in direction **I.** Cylinder **306** displaces extension **320** and moves force indicator tab **216** into window **210.** Cylinder **306** also forces door **316** in direction **J.** Figure 40 shows energy dissipation device **300** during an impact in direction **H.** Sinusoidal spring **308** has extended such that cylinder **306** passes over door **316** in level **310.** Door **316** moves in direction **K** to return to its neutral position. Figure 41 shows energy dissipation device **300** after an impact. Cylinder **306** slips from level **310** to level **312** through door **316** in direction **L.** Cylinder **306** then engages one of notches **304** in arm **302.** Figure 42 shows energy dissipation device **300** after an impact. Cylinder **306,** now arranged in level **312,** engages one of notches **304.** Sinusoidal spring **308** returns to its neutral position in direction **M,** which pulls cylinder **306,** and thus arm **302,** in direction **N.** Figure 43 shows energy dissipation device **300** after an impact. Cylinder **306** slips from level **312** to level **310** through door **318** in direction **O.** Sinusoidal spring **308** has returned to the neutral position. Arm **302** returns to its fully extended position relative dashpot **301.** It should be appreciated that force indicator tab **216** can be manually returned to a neutral position.

[0071] It will be appreciated that various aspects of the disclosure above and other features and functions, or alternatives thereof, may be desirably combined into many other different systems or applications. Various presently unforeseen or unanticipated alternatives, modifications, variations, or improvements therein may be subsequently made by those skilled in the art which are also intended to be encompassed by the following claims.

REFERENCE NUMERALS

[0072]

10	Multiple Protective Zone Helmet
12	Outer shell
14	Apertures
16	Diaphragm
18	Face Protection Device Attachments
18a	Face Protection Device Attachment
18b	Face Protection Device Attachment
20	Inner Shell
22	Sliding Connection
22a	U-Shaped Elastomeric Connector
24	Padding
24a	Loose Cushioning Pieces
30	Elastomeric Springs or Cords
31	Elastomeric Cords
31a	Elastomeric Portion
31b	Nonelastomeric Portion
32	Plugs
36	Cavities
36a	Concave Sides
40	Bladders
40a	Compartments
41	Leaf Springs
41'	Springs
41a	Elliptical Leaf Spring
42	Anchor Point
43	Arm
43a	Ends
43'	Arms
43a'	Ends
44	Bladder Wall
46	Valves
50	Intermediate Shell/Crumple Zone
52	Filler
54	Cones
60	Liftable Lids
62	Hinges
100	Articulating Helmet
101	Outer Surface
101a	Inner Surface
102a	Section
102b	Section
103a	Section
103b	Section
103c	Section
104	Articulating Means
104a	Swivel means
105	Cable
106	Lock
107	Universal Joint
108	Ear Apertures

108a	Membrane or Diaphragm
109	Spring
110	Air Vents
112	Pads or Cushions
120	Prongs or Tubes
122	Ports
200	Helmet
200A	Helmet
202	Outer Shell
202a	Overlapping Plates
203	Elastomeric Zone
204	Inner Shell
205	Outer Surface
207	Cover
208	Sinusoidal Spring (Springs)
210	Window
210a	Substrate
211	Edge portion
212	Channel
213	Inner surface
214	Rails
215	Energy Dissipation Device
215A	First Portion
215B	Second Portion
215A'	Teeth
215B'	Teeth
216	Force Indicator Tab(s)
216a	Tab Indicators
217	Release
218	Rivet
219	Return Tab
220	Pin
221	Piston Device
221a	First Rod
221b	Second Rod
221c	Cylinder
221d	Flange
222	Socket
230	Support
230a	Arms
240	Brackets
300	Energy Dissipation Device
301	Dashpot
302	Arm
304	Notches
306	Cylinder
308	Sinusoidal Spring
310	Level
312	Level
314	Barrier
316	Doors
318	Door
320	Extension
A	Force (Force Arrow)
B	Direction
C	Direction
D	Direction
E	Direction
F	Force
G	Direction
H	Direction
I	Direction
J	Direction
K	Direction
L	Direction
M	Direction
N	Direction
O	Direction
U	Top Head of User
L1	Length
L2	Length
L3	Length
L4	Length
RD1	Radial Direction
RD2	Radial Direction

Claims

1. A protective helmet (200) having multiple protective zones, comprising an inner shell (204) having a first inner surface and a first outer surface (205):

   an outer shell (202) having a second inner surface (213) and a second outer surface, said outer shell (202) functionally attached to said inner shell (204);
   an elastomeric zone (203) between said first outer surface (205) and said second inner surface (213); and
   a plurality of sinusoidal springs (208, 308) positioned in said elastomeric zone (203), each of the plurality of sinusoidal springs (208, 308) comprising:

      a first end and a second end;
      characterized by
      a plurality of energy dissipation devices (215, 221, 300) arranged between the inner and outer shells (204; 202); and
      wherein the second end of each of the plurality of sinusoidal springs (208, 308) is connected to one of said plurality of energy dissipation devices (215, 221, 300).

2. The protective helmet as recited in Claim 1, wherein the plurality of energy dissipation devices (221, 300) are

   piston devices (221) each comprising:
   a first component (221A,) connected to the second end of each of the plurality of sinusoidal springs (208); and,
   a second component (221C).

3. The protective helmet as recited in any of the pre-

ceding Claims, wherein said first end of at least one of said plurality of sinusoidal springs (208, 308) is attached to said first outer surface (205).

4. The protective helmet as recited in any of the preceding Claims, wherein each one of said plurality of sinusoidal springs (208, 308) is attached at common point (218) on said inner shell (204).

5. The protective helmet as recited in any of the preceding Claims, further comprising a plurality of brackets (240) connected to said first outer surface (205), said second inner surface (213), or both said first outer surface (205) and said second inner surface (213), wherein said plurality of brackets (240) are operatively arranged adjacent to said plurality of sinusoidal springs (208, 308) to limit their lateral and torsional movement.

6. The protective helmet as recited in any of the preceding Claims, wherein said outer shell (202) comprises at least one window (210) defined by said outer shell (202).

7. The protective helmet as recited in Claim 6, wherein said at least one window (210) extends in a generally sagittal direction.

8. The protective helmet as recited in any of the preceding Claims, further comprising a force indicator tab (216) in operative contact with said first end of at least one of said plurality of sinusoidal springs (208, 308), wherein said force indicator tab (216) is moved to said at least one window (210) by said first end when said helmet (200) is impacted with sufficient force.

9. The protective helmet as recited in Claim 8, wherein said force indicator tab (216) is positioned in a slot or between two rails (214).

10. The protective helmet as recited in the preceding Claims 8 - 9, wherein said force indicator tab (216) comprises a return tab (219).

11. The protective helmet as recited in the preceding Claims 8 - 10, further comprising a Bluetooth device (250) operatively arranged to determine a location of the force indicator tab (216), wherein the Bluetooth device is capable of sending the location to a remote location.

Patentansprüche

1. Schutzhelm (200) mit mehreren Schutzzonen, umfassend:

eine Innenschale (204) mit einer ersten Innenfläche und einer ersten Außenfläche (205);
eine Außenschale (202) mit einer zweiten Innenfläche (213) und einer zweiten Außenfläche, wobei die Außenschale (202) funktionell an der Innenschale (204) befestigt ist;
eine Elastomerzone (203) zwischen der ersten Außenfläche (205) und der zweiten Innenfläche (213); und
eine Vielzahl von sinusförmigen Federn (208, 308), die in der Elastomerzone (203) positioniert sind, wobei jede der Vielzahl von sinusförmigen Federn (208, 308) Folgendes umfasst:

ein erstes Ende und ein zweites Ende;
gekennzeichnet durch
eine Vielzahl von Energiedissipationsvorrichtungen (215, 221, 300), die zwischen der Innen- und Außenschale (204, 202) angeordnet sind; und
wobei das zweite Ende von jeder der Vielzahl von sinusförmigen Federn (208, 308) mit einer der Vielzahl von Energiedissipationsvorrichtungen (215, 221, 300) verbunden ist.

2. Schutzhelm nach Anspruch 1, wobei es sich bei der Vielzahl von Energiedissipationsvorrichtungen (221, 300) um Kolbenvorrichtungen (221) handelt, die jeweils Folgendes umfassen:

eine erste Komponente (221A), die mit dem zweiten Ende von jeder der Vielzahl von sinusförmigen Federn (208) verbunden ist; und
eine zweite Komponente (221C).

3. Schutzhelm nach einem der vorstehenden Ansprüche, wobei das erste Ende von mindestens einer der Vielzahl von sinusförmigen Federn (208, 308) an der ersten Außenfläche (205) befestigt ist.

4. Schutzhelm nach einem der vorstehenden Ansprüche, wobei jede der Vielzahl von sinusförmigen Federn (208, 308) an einem gemeinsamen Punkt (218) auf der Innenschale (204) befestigt ist.

5. Schutzhelm nach einem der vorstehenden Ansprüche, ferner umfassend eine Vielzahl von Halterungen (240), die mit der ersten Außenfläche (205), der zweiten Innenfläche (213) oder sowohl der ersten Außenfläche (205) als auch der zweiten Innenfläche (213) verbunden sind, wobei die Vielzahl von Halterungen (240) betriebsmäßig neben der Vielzahl von sinusförmigen Federn (208, 308) angeordnet ist, um deren Seitwärts- und Torsionsbewegung zu begrenzen.

6. Schutzhelm nach einem der vorstehenden Ansprüche, wobei die Außenschale (202) mindestens ein Fenster (210) umfasst, das durch die Außenschale (202) definiert ist.

7. Schutzhelm nach Anspruch 6, wobei sich das mindestens eine Fenster (210) in eine im Allgemeinen sagittale Richtung erstreckt.

8. Schutzhelm nach einem der vorstehenden Ansprüche, ferner umfassend eine Kraftanzeigelasche (216) in betriebsmäßigem Kontakt mit dem ersten Ende von mindestens einer der Vielzahl von sinusförmigen Federn (208, 308), wobei die Kraftanzeigelasche (216) durch das erste Ende zu dem mindestens einen Fenster (210) bewegt wird, wenn der Helm (200) mit einer ausreichenden Kraft beaufschlagt wird.

9. Schutzhelm nach Anspruch 8, wobei die Kraftanzeigelasche (216) in einem Schlitz oder zwischen zwei Schienen (214) positioniert ist.

10. Schutzhelm nach einem der vorstehenden Ansprüche 8 bis 9, wobei die Kraftanzeigelasche (216) eine Rückkehrlasche (219) umfasst.

11. Schutzhelm nach einem der vorstehenden Ansprüche 8 bis 10, ferner umfassend eine Bluetooth-Vorrichtung (250), die betriebsmäßig angeordnet ist, um eine Position der Kraftanzeigelasche (216) zu bestimmen, wobei die Bluetooth-Vorrichtung dazu in der Lage ist, die Position an eine entfernte Position zu senden.

Revendications

1. Casque de protection (200) ayant de multiples zones de protection, comprenant :

> une coque interne (204) ayant une première surface interne et une première surface externe (205) ;
> une coque externe (202) ayant une seconde surface interne (213) et une seconde surface externe, ladite coque externe (202) étant attachée fonctionnellement à ladite coque interne (204) ;
> une zone élastomère (203) entre ladite première surface externe (205) et ladite seconde surface interne (213) ; et
> une pluralité de ressorts sinusoïdaux (208, 308) positionnés dans ladite zone élastomère (203), chacun de la pluralité de ressorts sinusoïdaux (208, 308) comprenant :
>
> > une première extrémité et une seconde extrémité ;
> > **caractérisé par**
> > une pluralité de dispositifs de dissipation d'énergie (215, 221, 300) agencés entre les coques interne et externe (204, 202) ; et
> > dans lequel la seconde extrémité de chacun de la pluralité de ressorts sinusoïdaux (208, 308) est raccordée à l'un de ladite pluralité de dispositifs de dissipation d'énergie (215, 221, 300).

2. Casque de protection selon la revendication 1, dans lequel la pluralité de dispositifs de dissipation d'énergie (221, 300) sont des dispositifs à piston (221) comprenant chacun :

> un premier composant (221A), raccordé à la seconde extrémité de chacun de la pluralité de ressorts sinusoïdaux (208) ; et,
> un second composant (221C).

3. Casque de protection selon l'une quelconque des revendications précédentes, dans lequel ladite première extrémité d'au moins l'un de ladite pluralité de ressorts sinusoïdaux (208, 308) est attachée à ladite première surface externe (205).

4. Casque de protection selon l'une quelconque des revendications précédentes, dans lequel chacun de ladite pluralité de ressorts sinusoïdaux (208, 308) est attaché au niveau d'un point commun (218) sur ladite coque interne (204).

5. Casque de protection selon l'une quelconque des revendications précédentes, comprenant en outre une pluralité de ferrures (240) raccordées à ladite première surface externe (205), à ladite seconde surface interne (213), ou à la fois à ladite première surface externe (205) et à ladite seconde surface interne (213), dans lequel ladite pluralité de ferrures (240) sont agencées opérationnellement adjacentes à ladite pluralité de ressorts sinusoïdaux (208, 308) pour limiter leur déplacement latéral et en torsion.

6. Casque de protection selon l'une quelconque des revendications précédentes, dans lequel ladite coque externe (202) comprend au moins une fenêtre (210) définie par ladite coque externe (202).

7. Casque de protection selon la revendication 6, dans lequel ladite au moins une fenêtre (210) s'étend dans une direction généralement sagittale.

8. Casque de protection selon l'une quelconque des revendications précédentes, comprenant en outre une languette d'indicateur de force (216) en contact opérationnel avec ladite première extrémité d'au moins l'un de ladite pluralité de ressorts sinusoïdaux (208, 308), dans lequel ladite languette d'indicateur de force (216) est déplacée jusqu'à ladite au moins une fenêtre (210) par ladite première extrémité lorsque ledit casque (200) est heurté avec une force suffisante.

9. Casque de protection selon la revendication 8, dans lequel ladite languette d'indicateur de force (216) est positionnée dans un interstice ou entre deux rails (214).

10. Casque de protection selon les revendications 8 ou 9, dans lequel ladite languette d'indicateur de force (216) comprend une languette de rappel (219).

11. Casque de protection selon l'une des revendications 8 à 10, comprenant en outre un dispositif Bluetooth (250) agencé opérationnellement pour déterminer un emplacement de la languette d'indicateur de force (216), dans lequel le dispositif Bluetooth est capable d'envoyer l'emplacement à un emplacement distant.

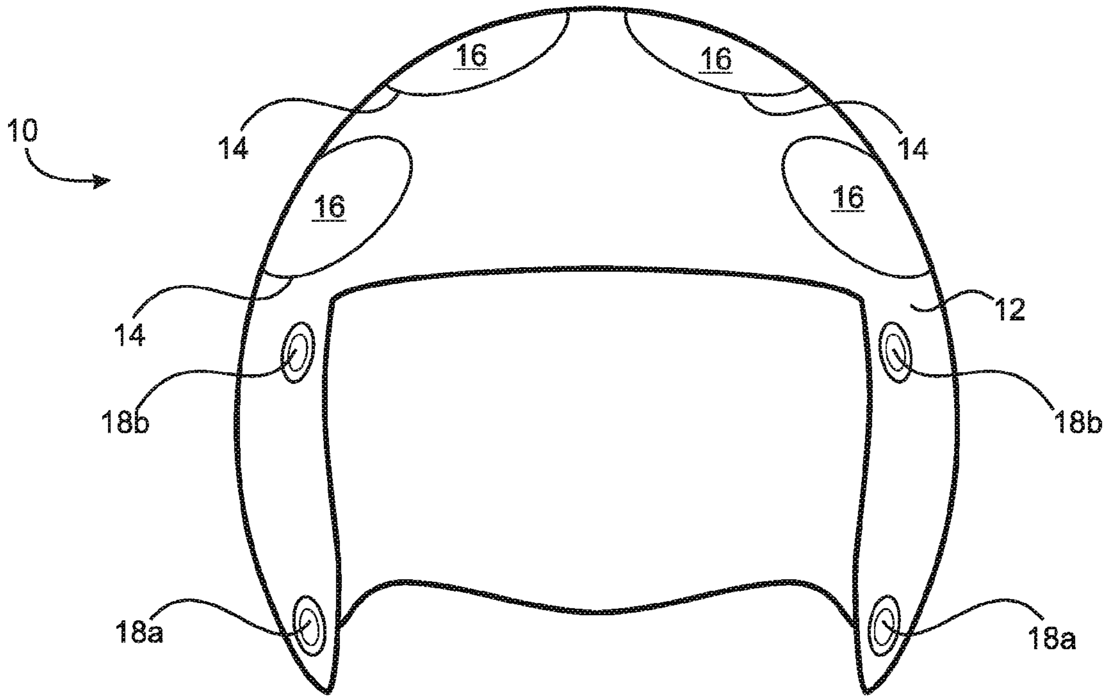
10
16
16
14
14
16
16
14
12
18b
18b
18a
18a

Fig. 1

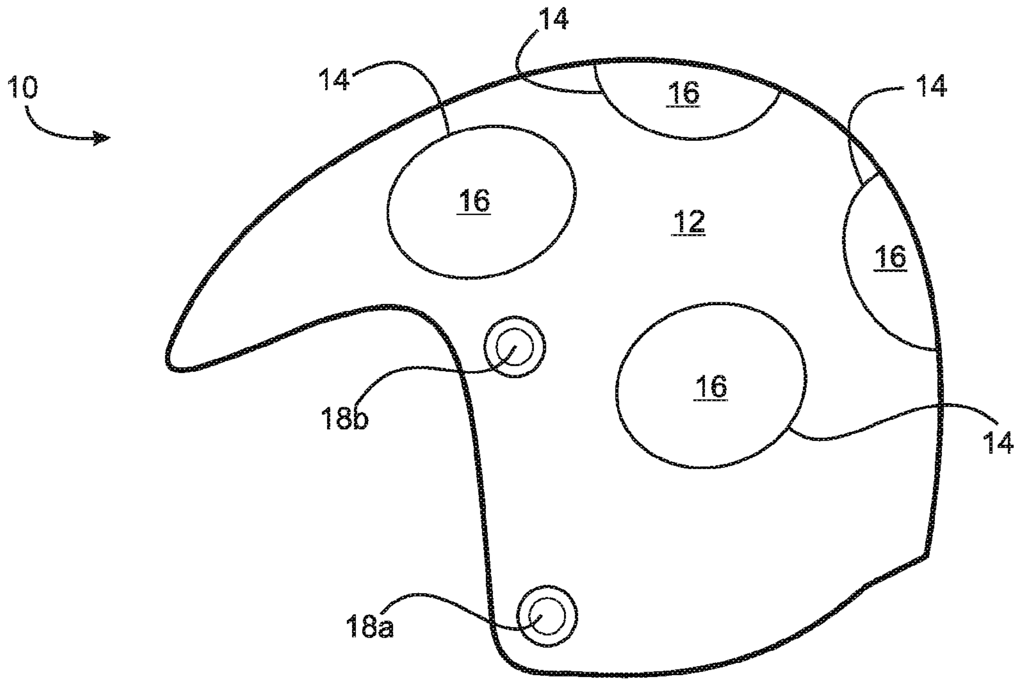
14
10
14
16
14
16
12
16
18b
16
14
18a

Fig. 2

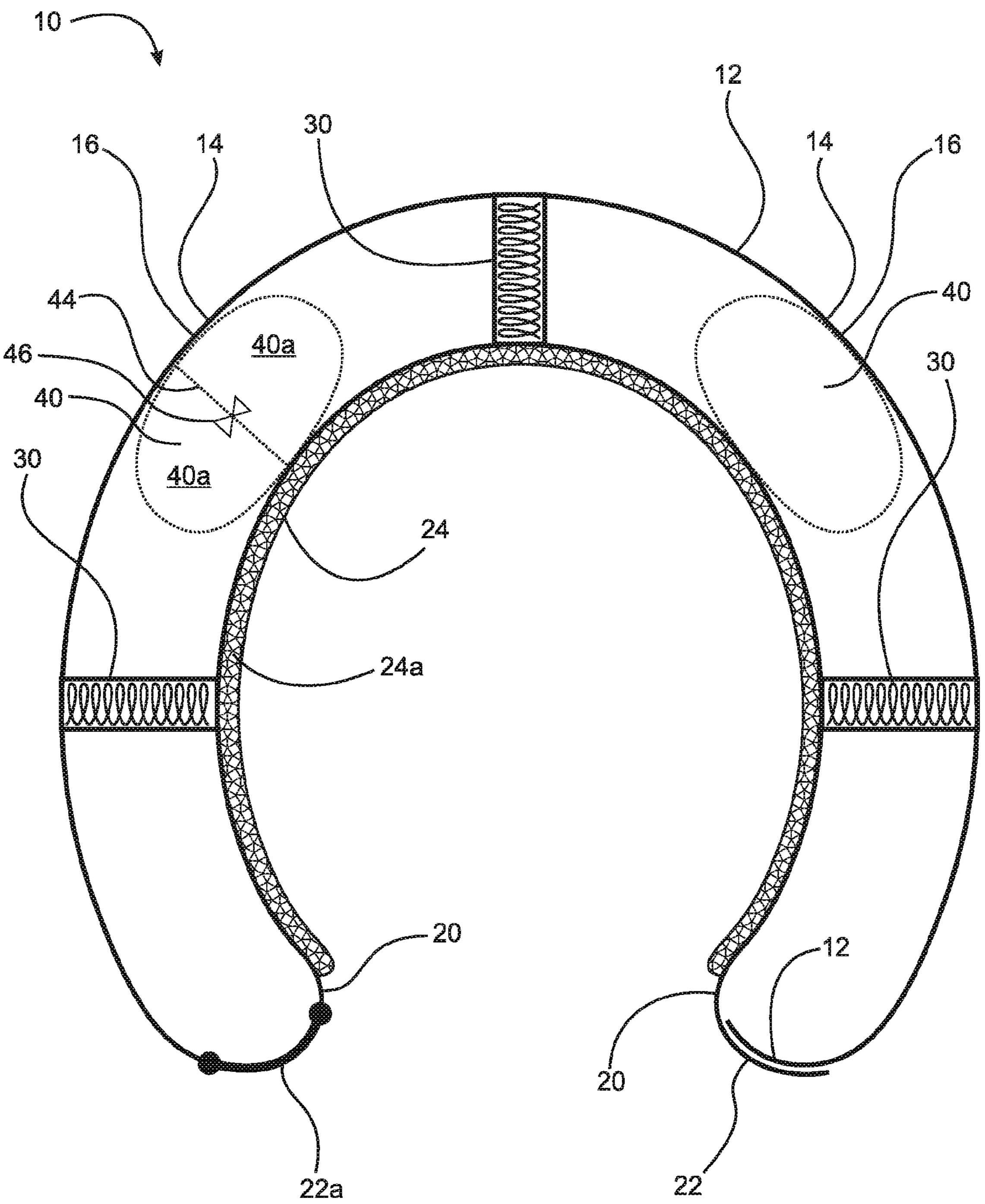

Fig. 3A

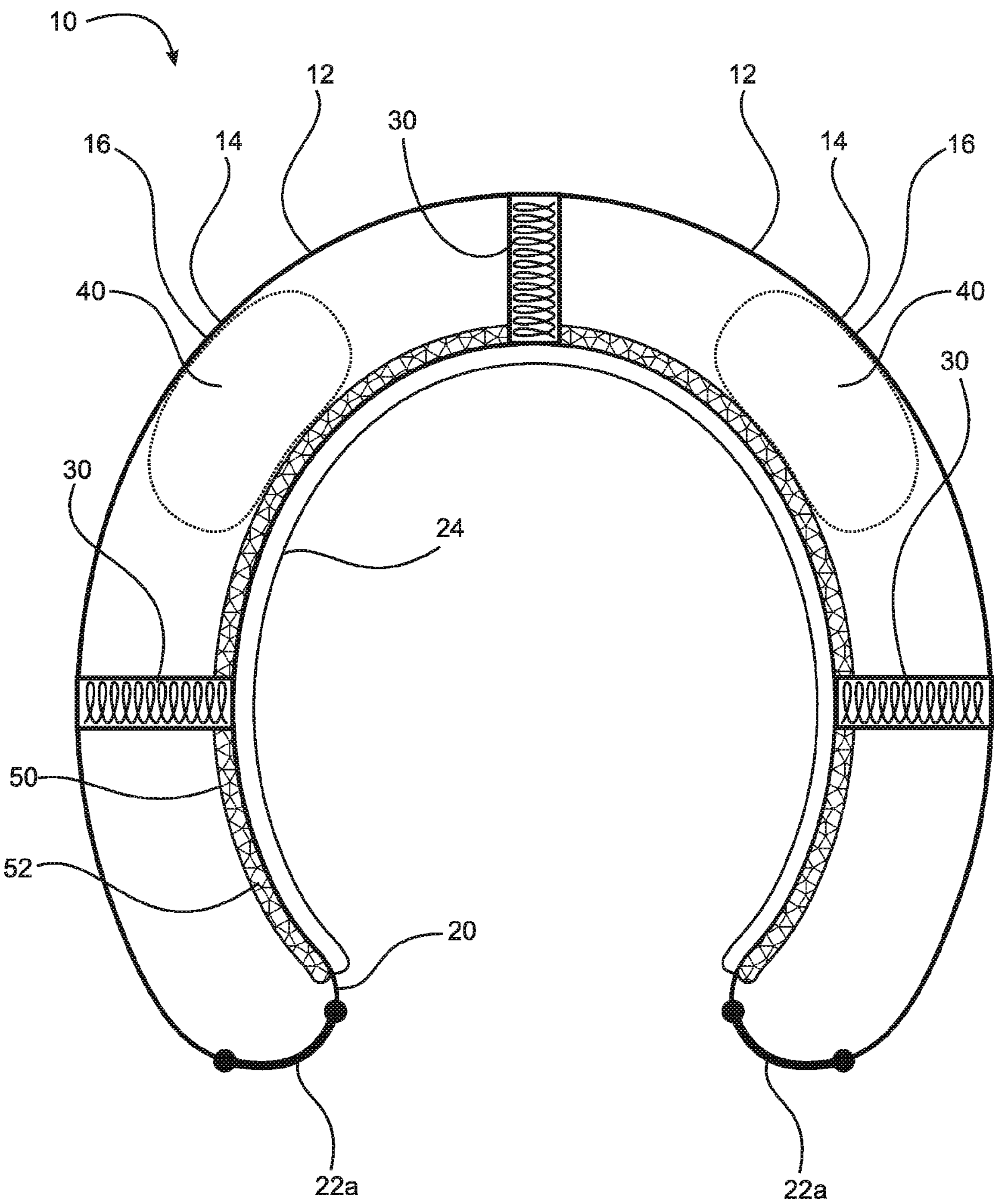

Fig. 3B

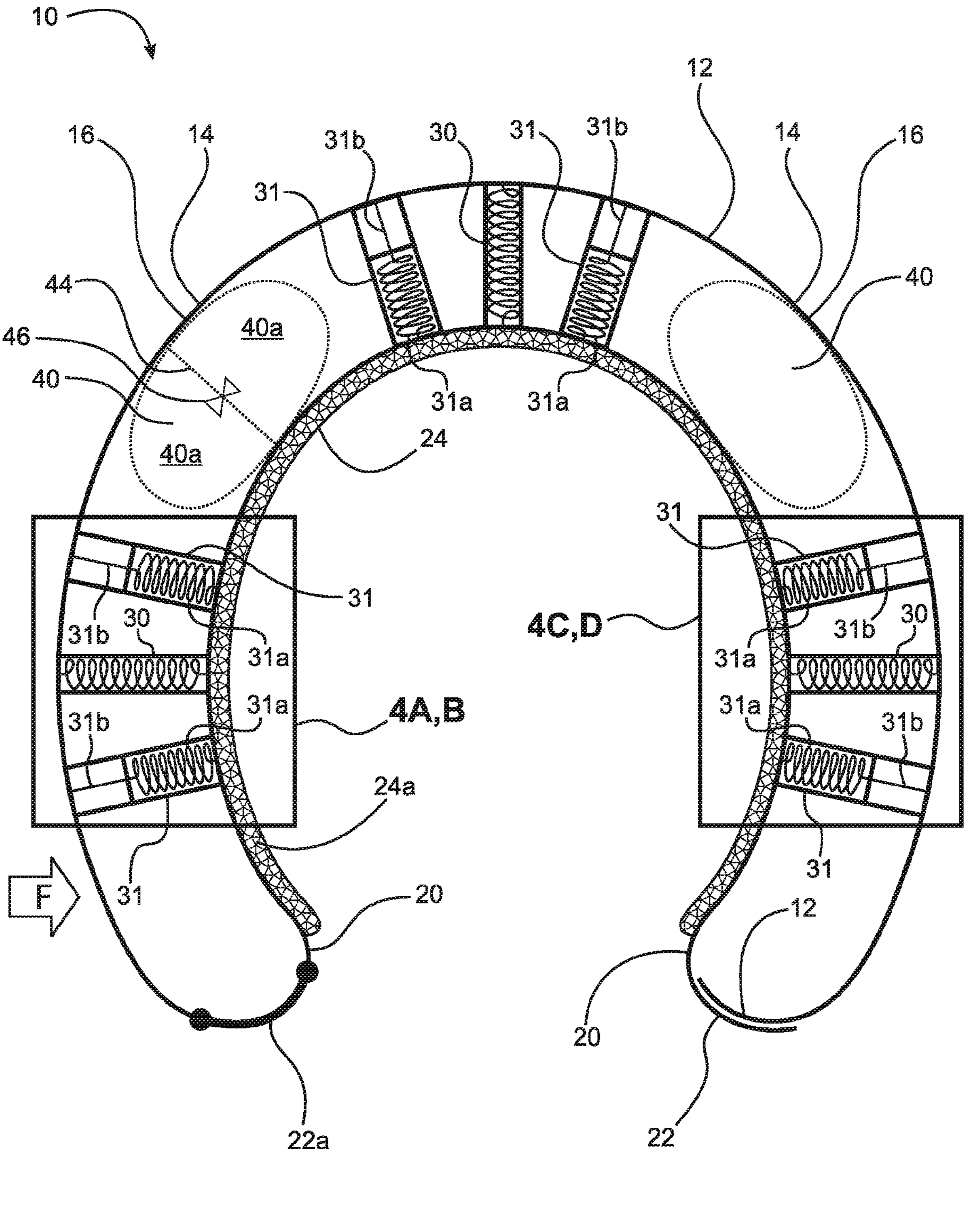
10
12
16
14
31b
30
31
31b
14
16
31
44
40a
40
46
40
40a
31a
31a
24
31
31
31b
30
31a
4C,D
31b
30
31a
31a
31b
31a
4A,B
31b
24a
31
31
F
20
12
20
22a
22

Fig. 3C

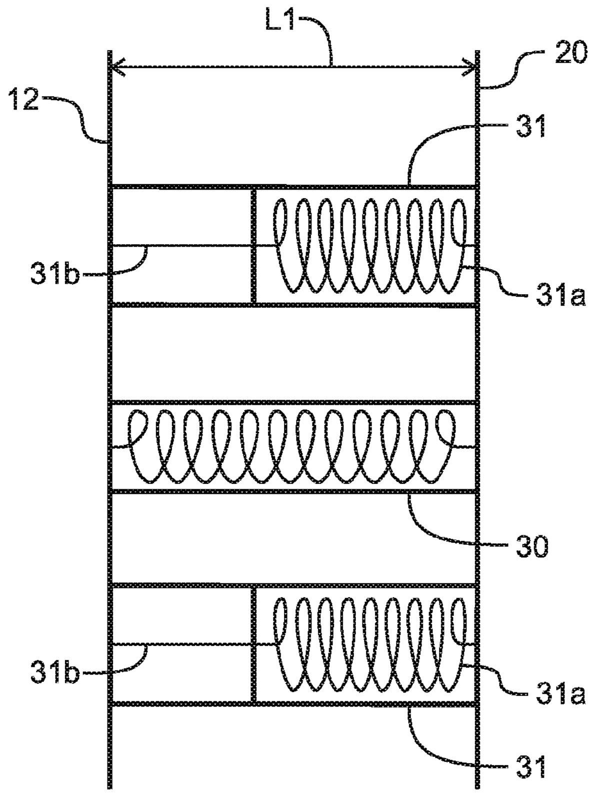

Fig. 4A

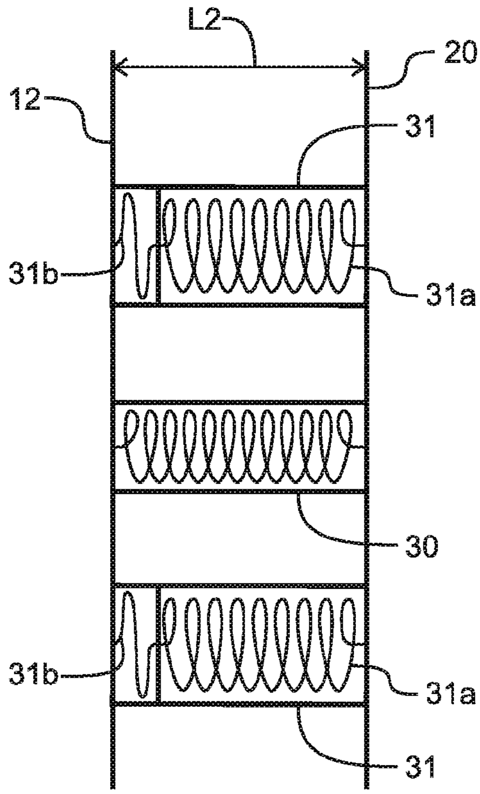

Fig. 4B

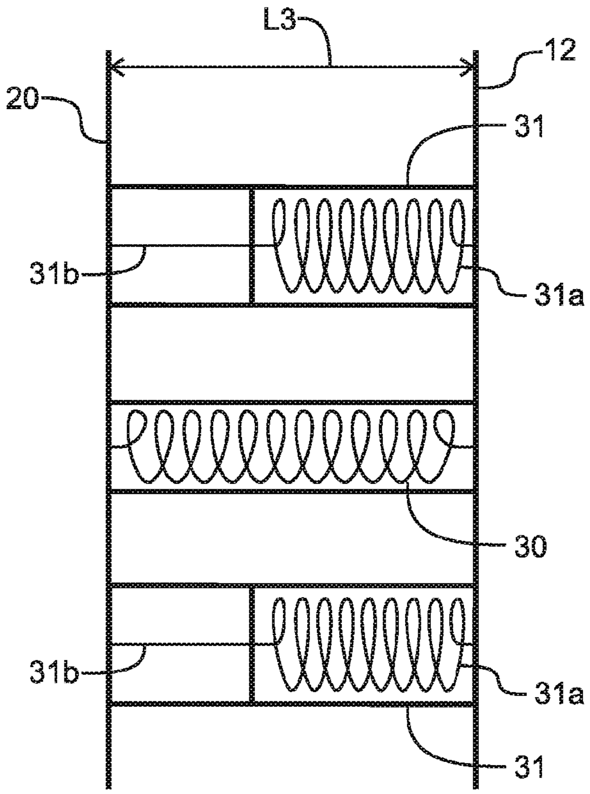

Fig. 4C

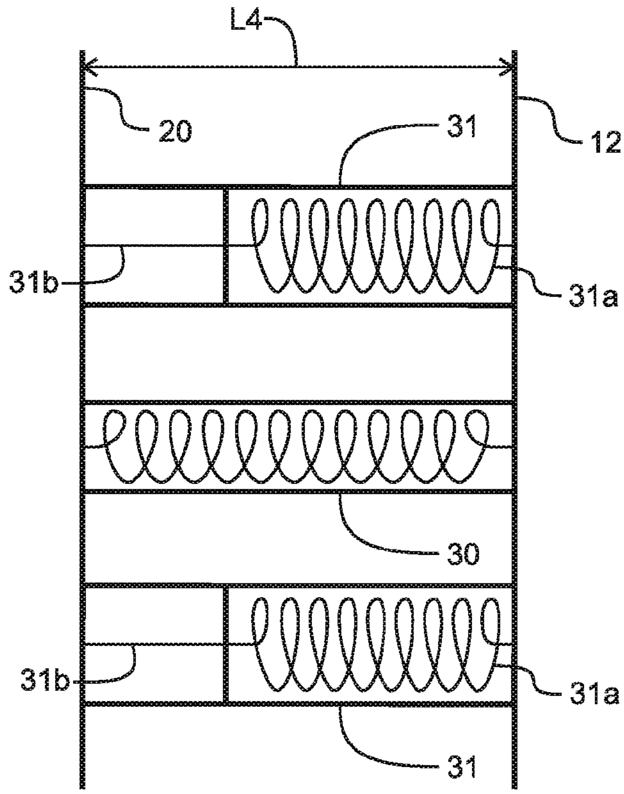

Fig. 4D

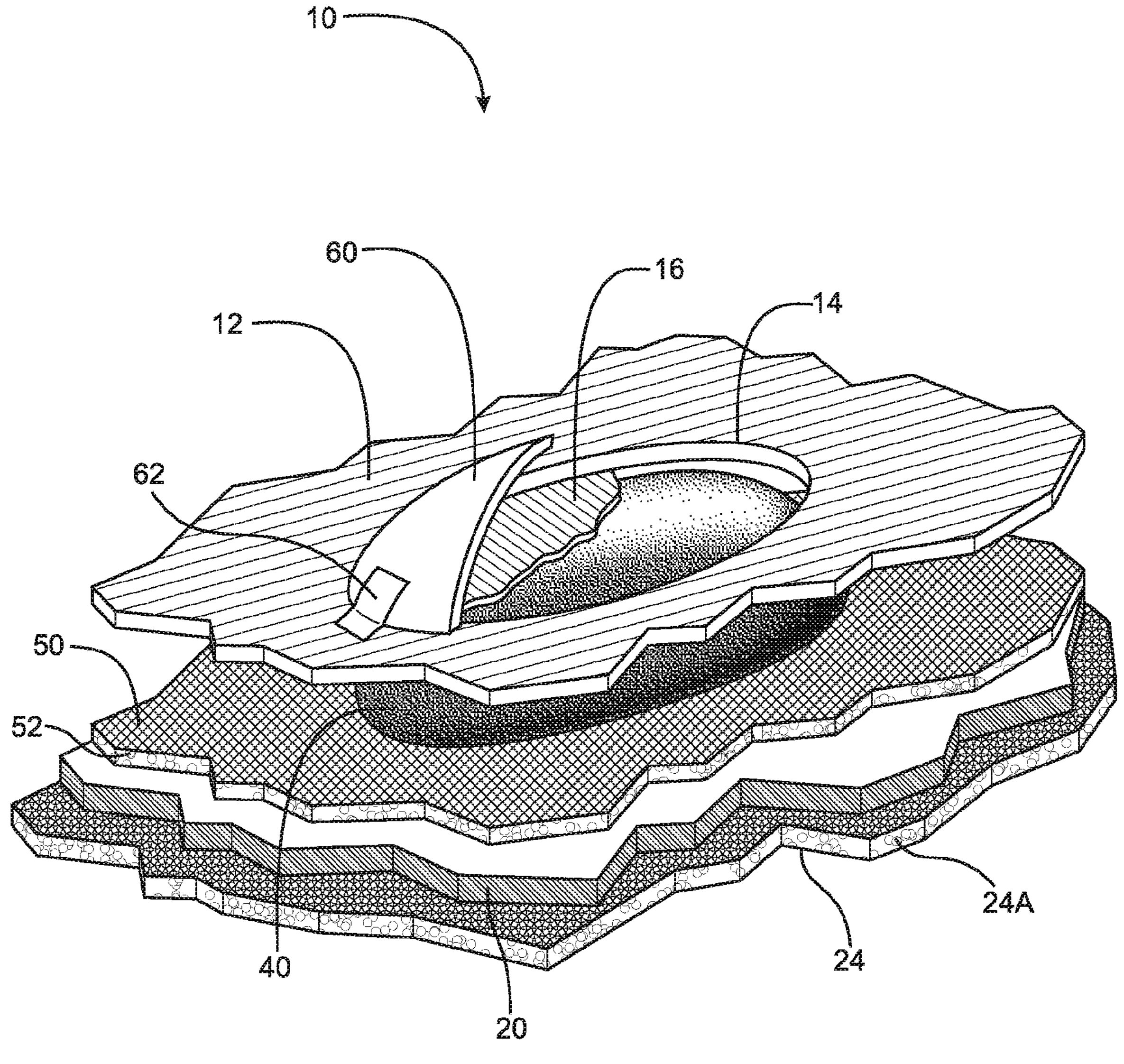

Fig. 5A

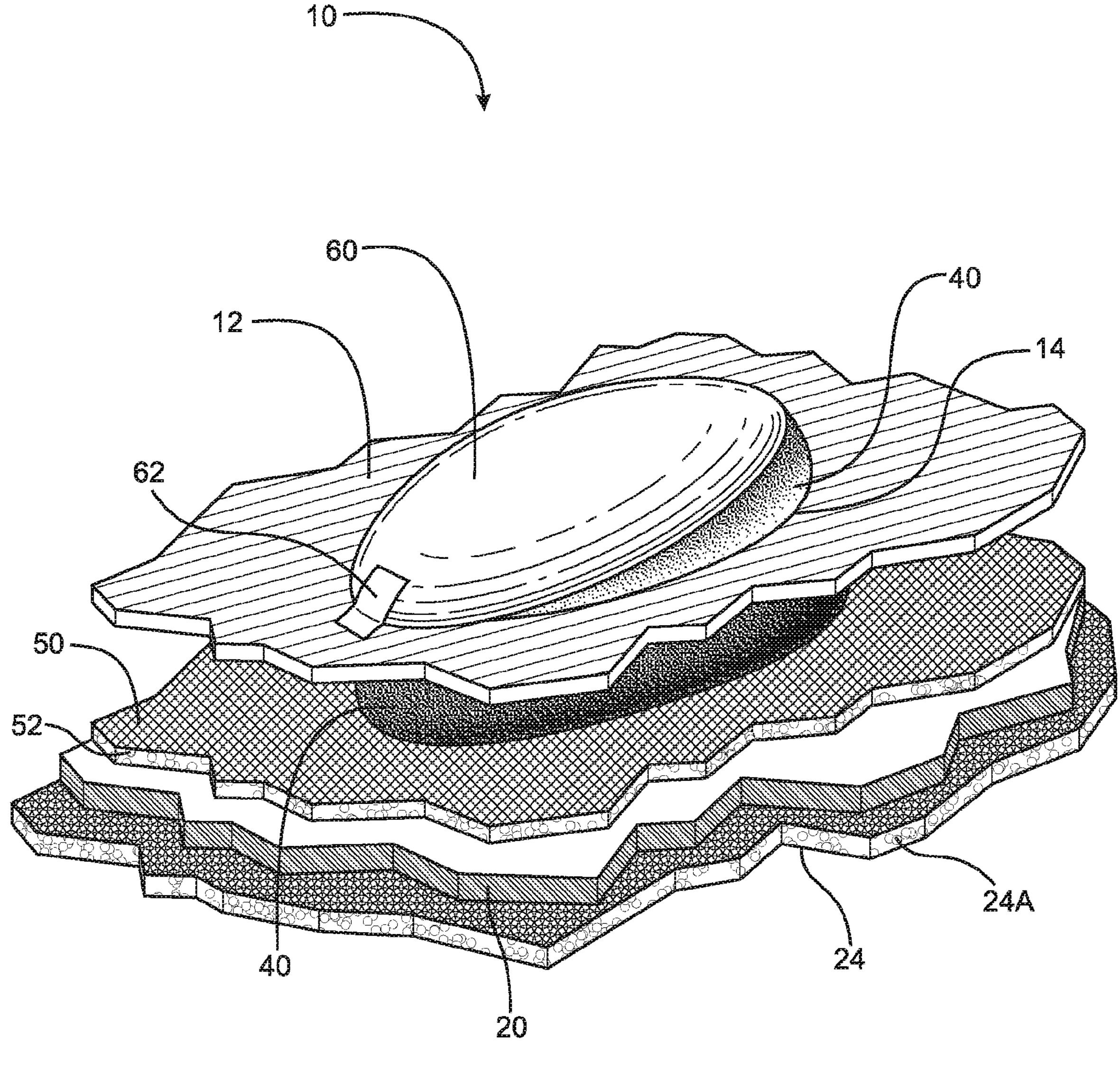

Fig. 5B

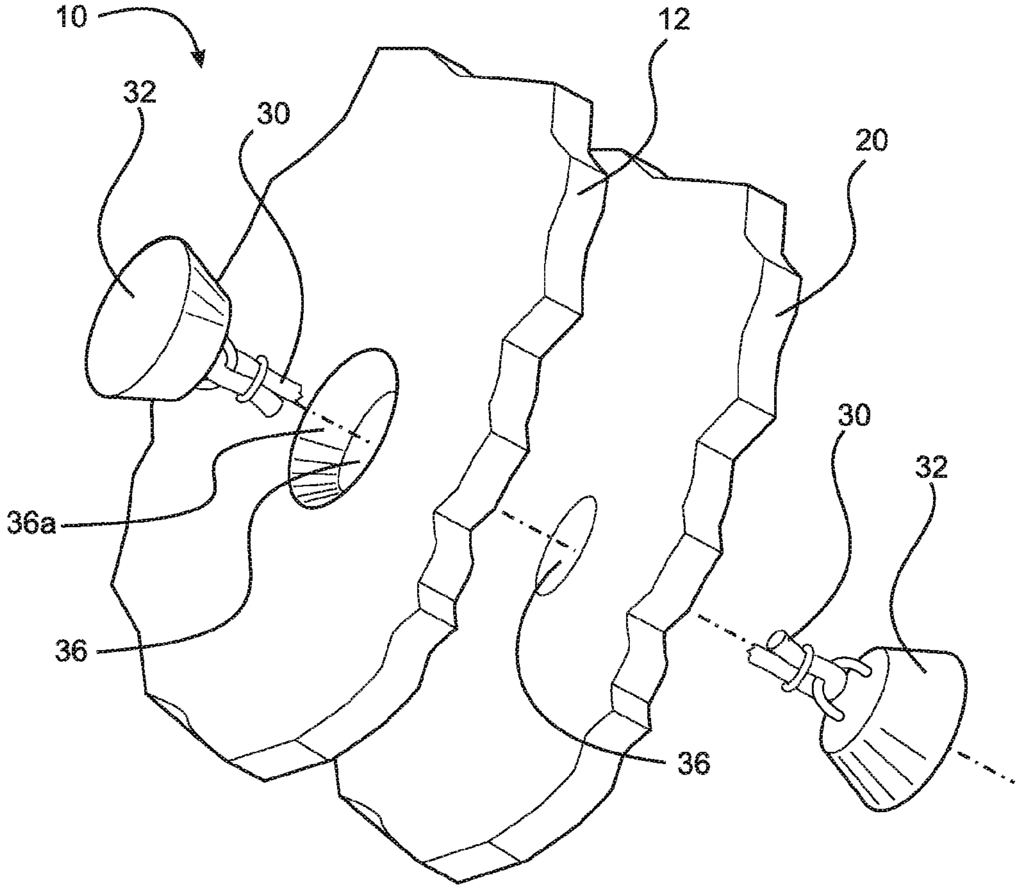

Fig. 6A

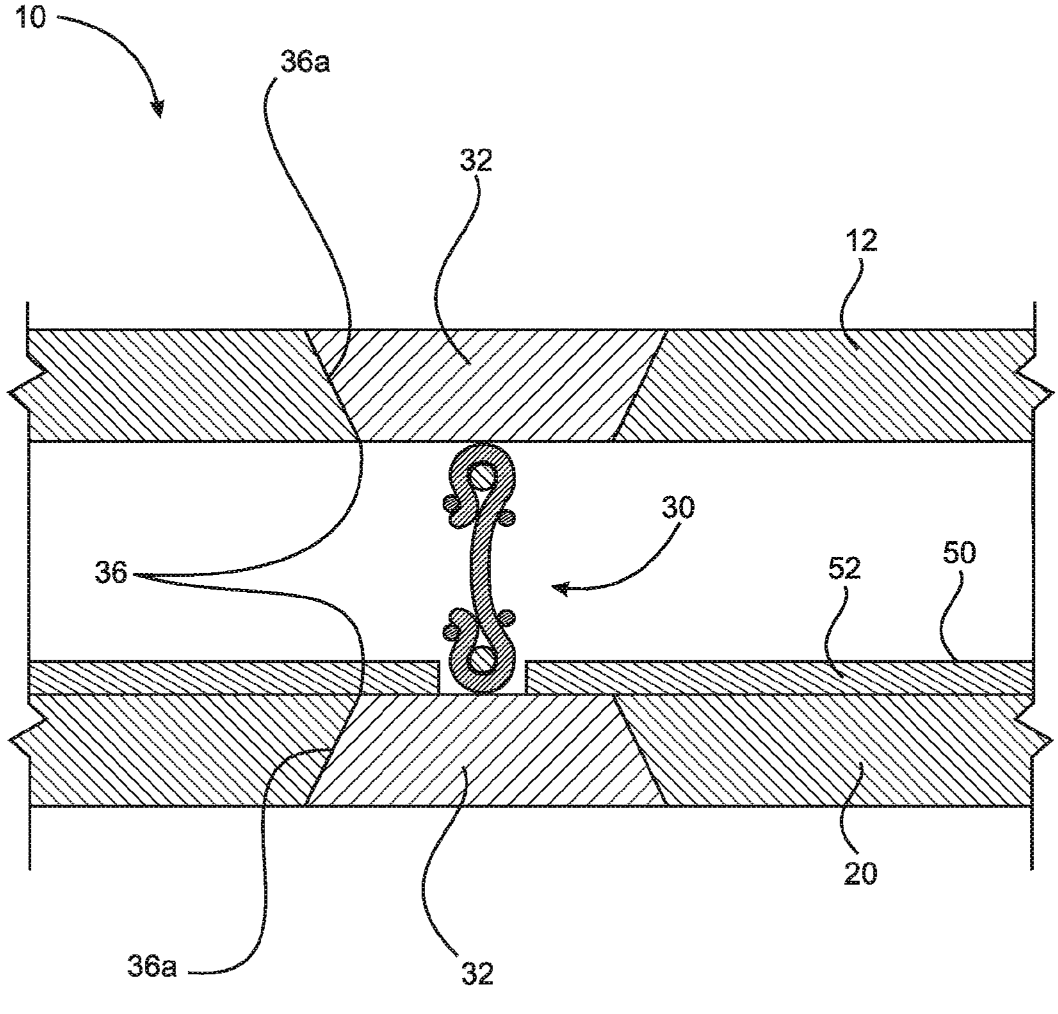

Fig. 6B

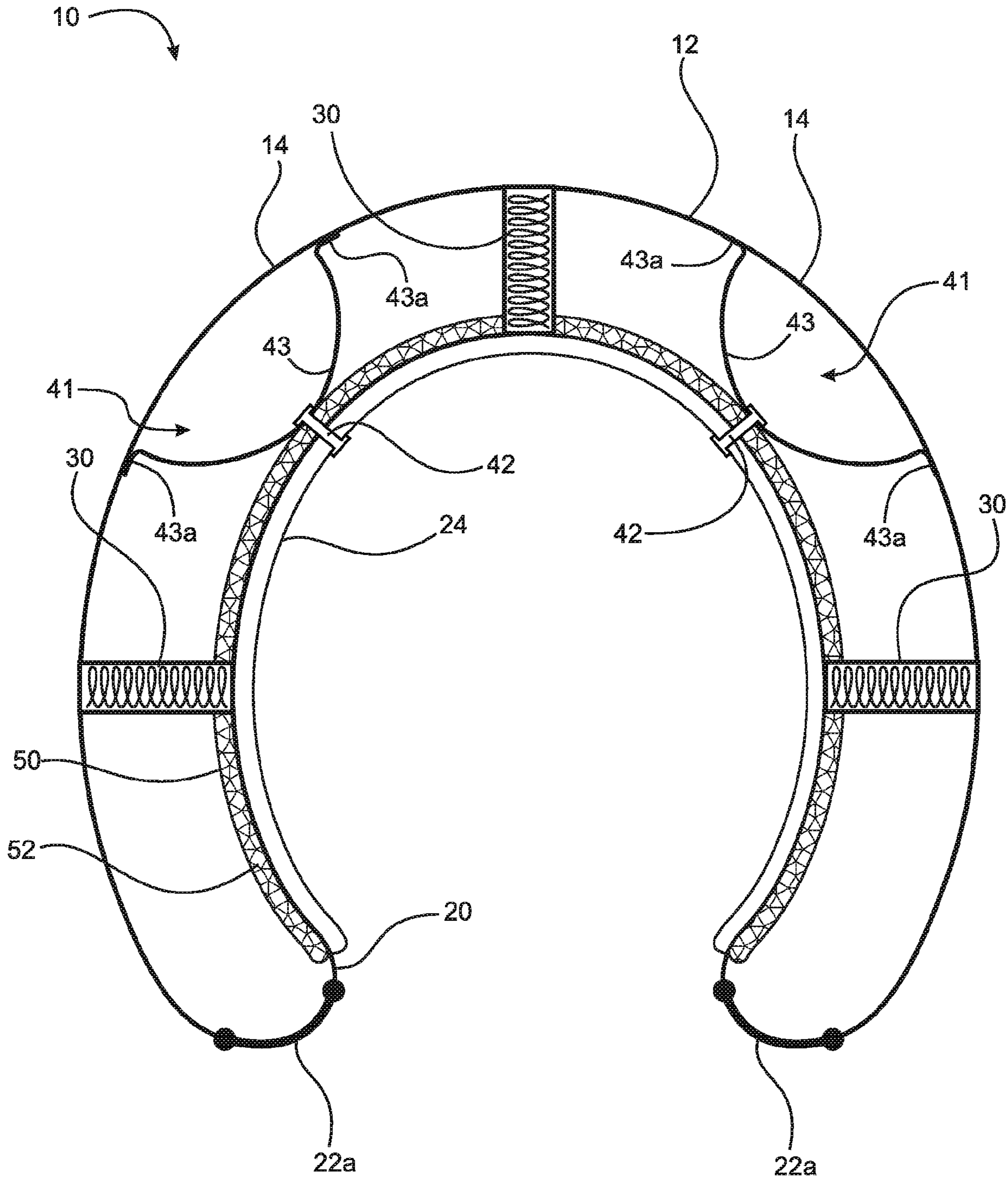
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Fig. 7

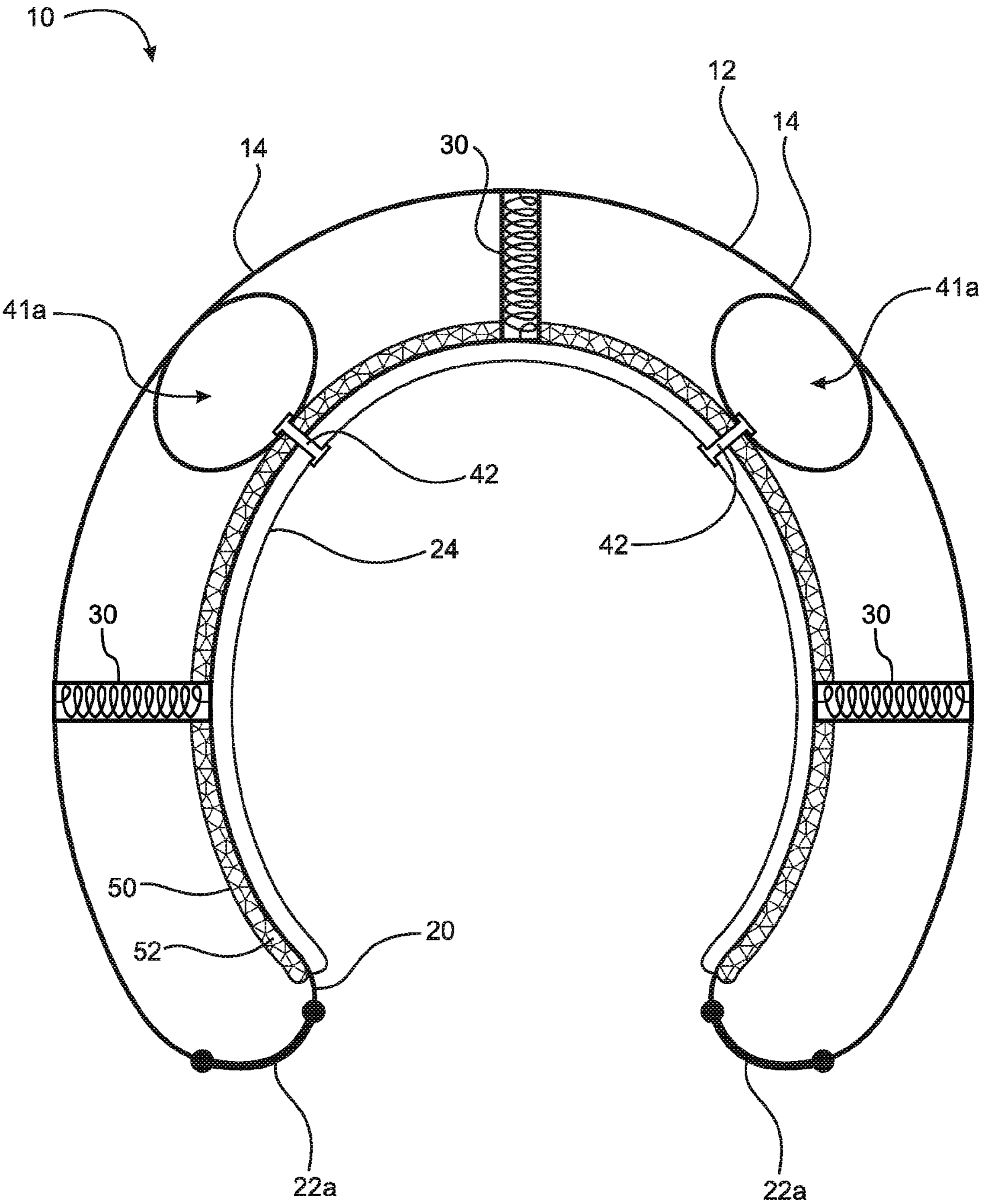

Fig. 7A

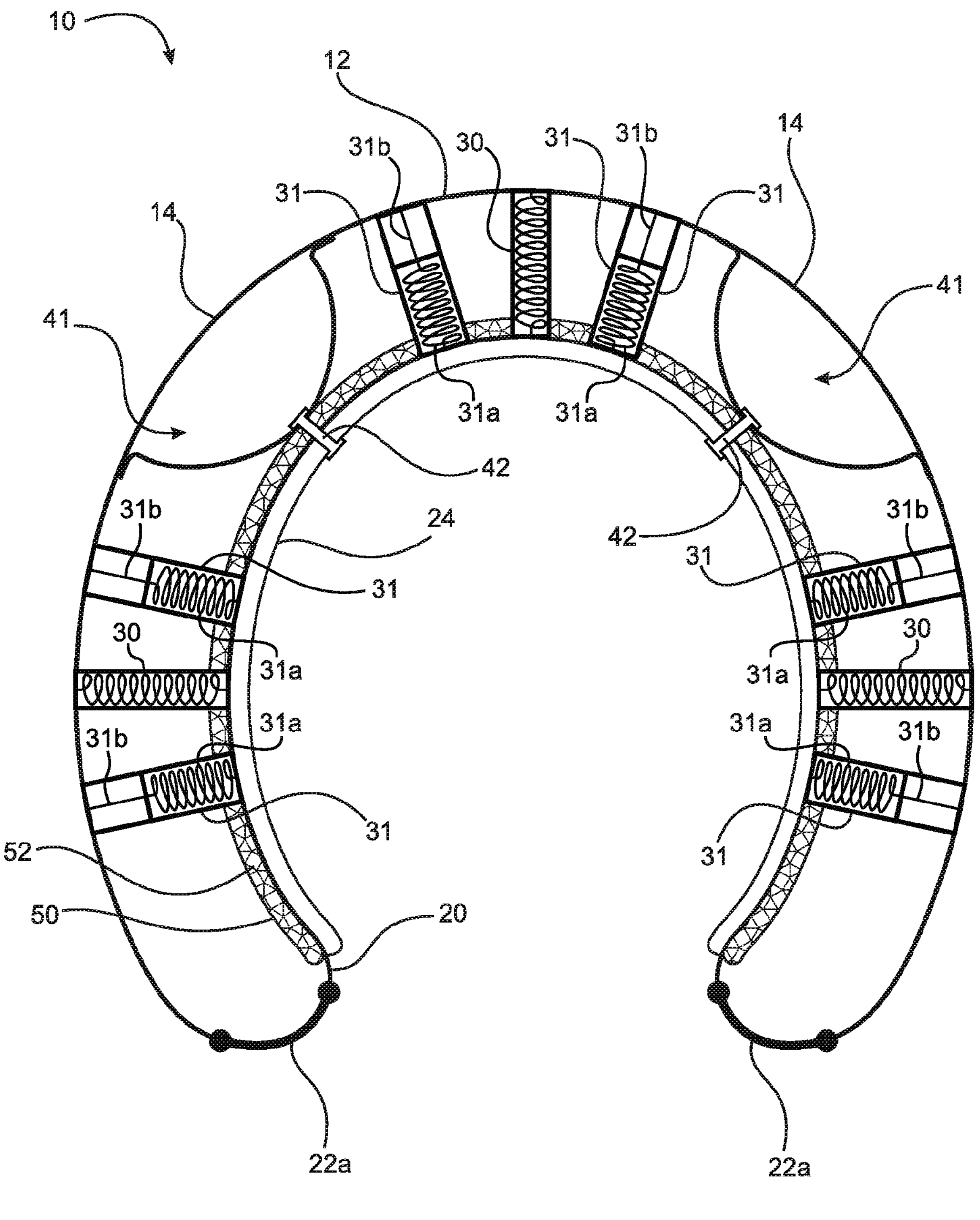
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Fig. 8

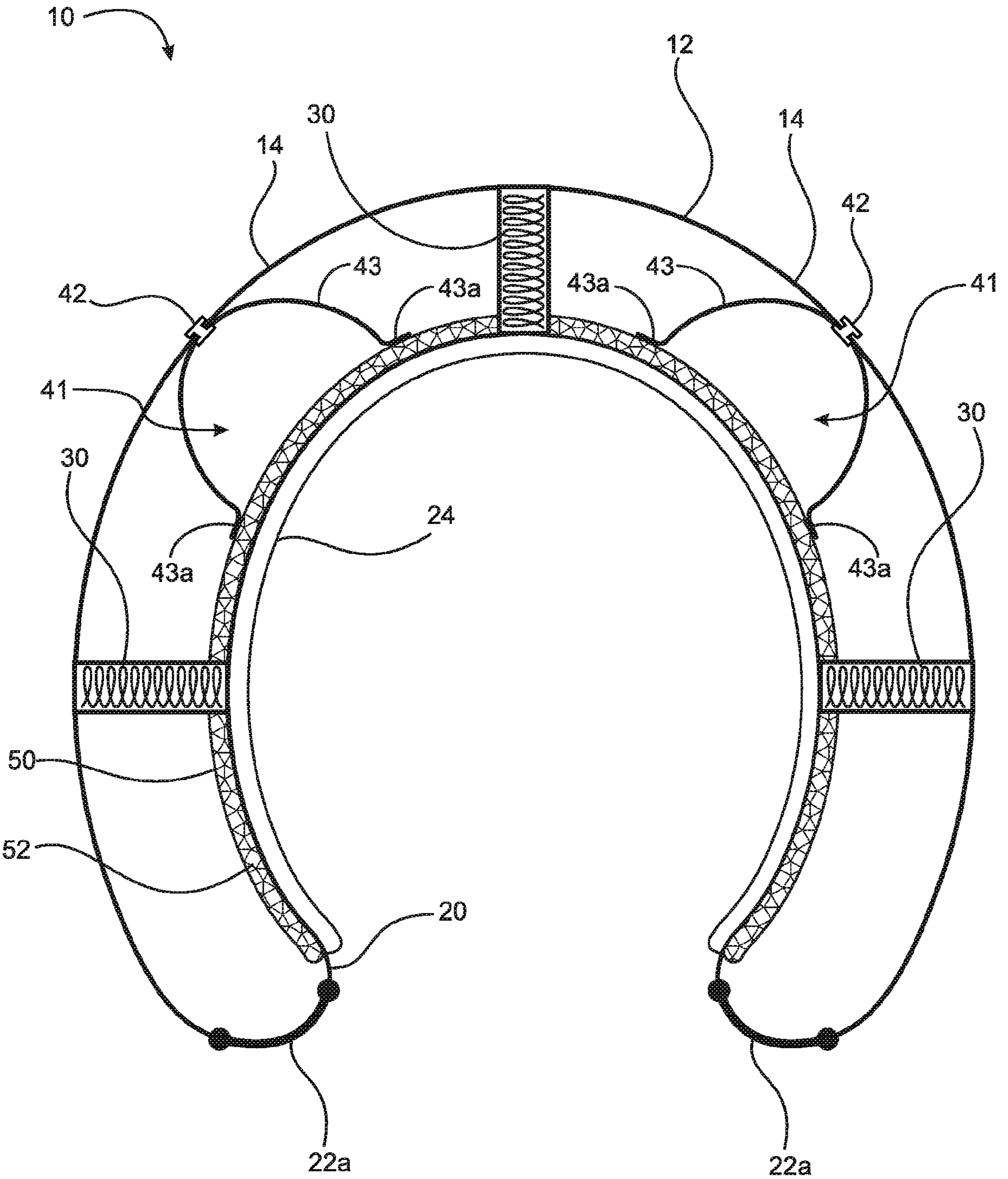
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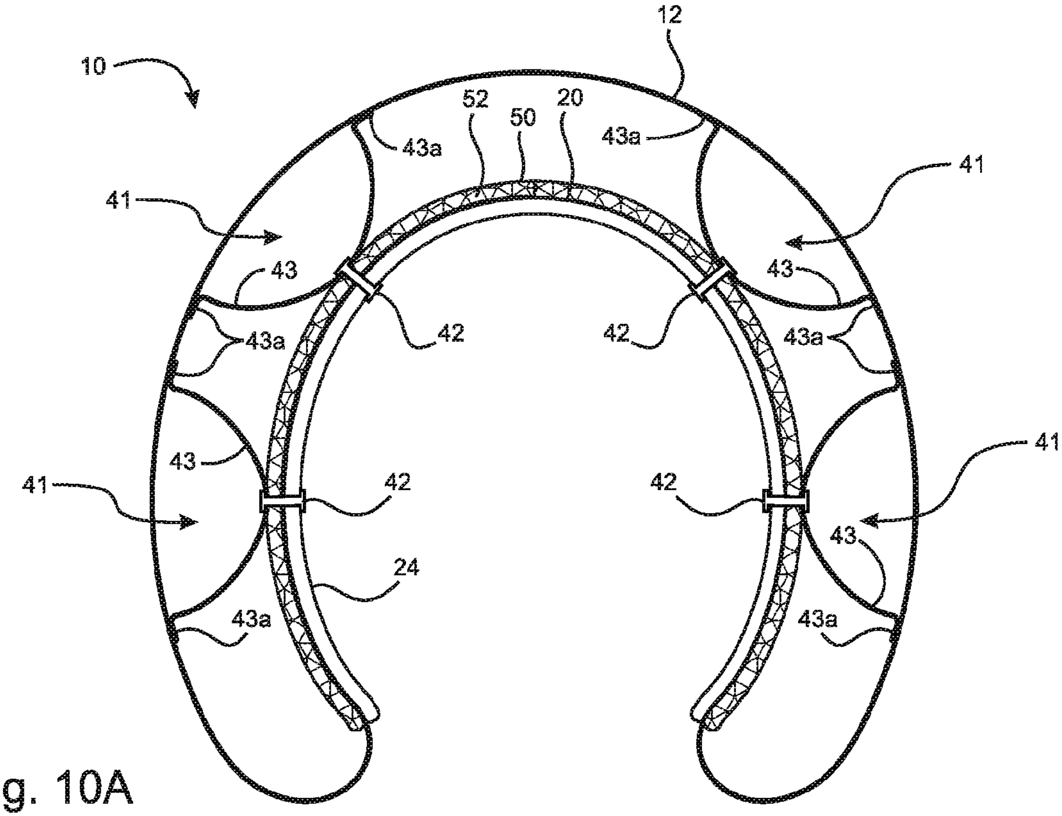
Fig. 9



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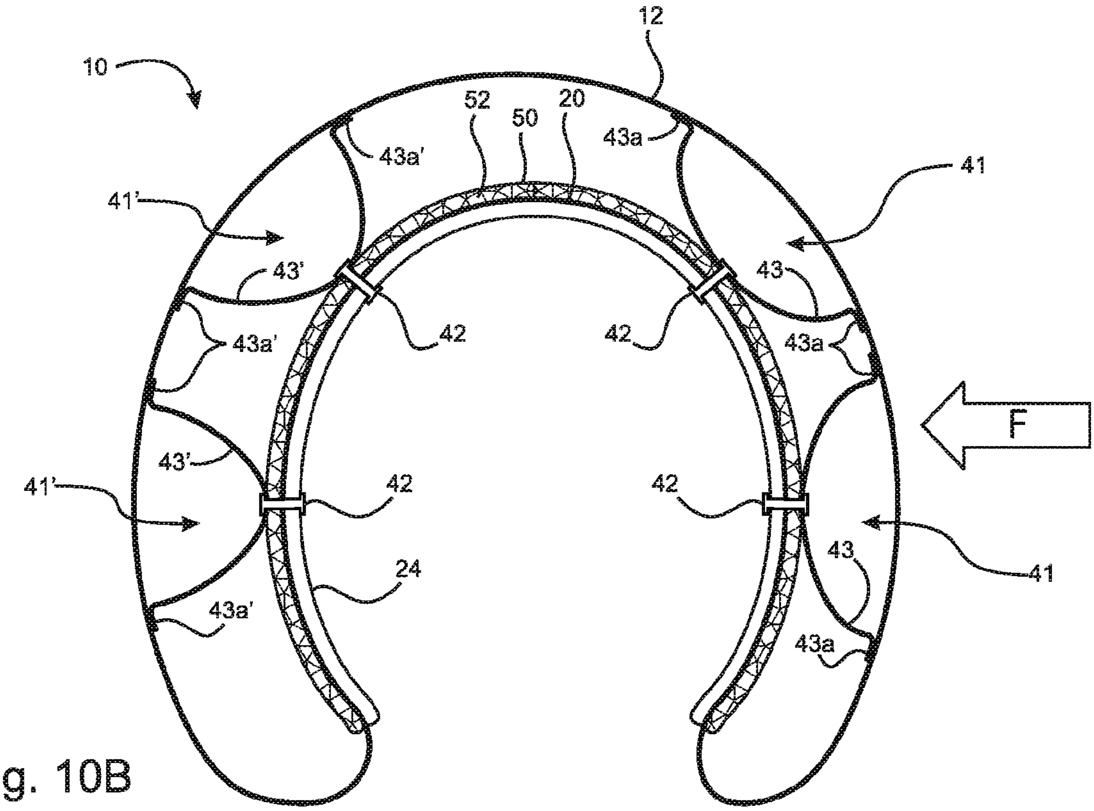

Fig. 10B

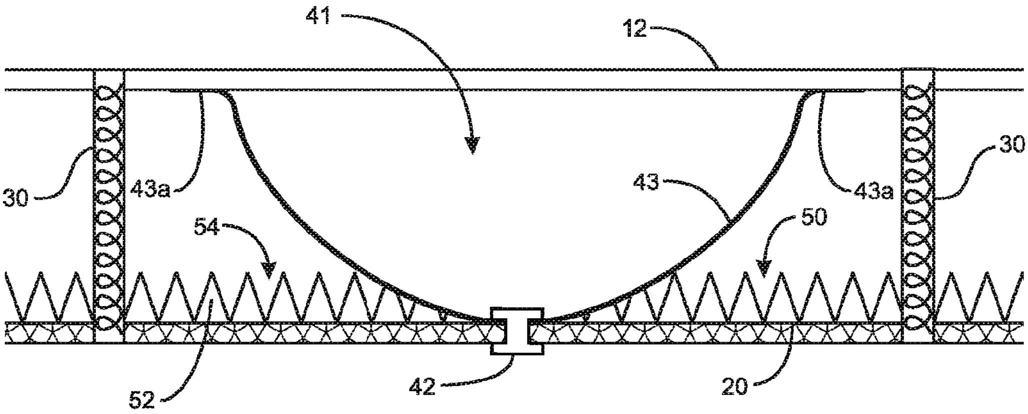

Fig. 11

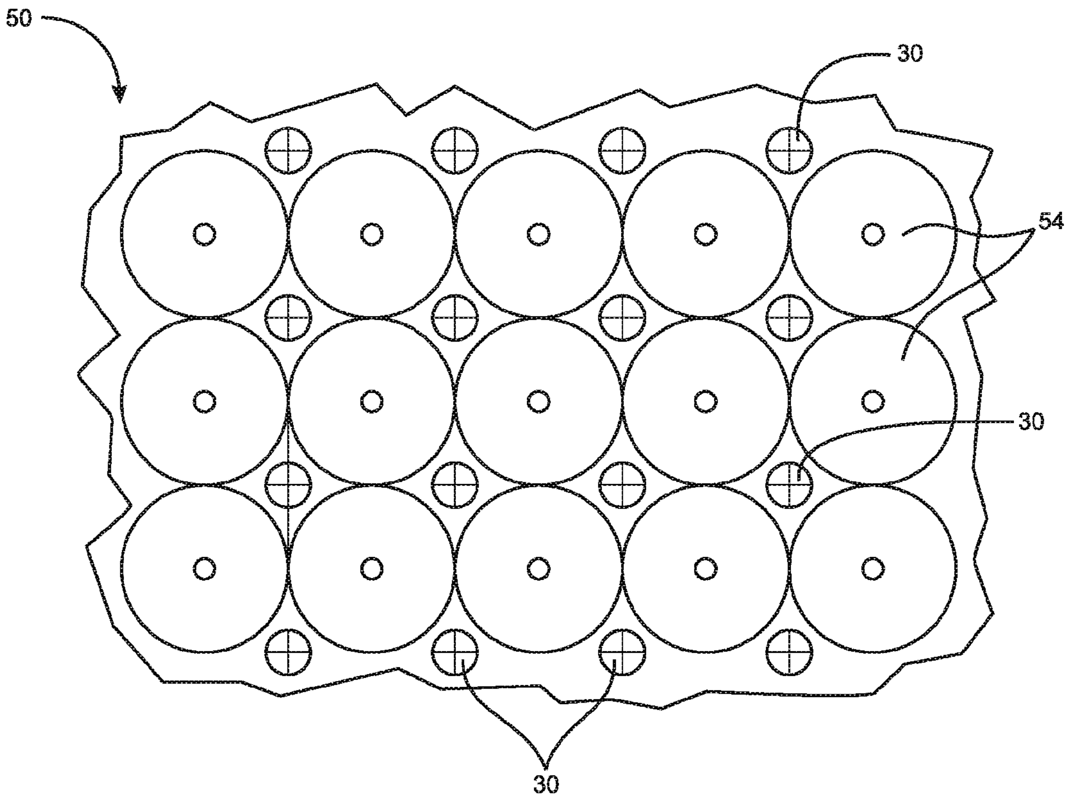

Fig. 12

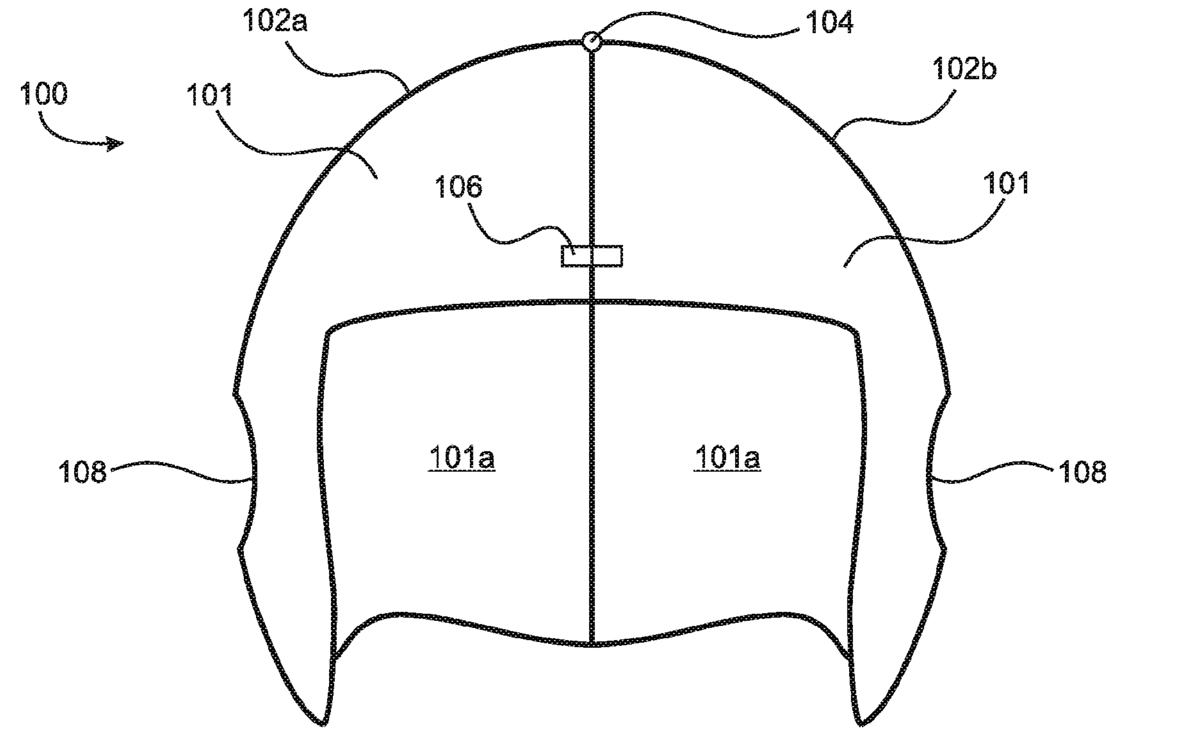

Fig. 13A

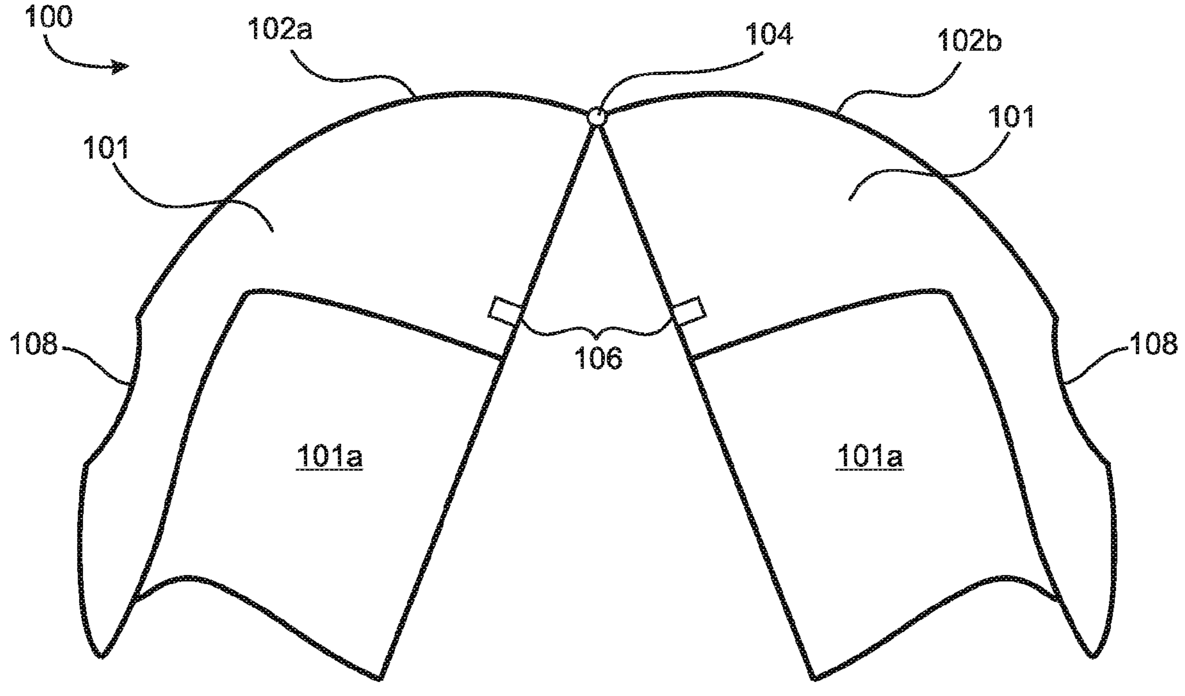

Fig. 13B

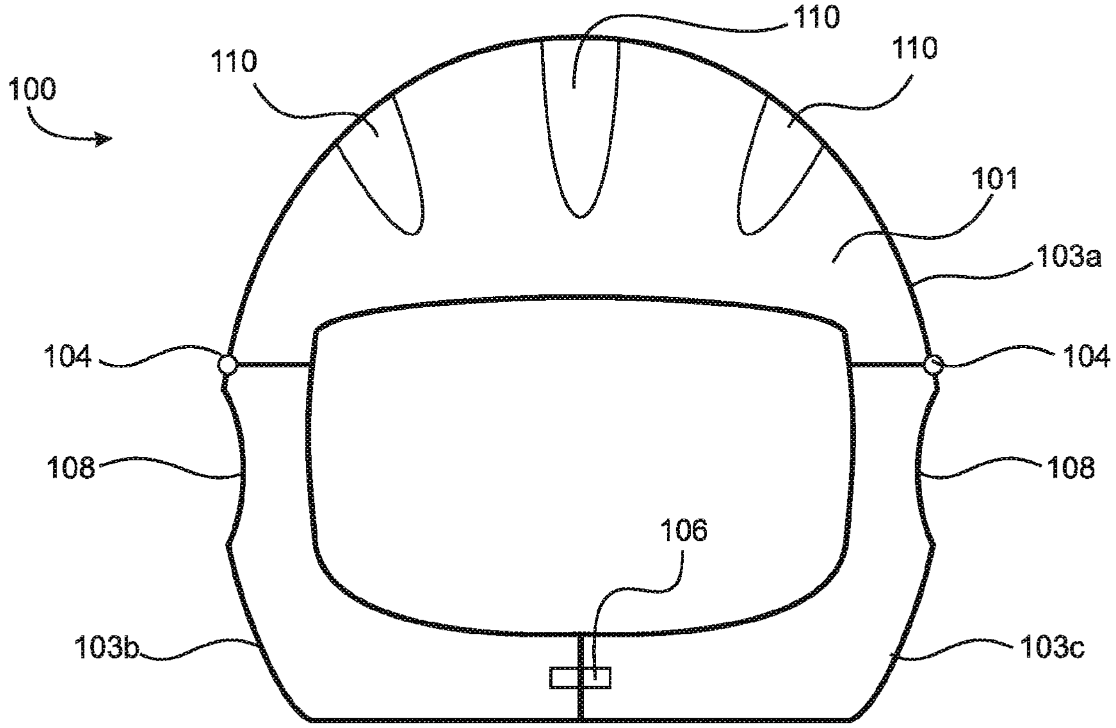

Fig. 14A

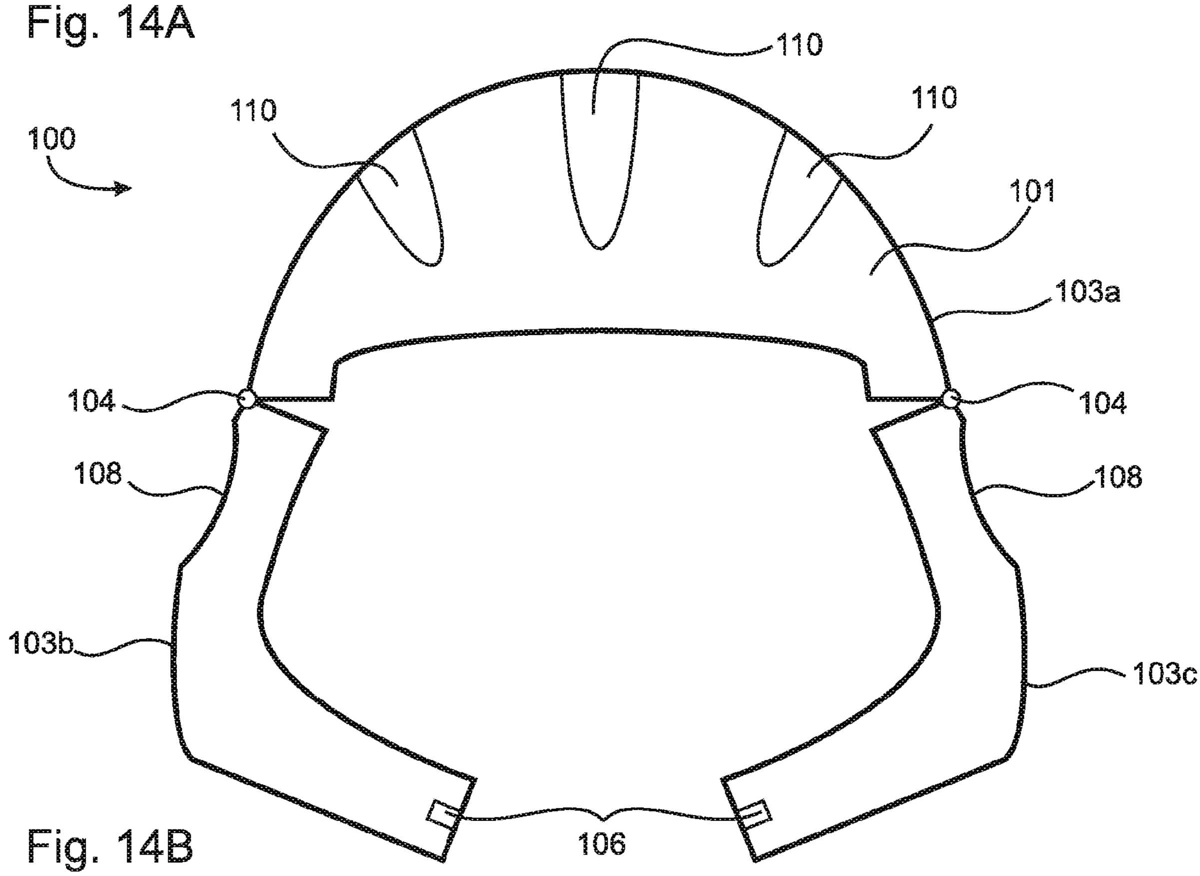

Fig. 14B

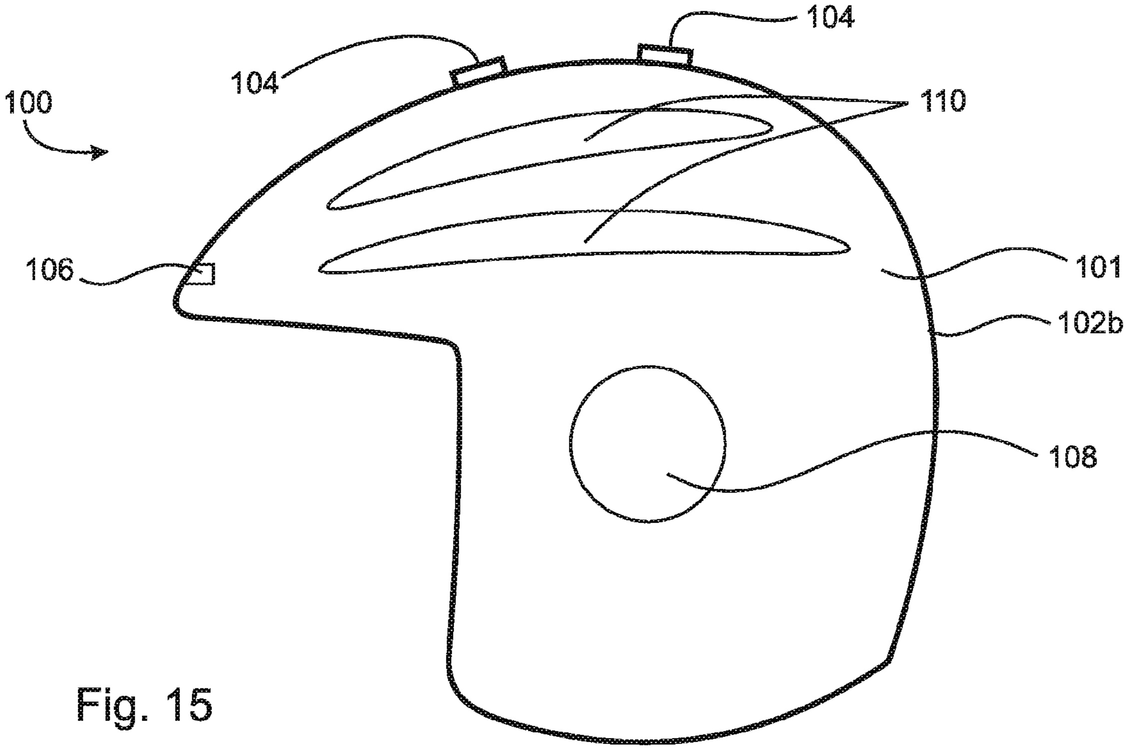
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Fig. 15

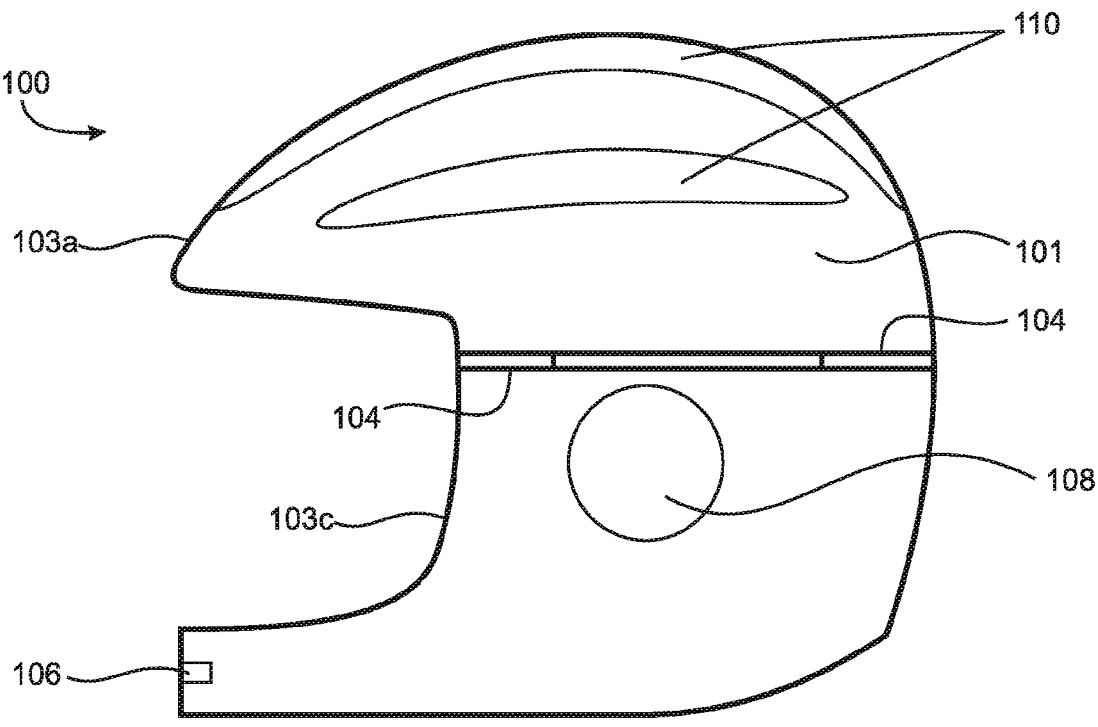
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Fig. 16

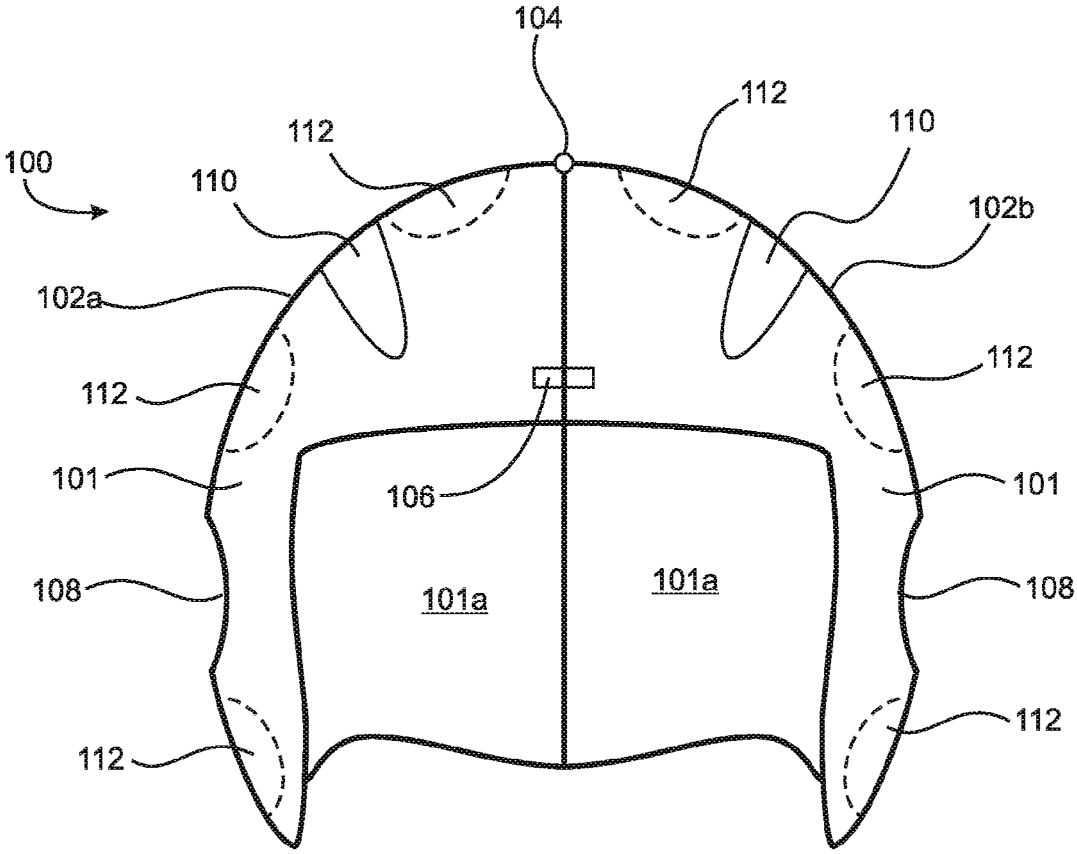
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Fig. 17

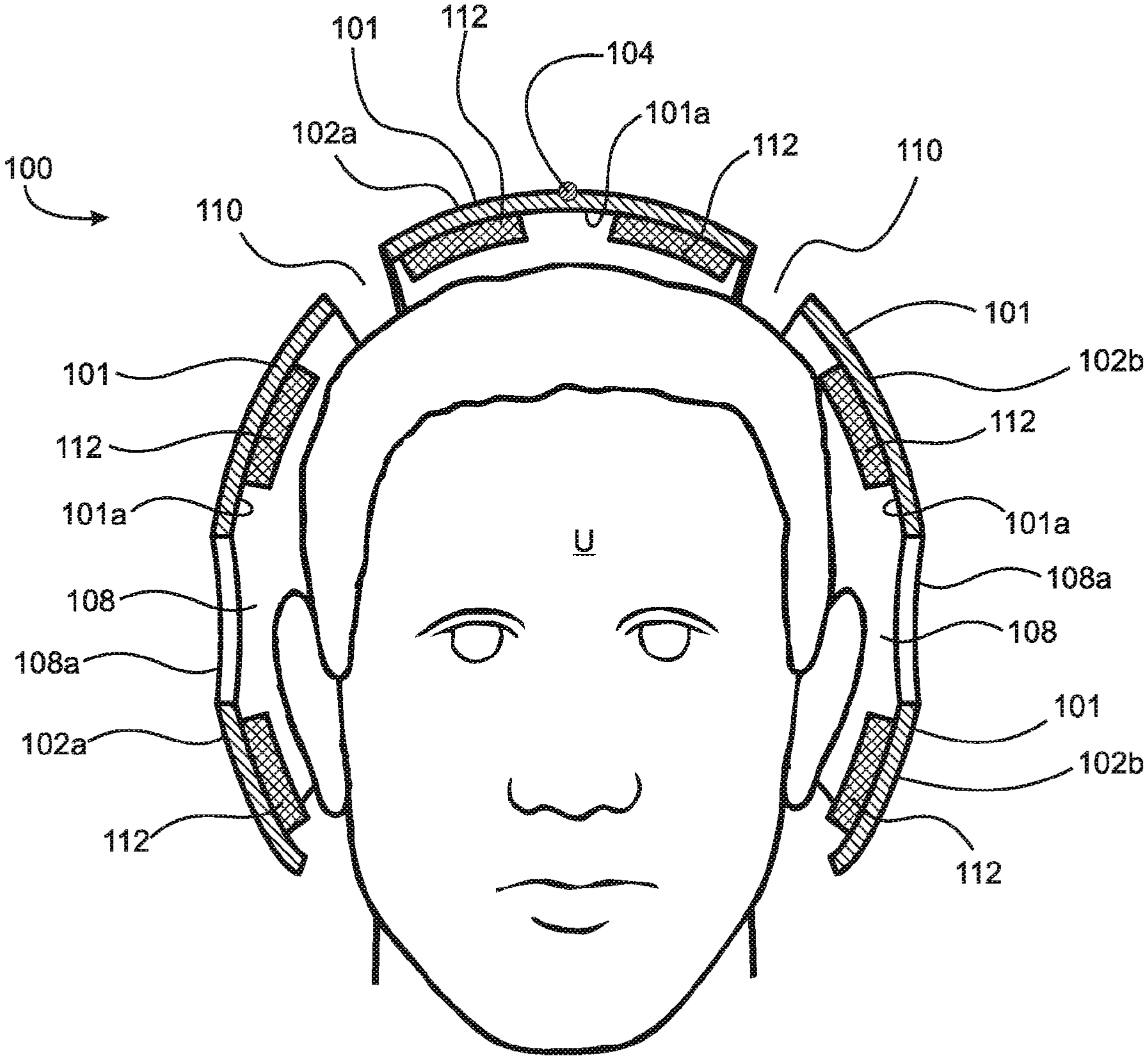
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Fig. 17A

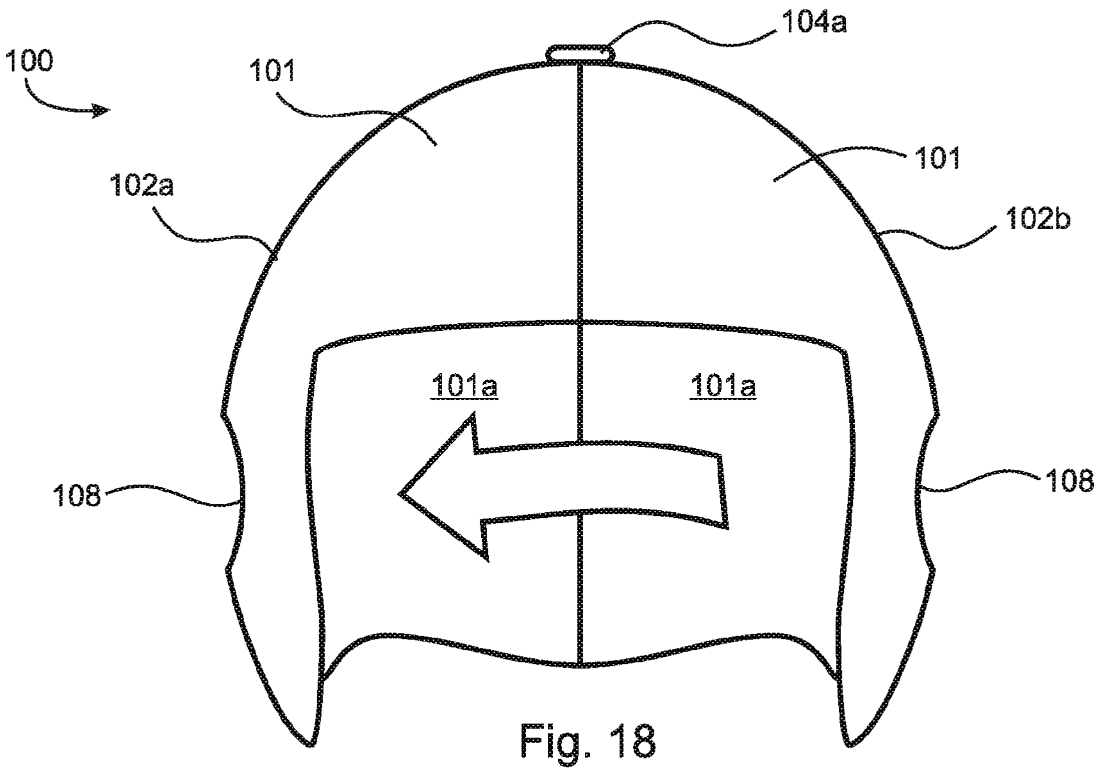

Fig. 18

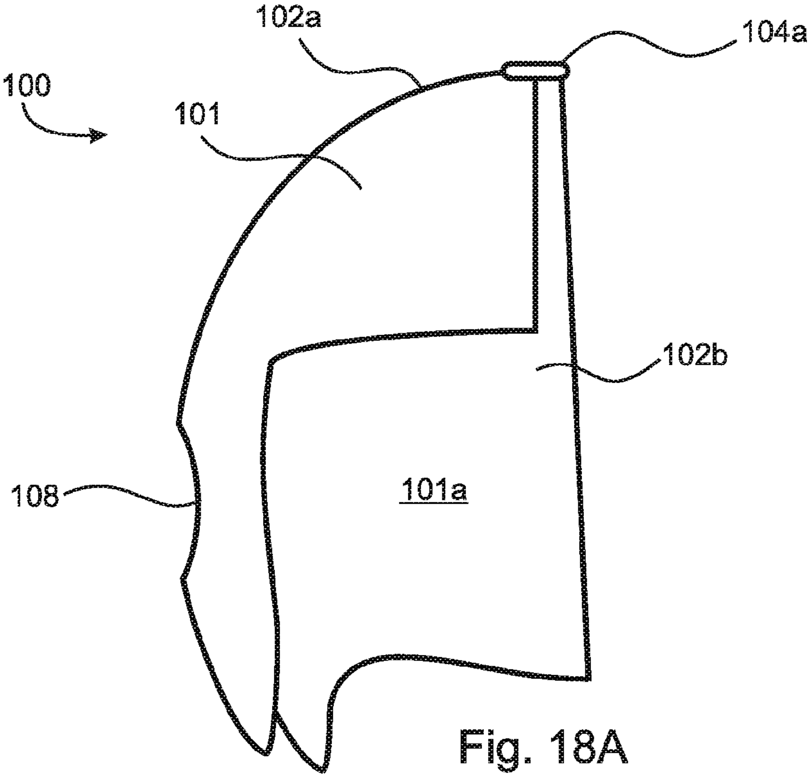

Fig. 18A

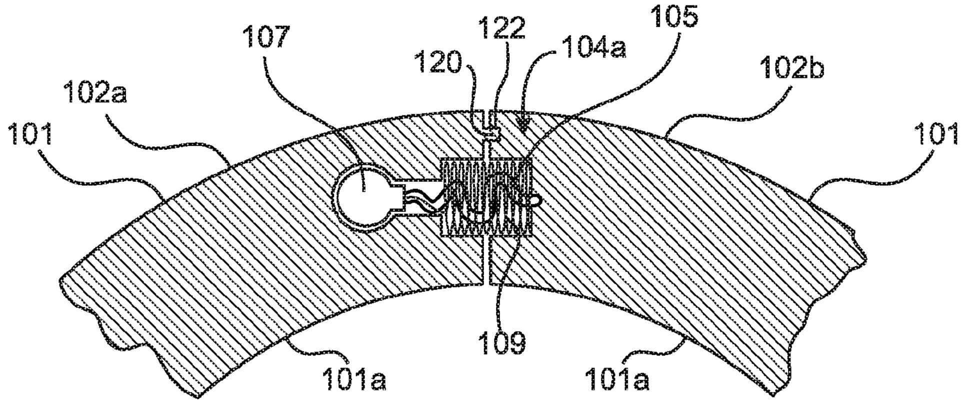

Fig. 19A

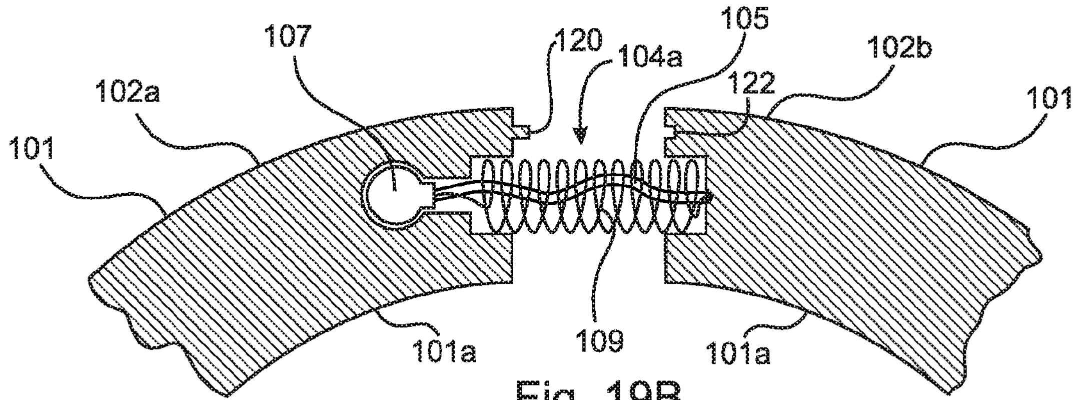

Fig. 19B

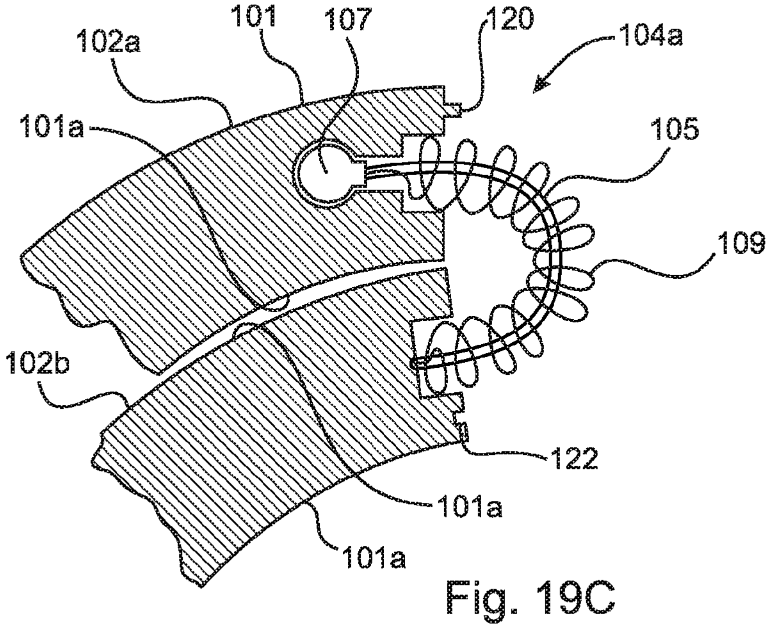

Fig. 19C

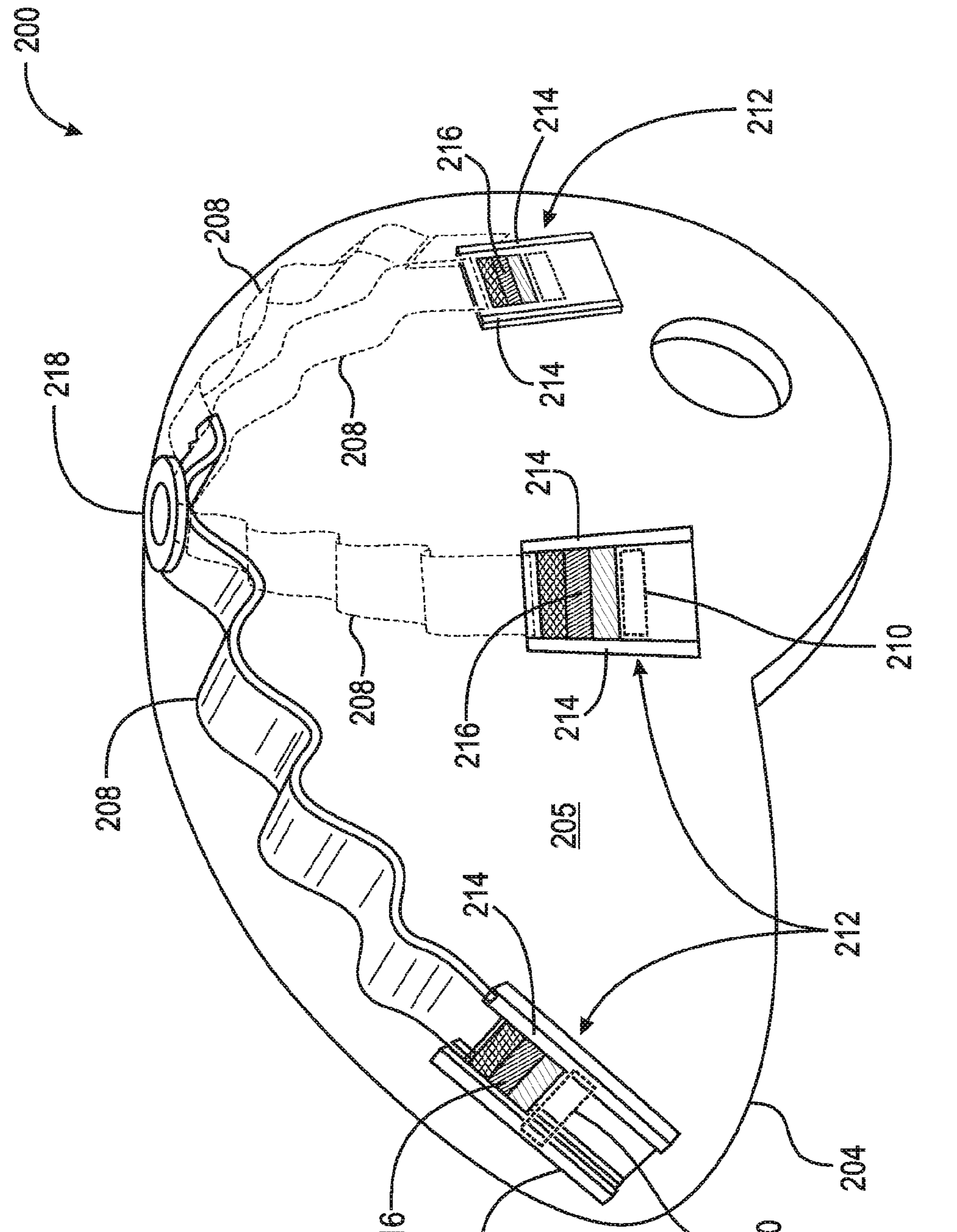
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Fig. 20

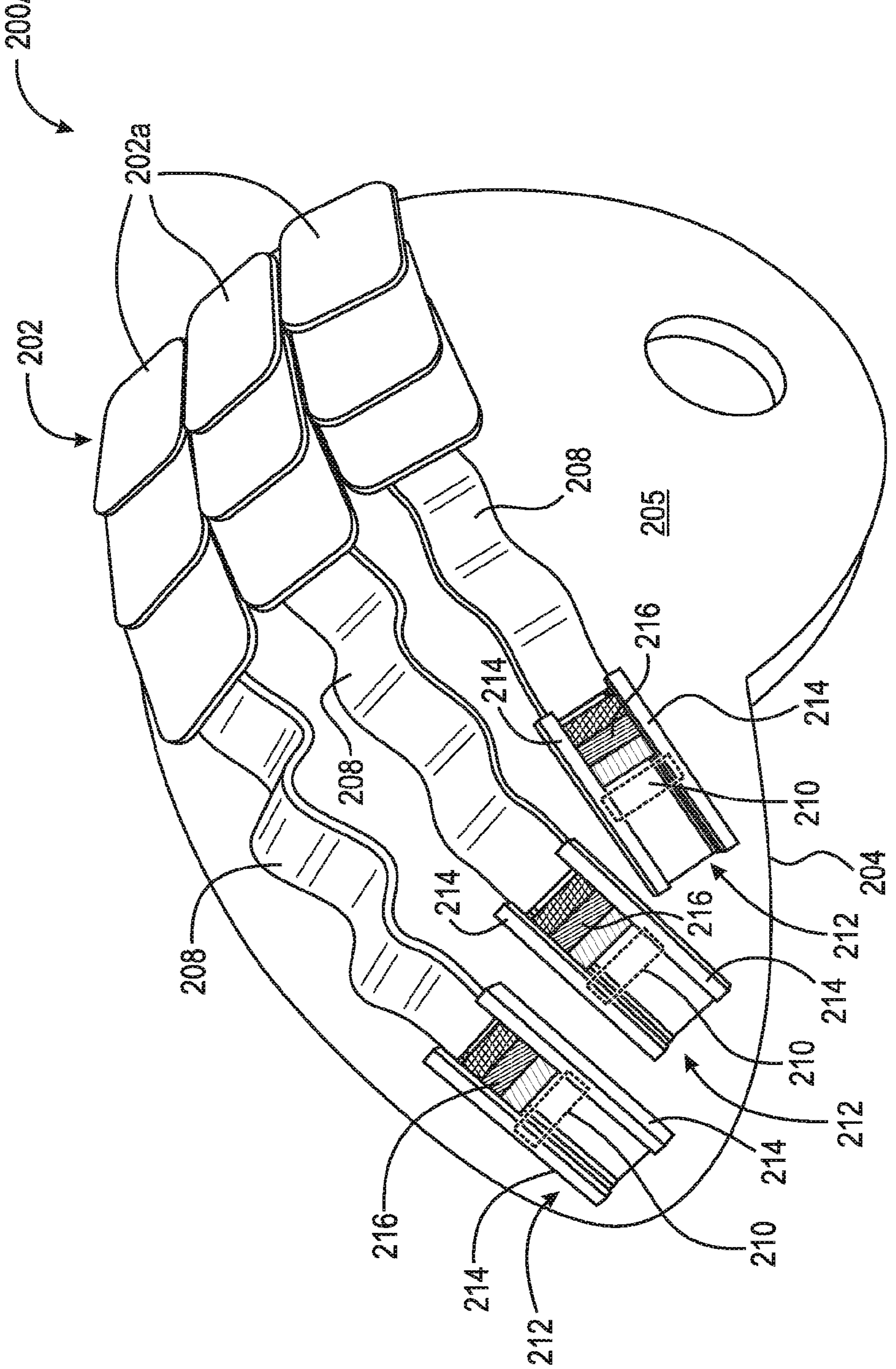


Fig. 20A

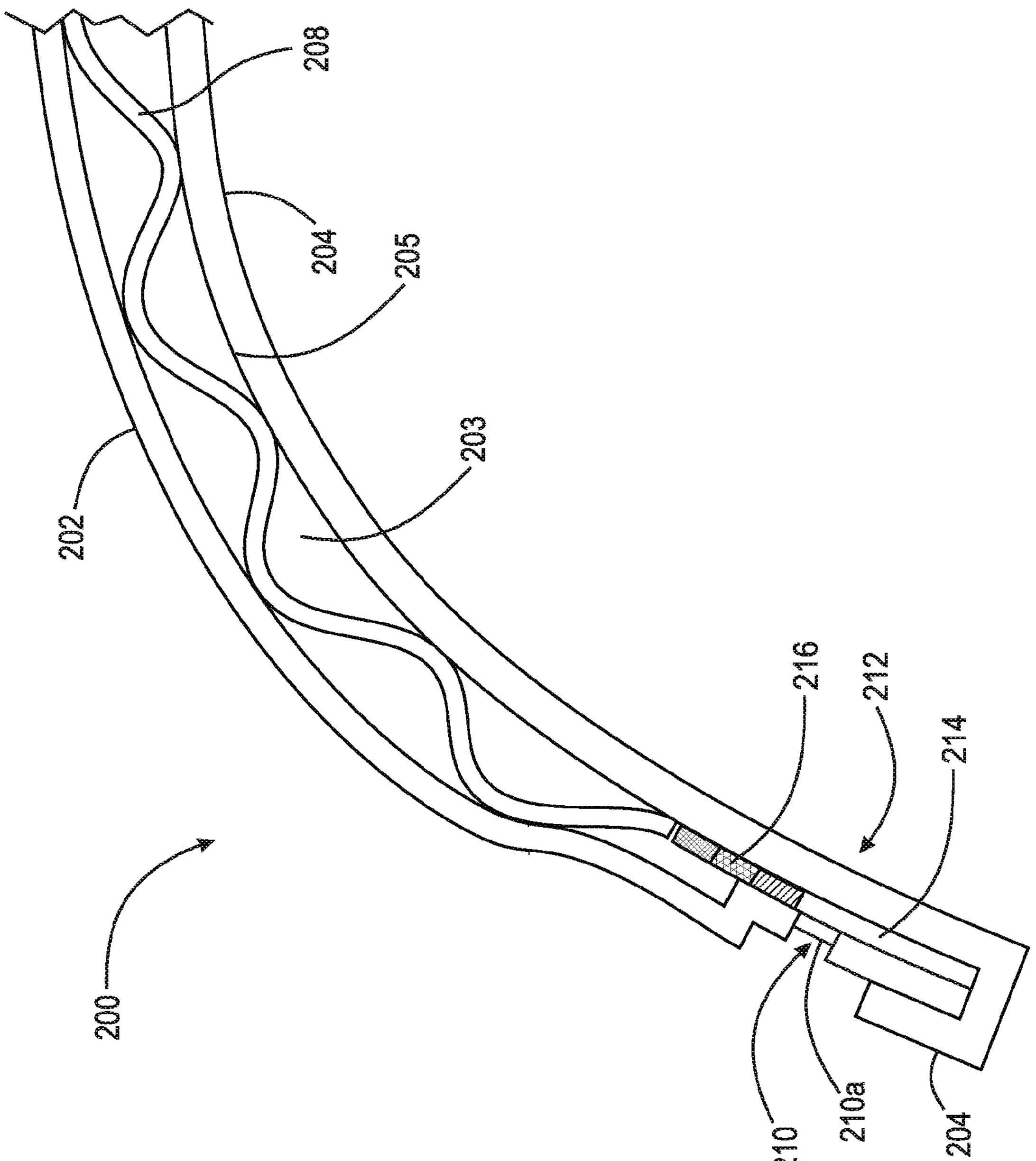


Fig. 21

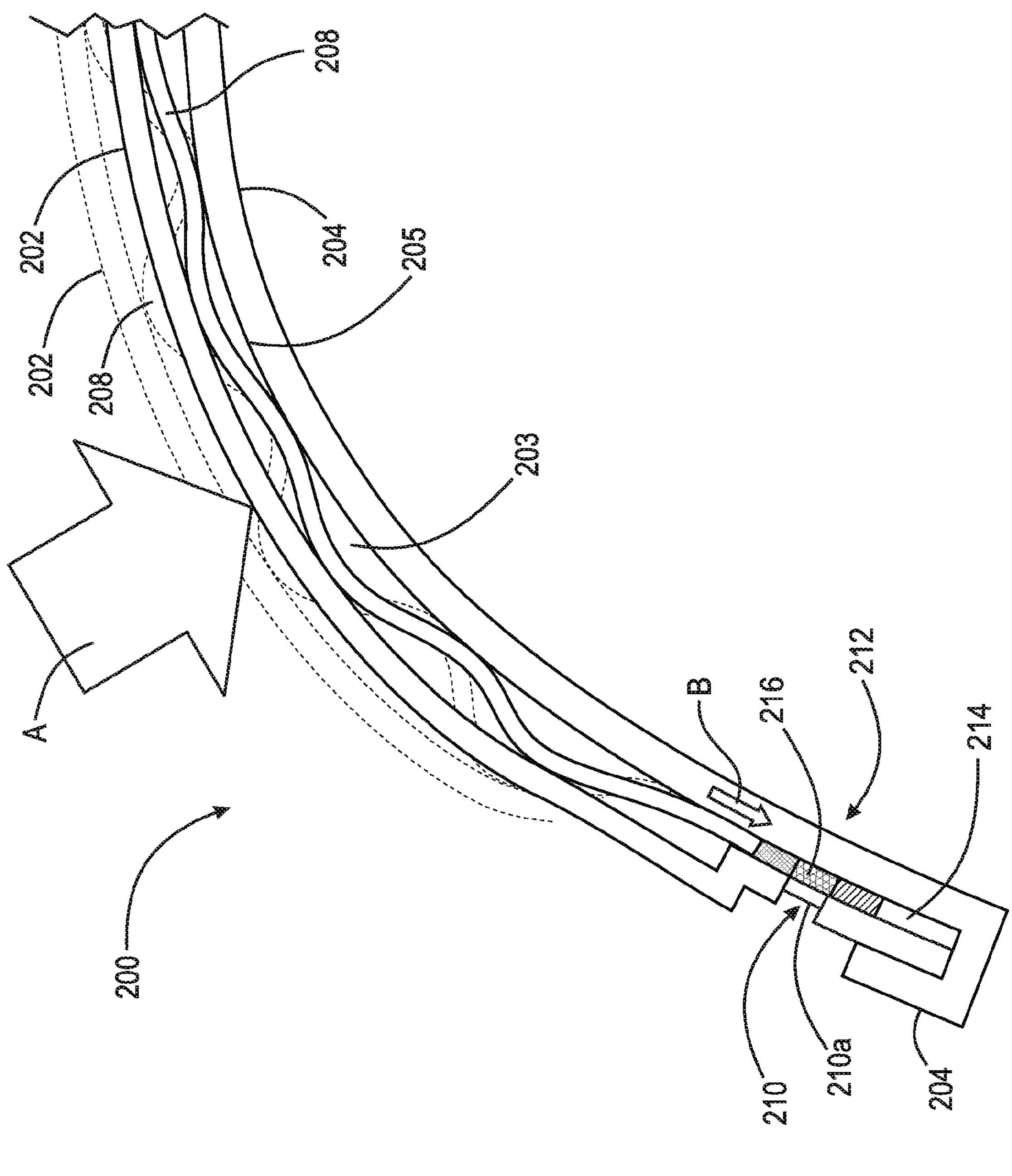
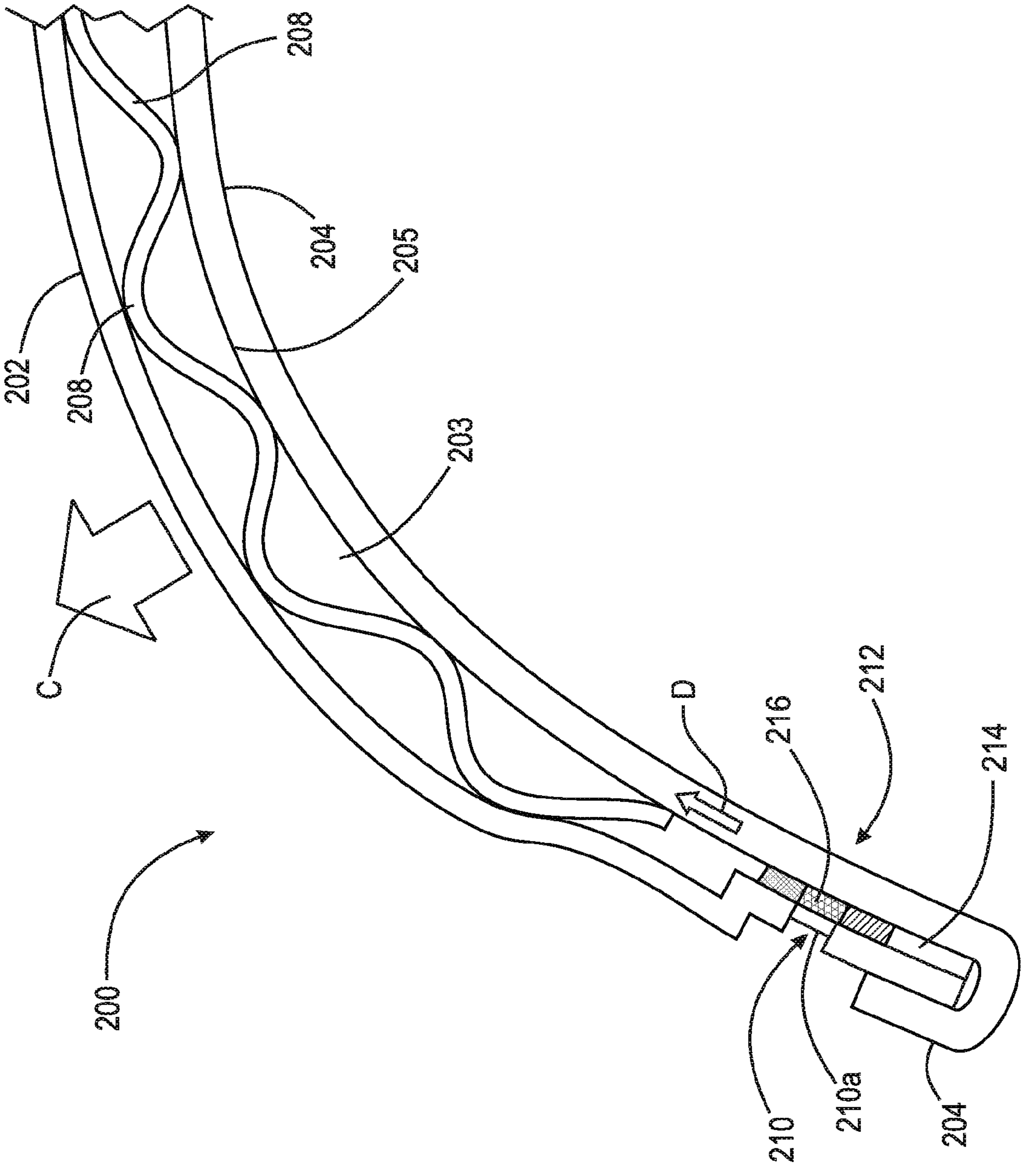


Fig. 22



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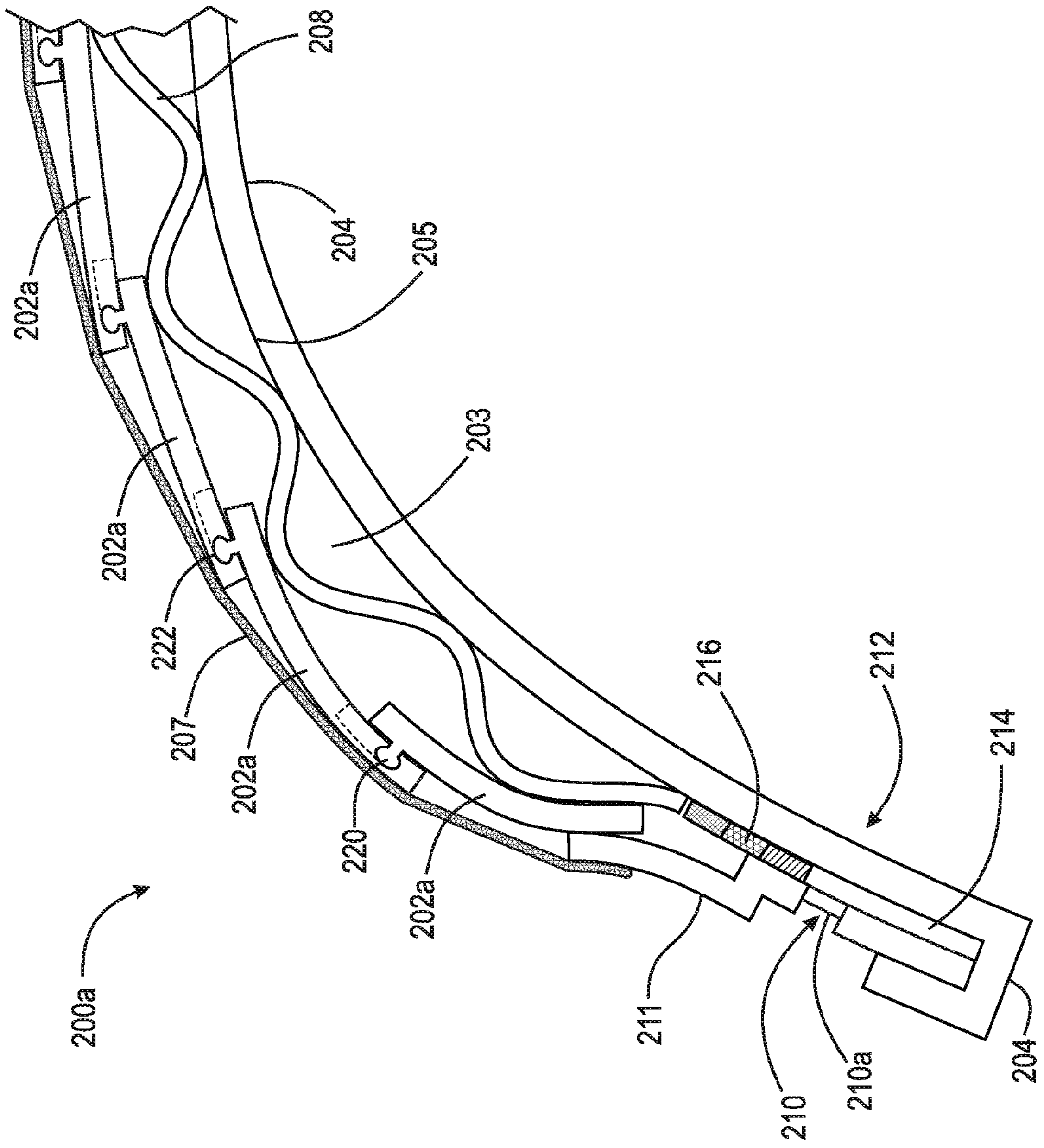
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Fig. 24

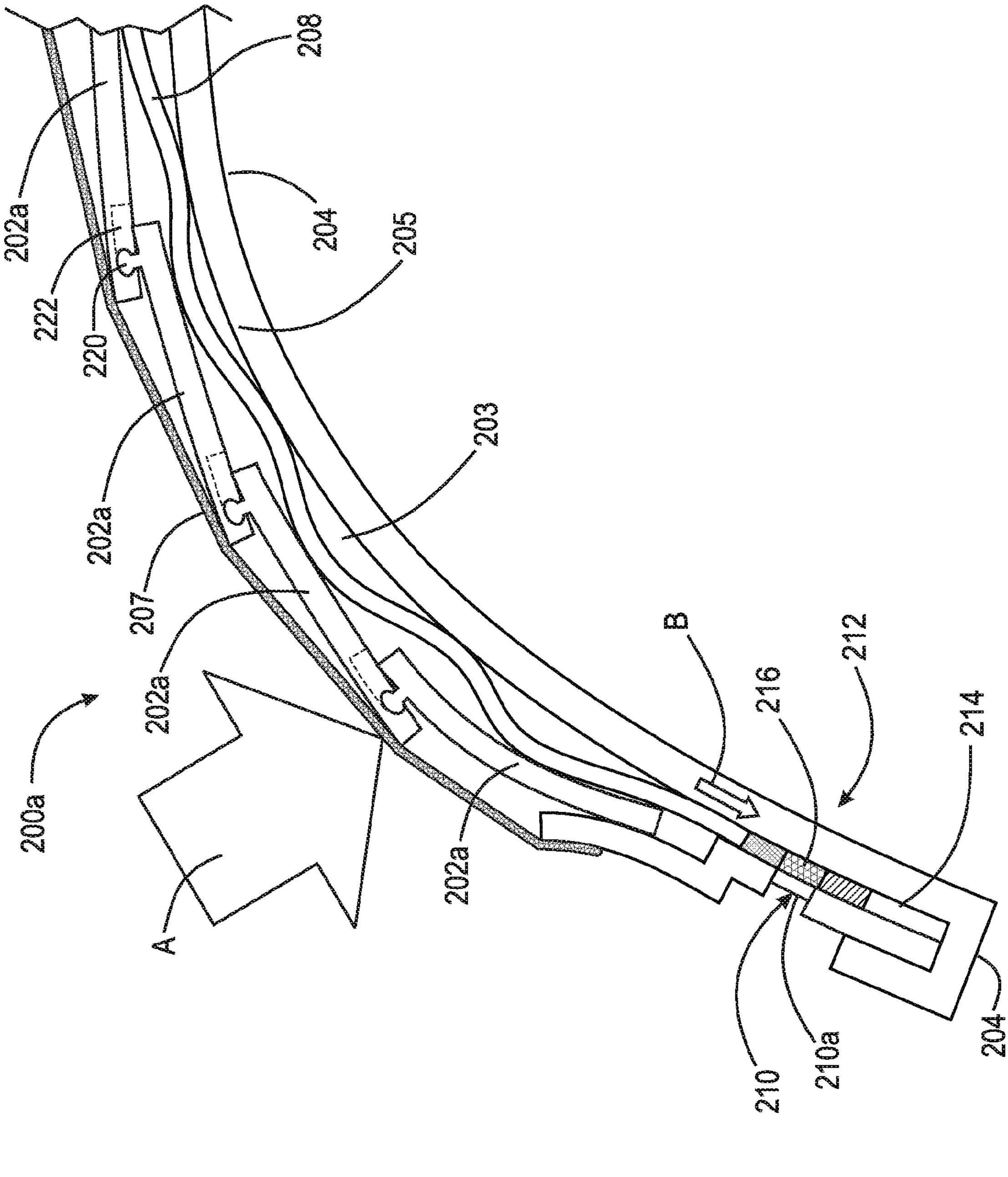
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Fig. 25

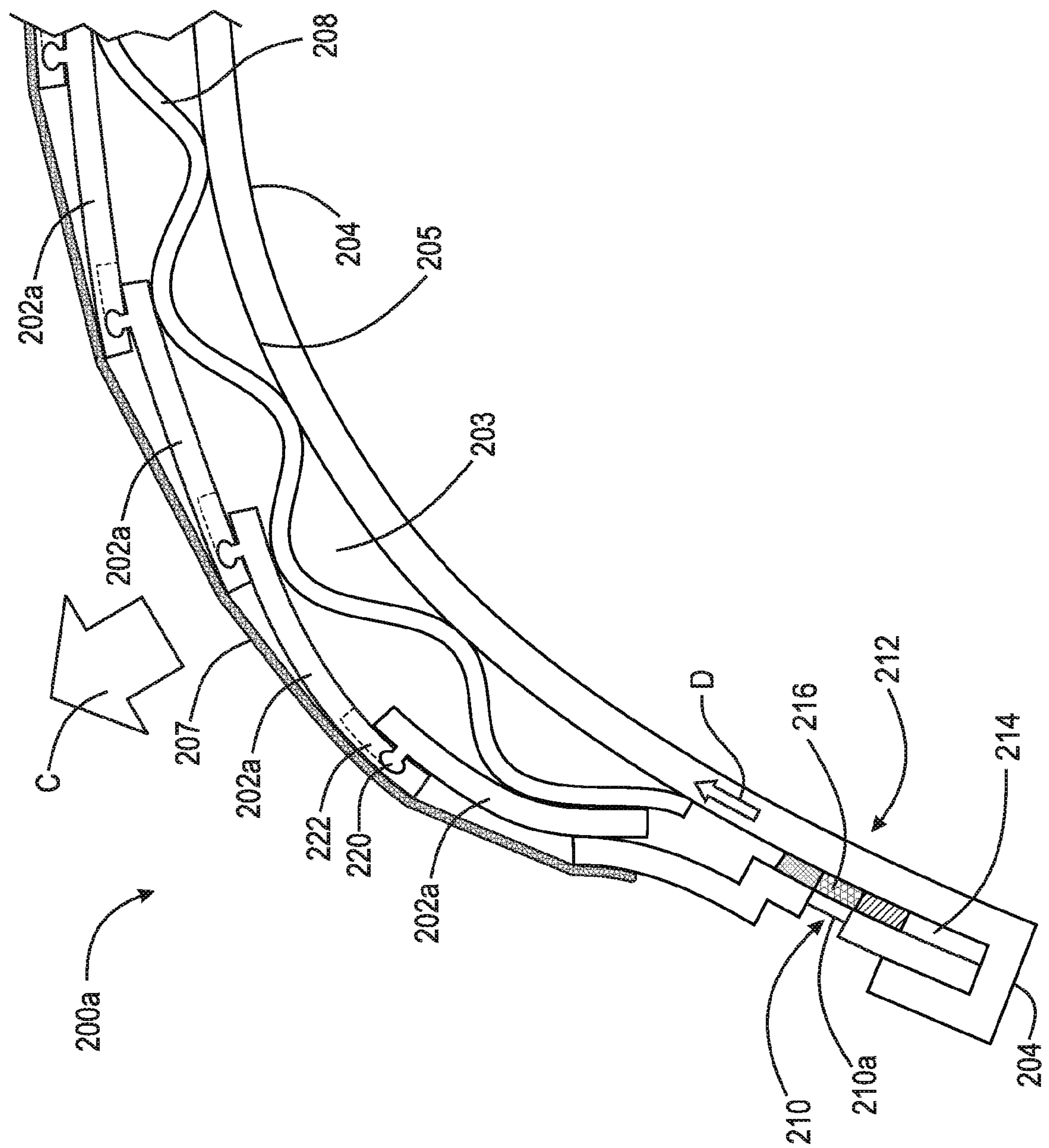
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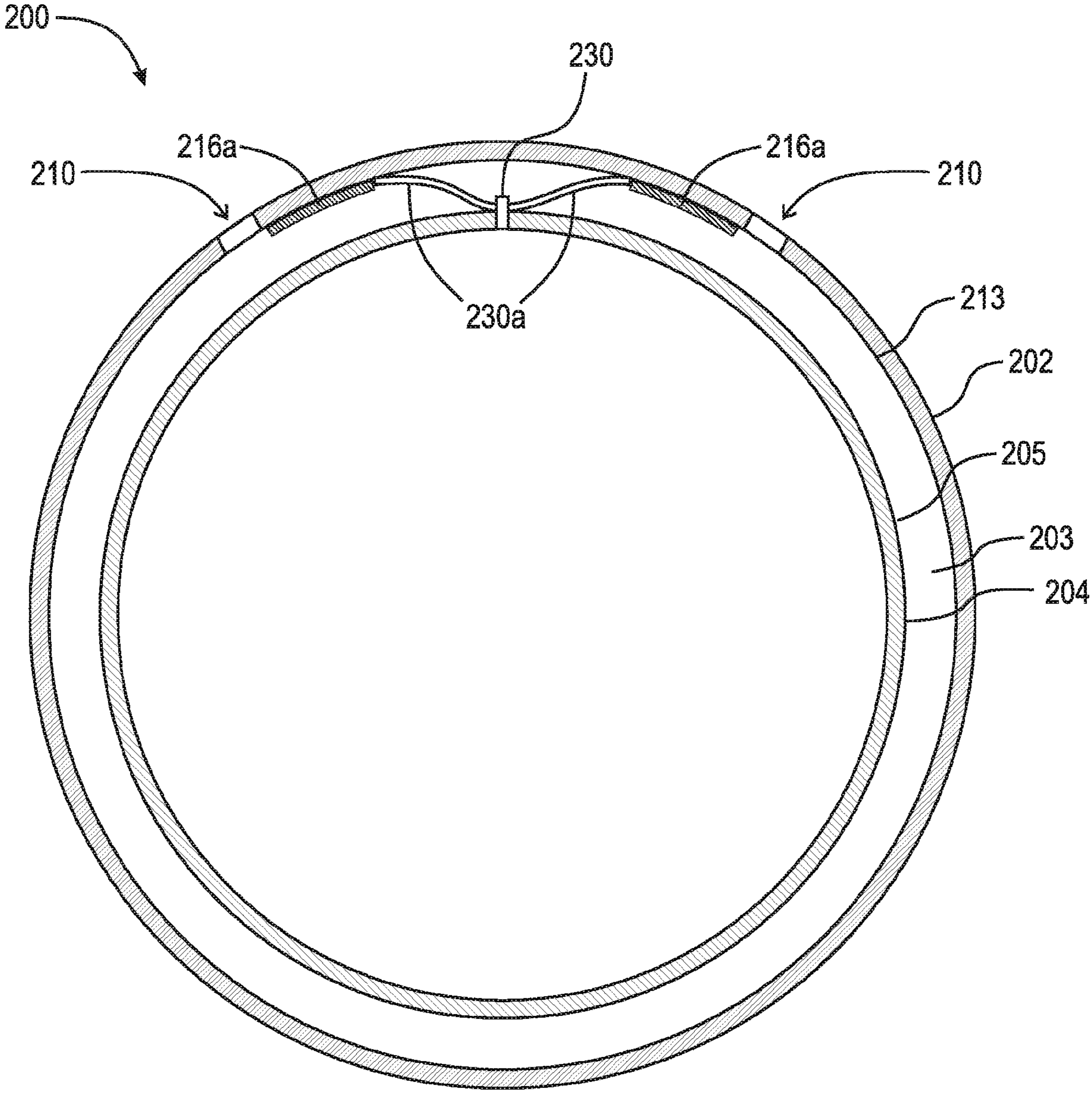
Fig. 26



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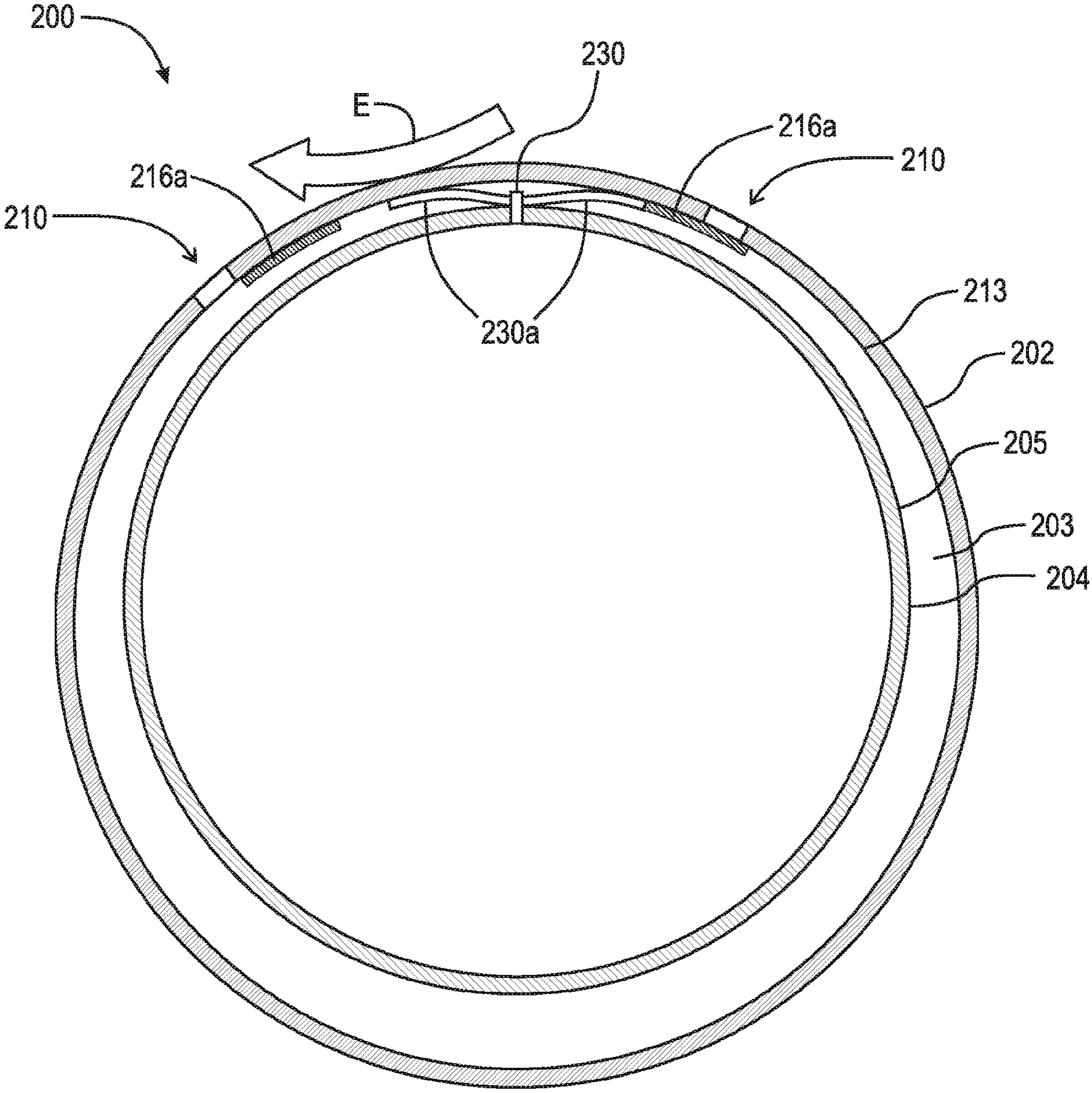

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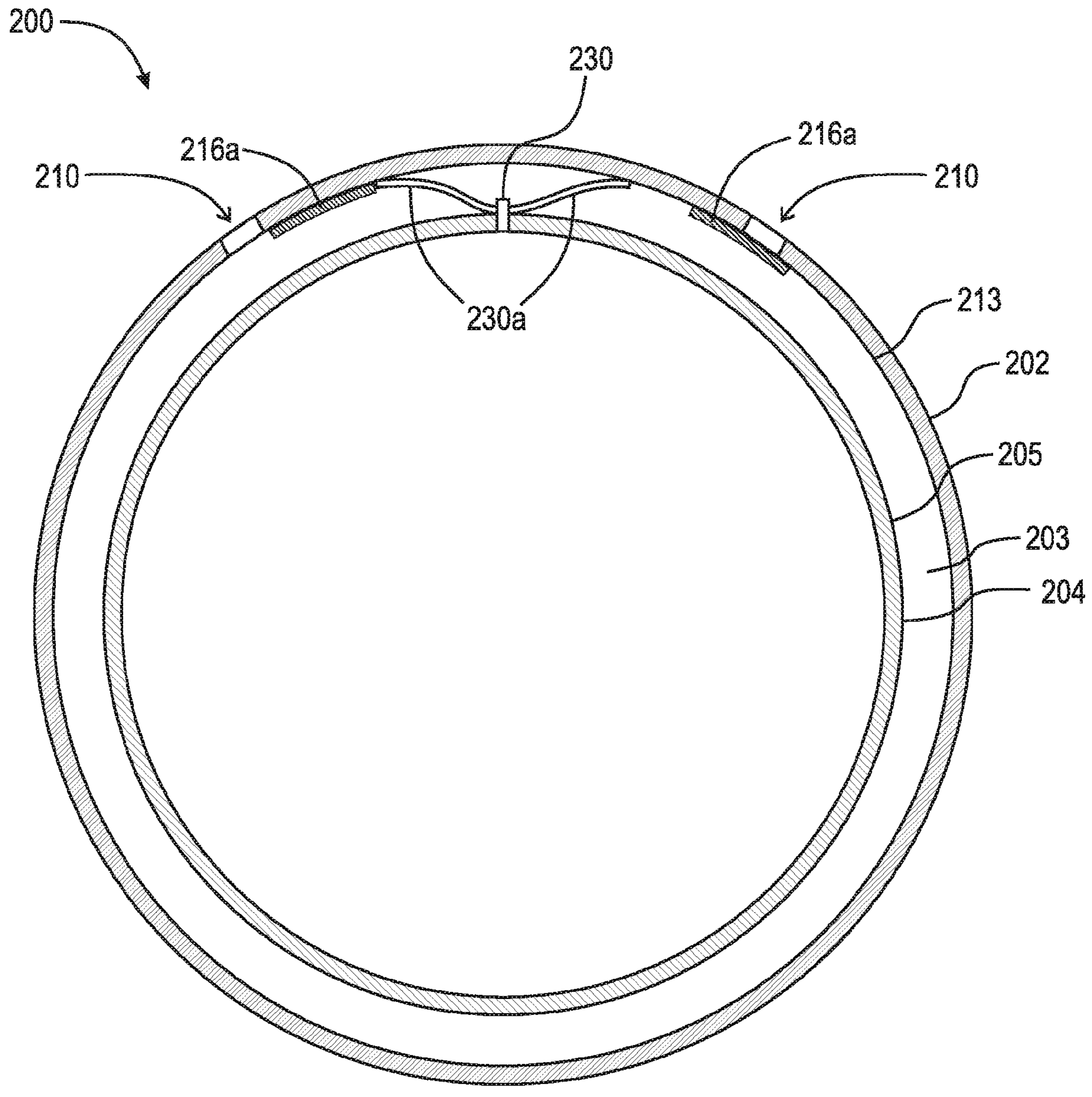

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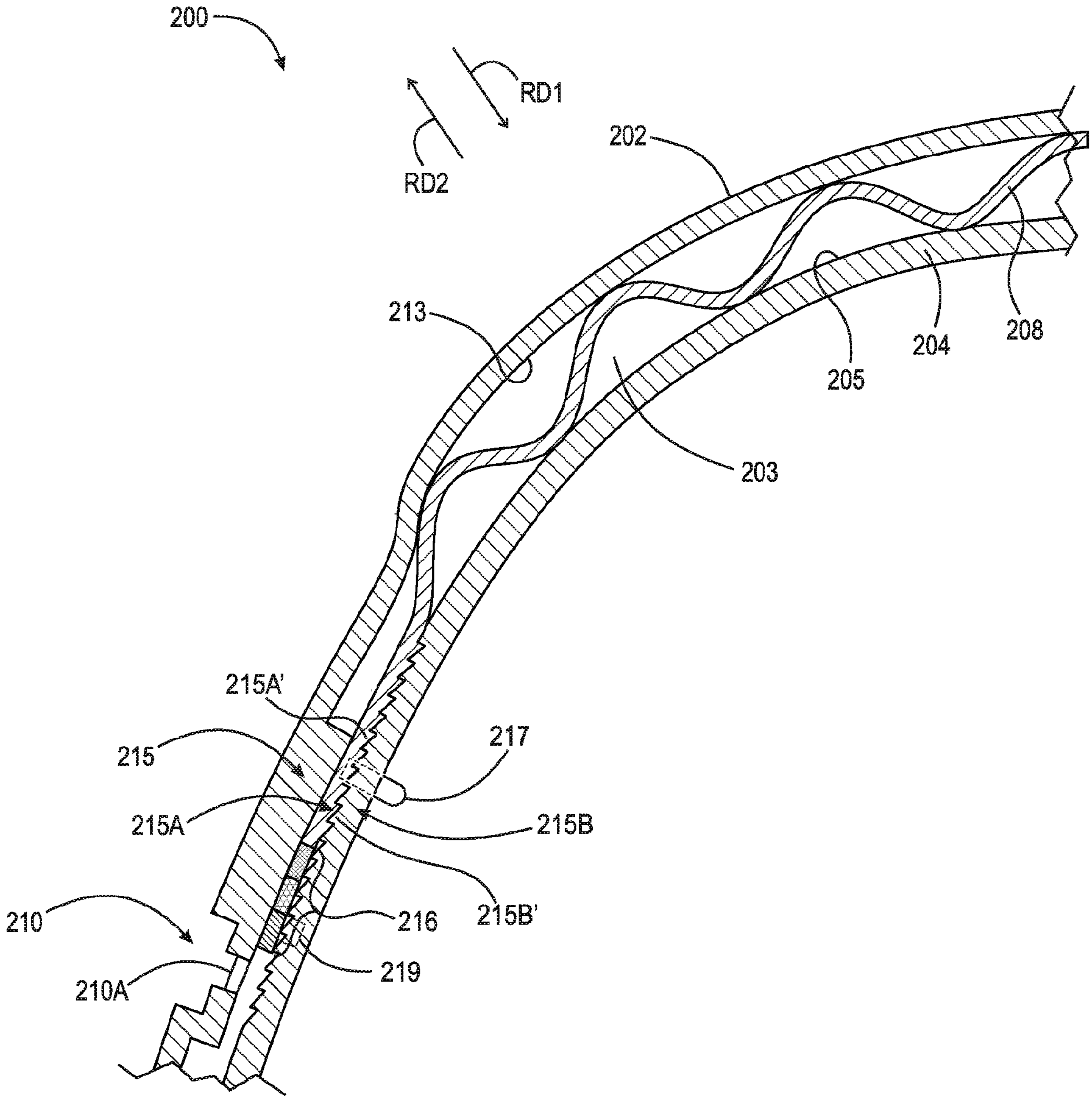
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210A

Fig. 30

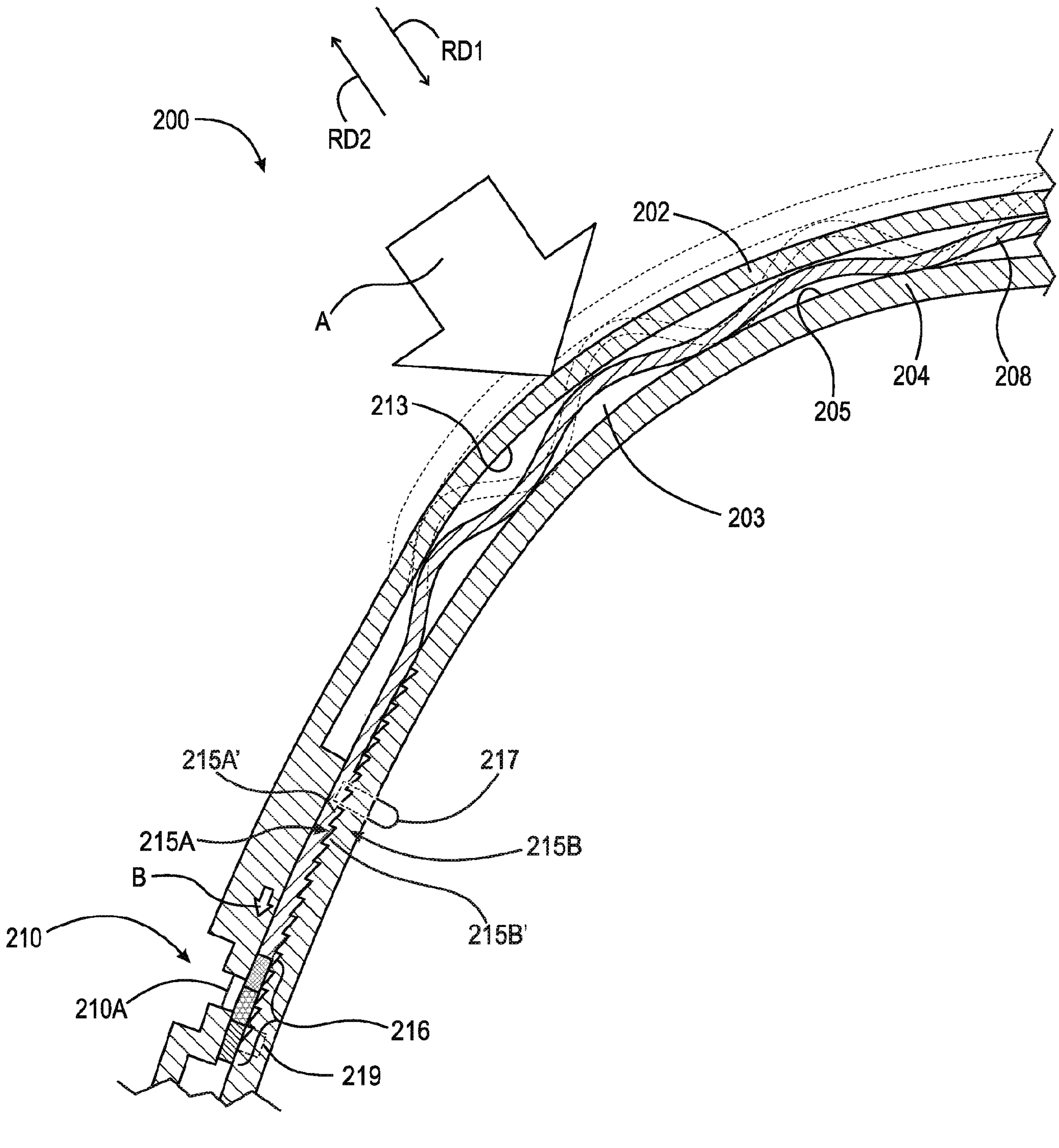
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Fig. 31

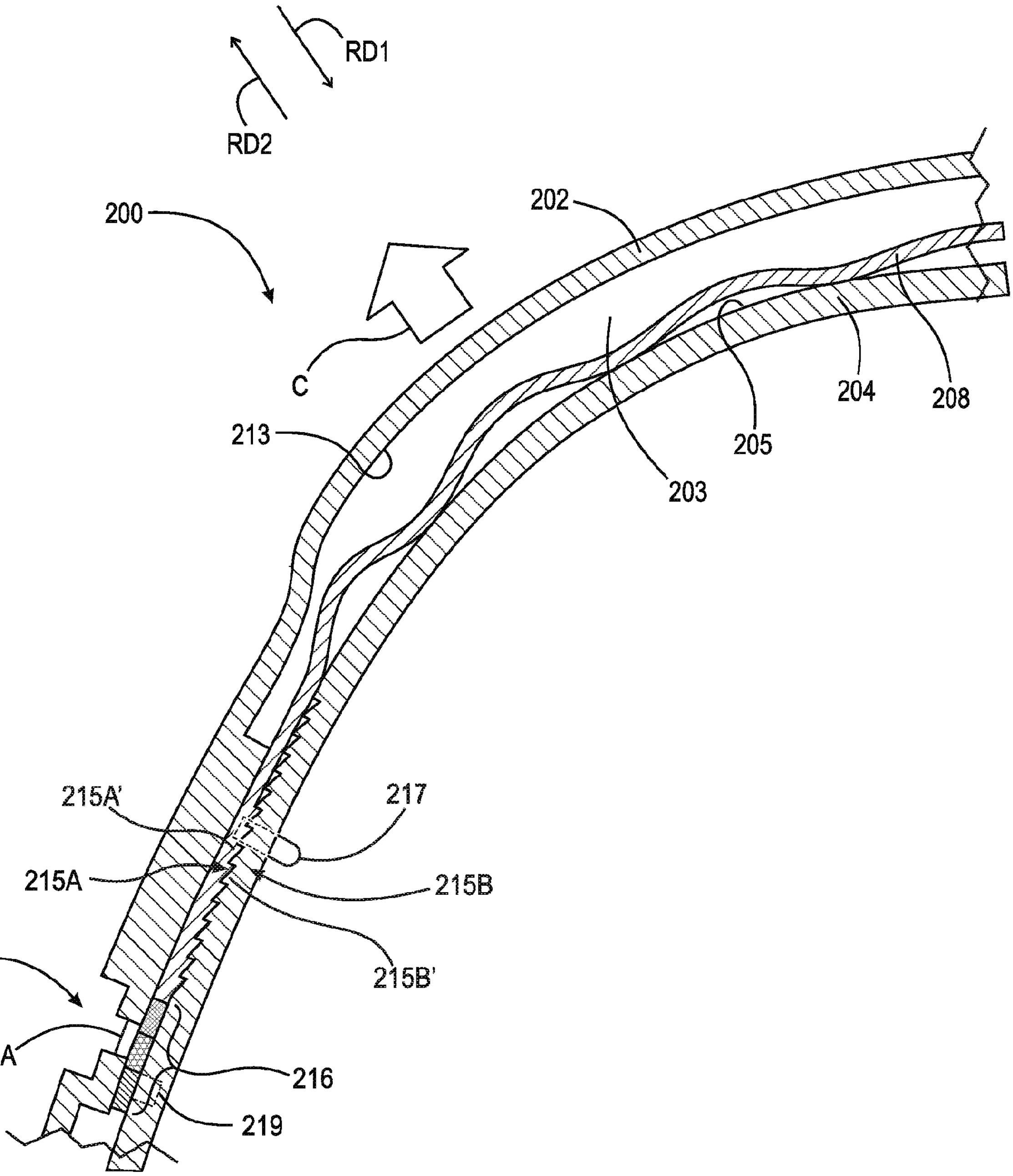
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Fig. 32

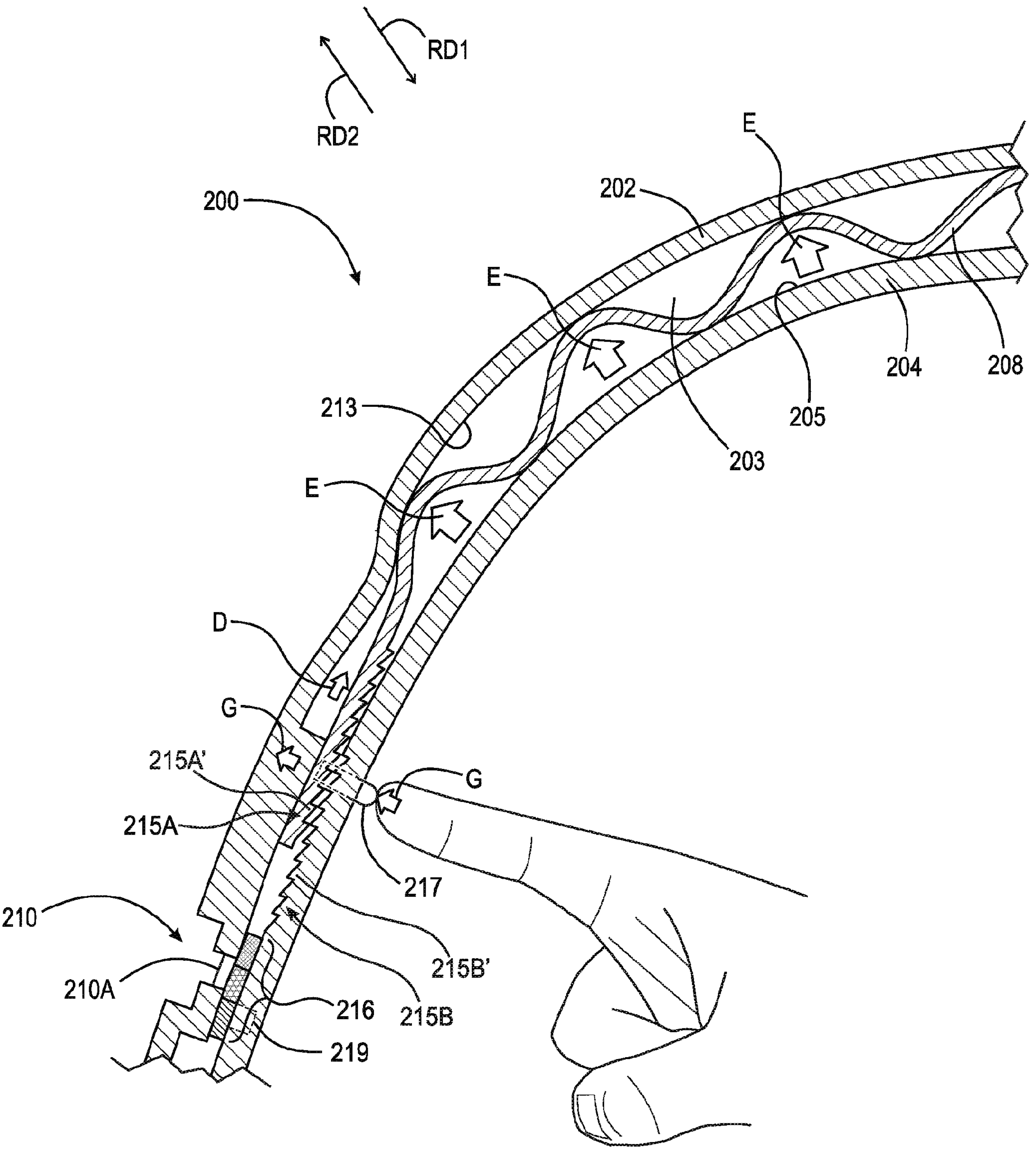
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Fig. 33

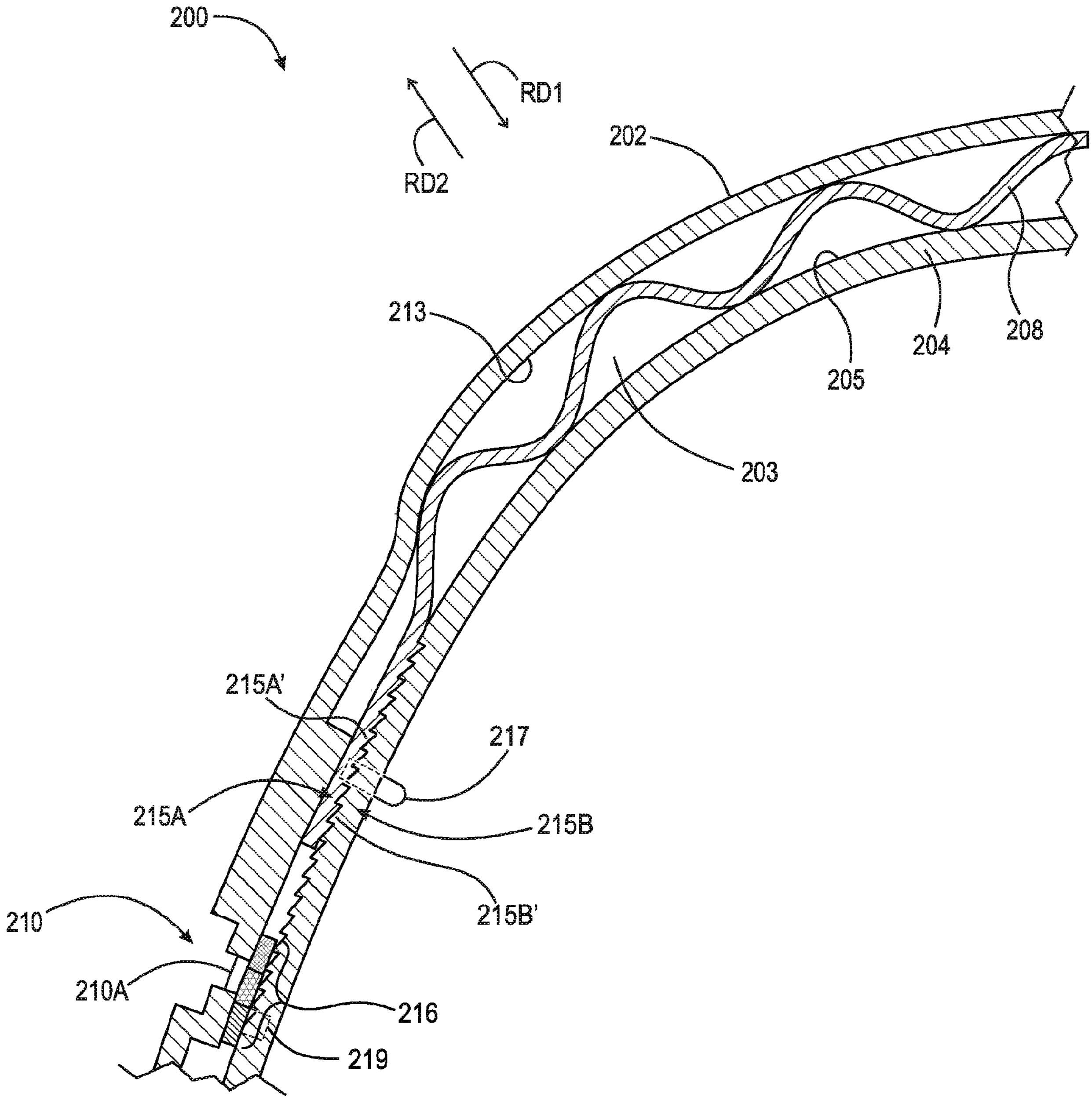
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Fig. 34

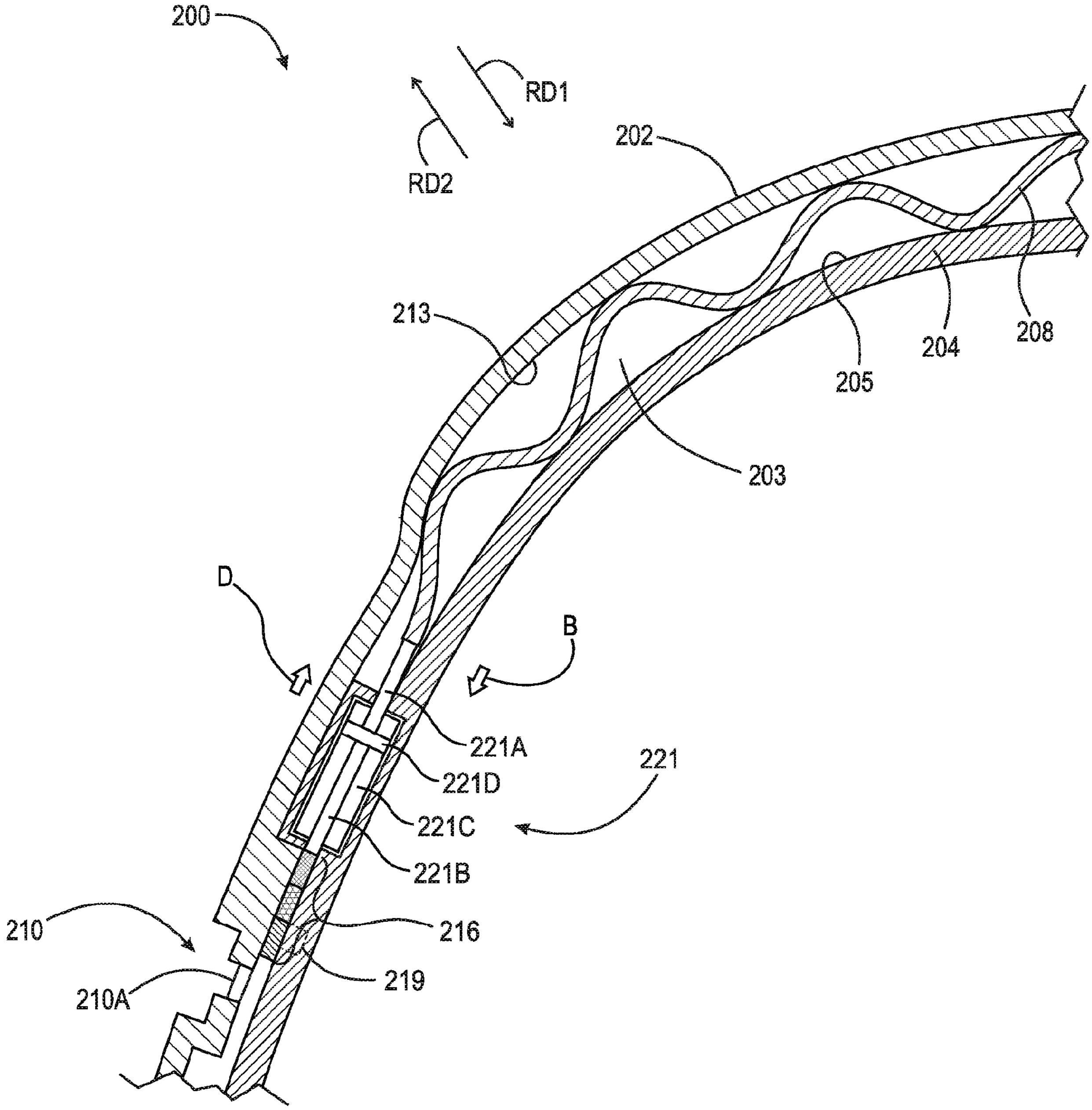
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Fig. 35

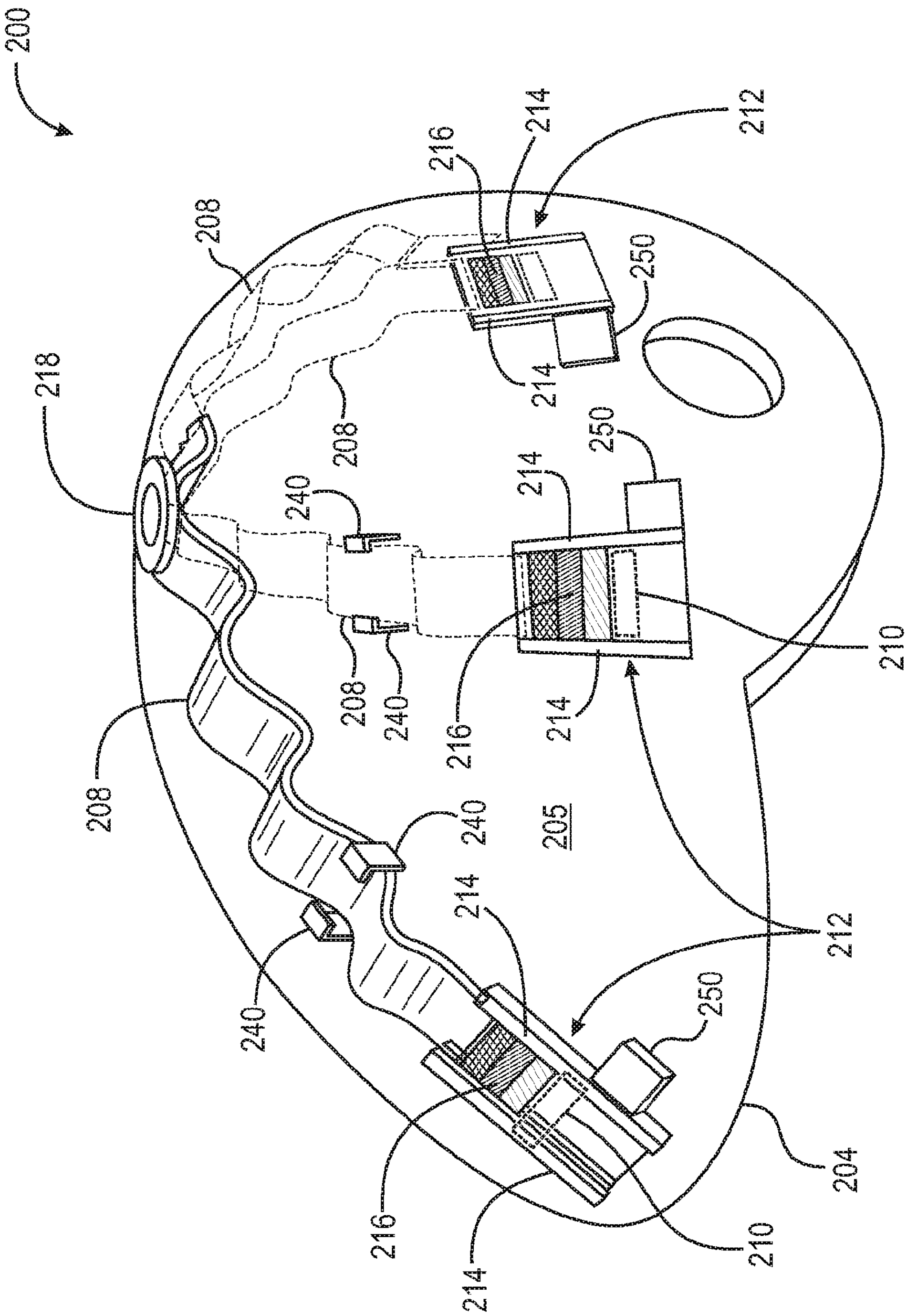

Fig. 36

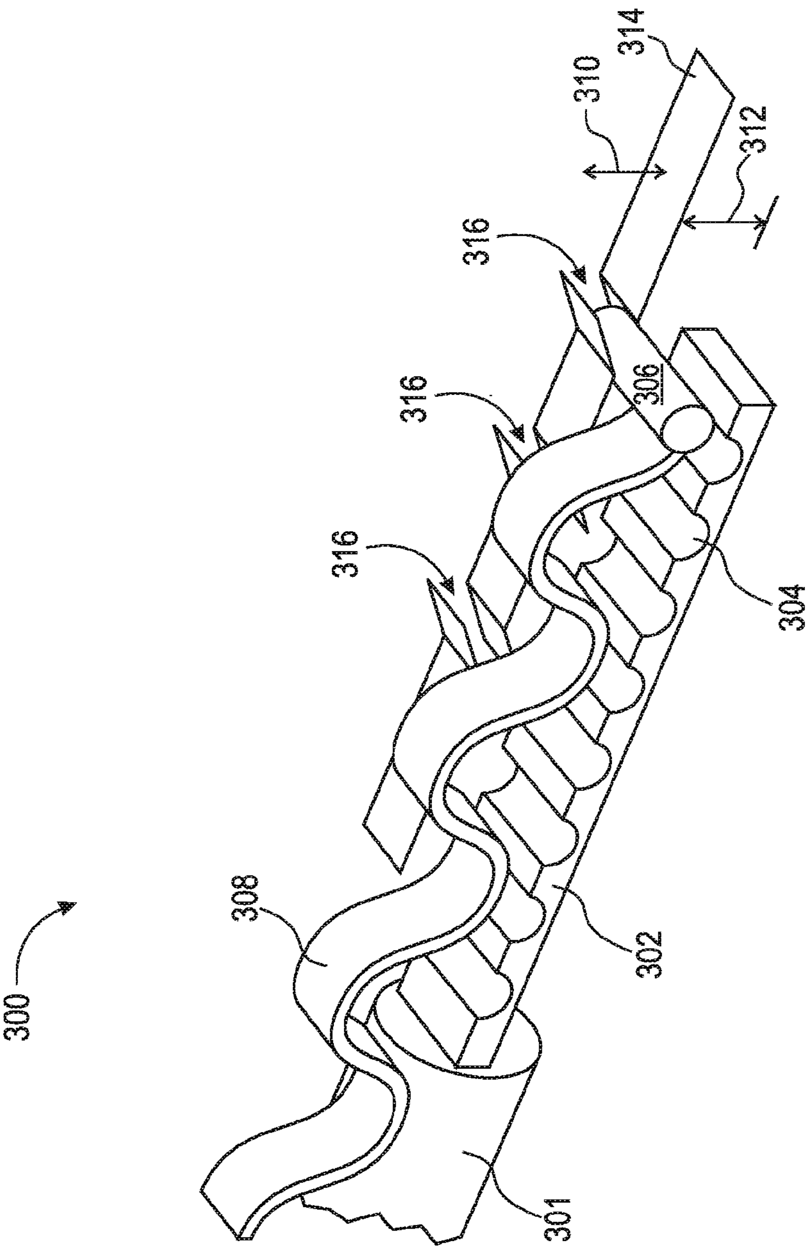

Fig. 37

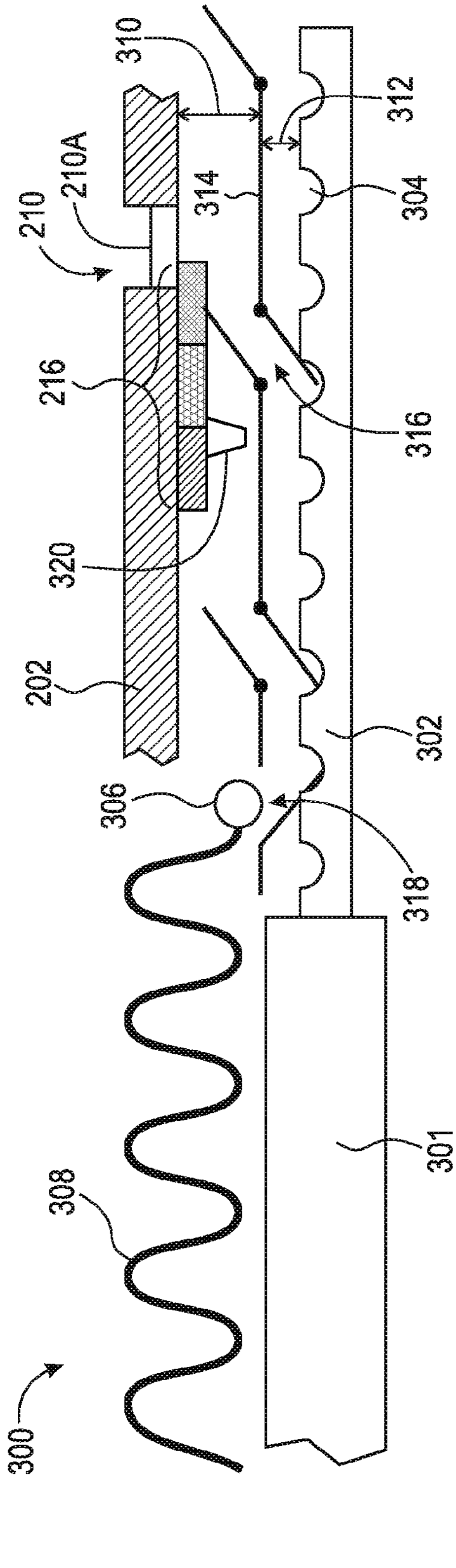
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Fig. 38

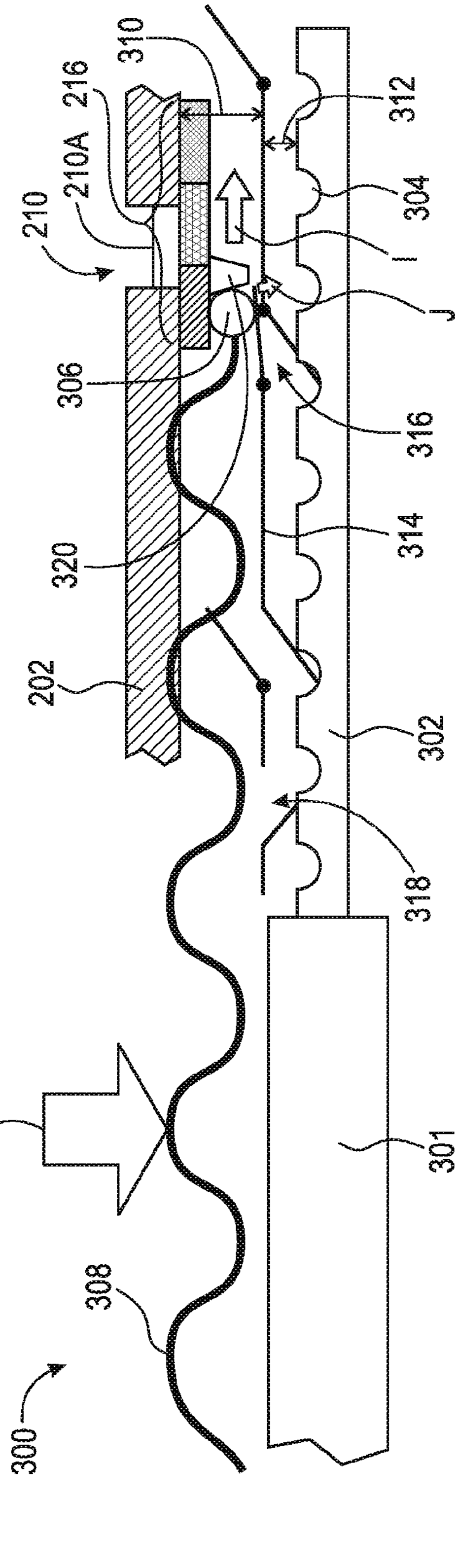
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Fig. 39

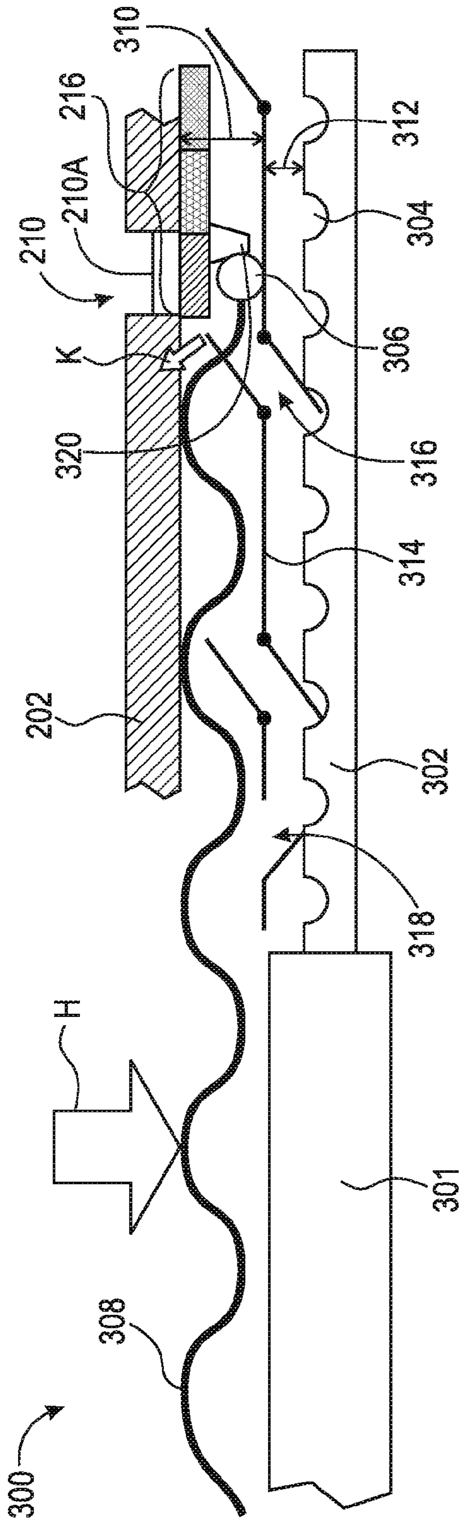
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Fig. 40

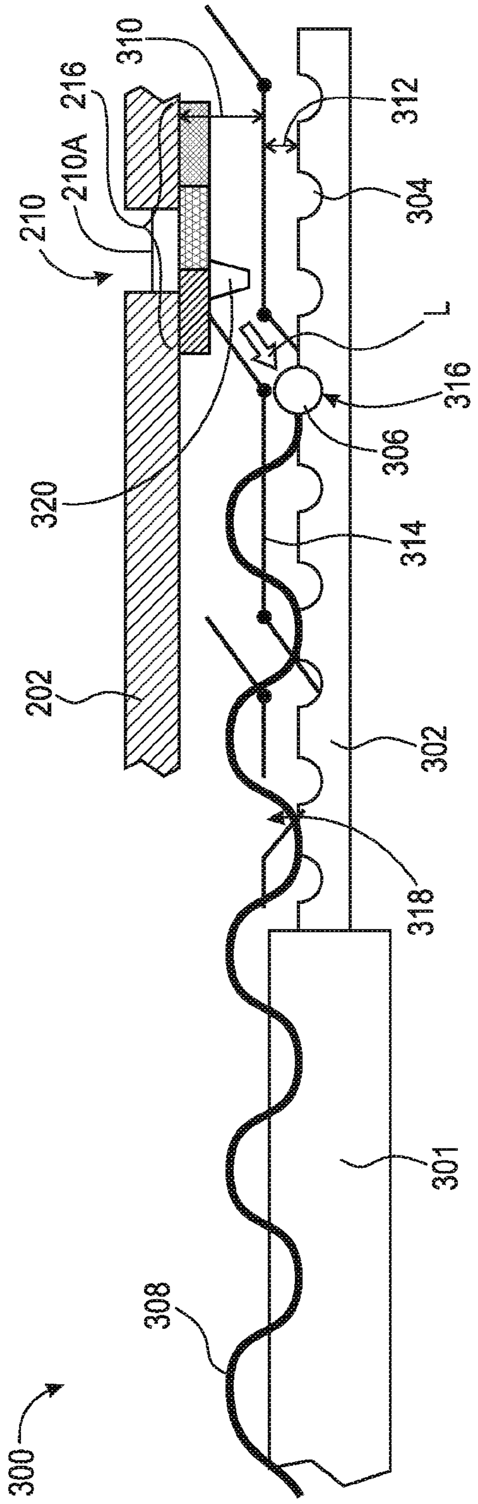
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Fig. 41

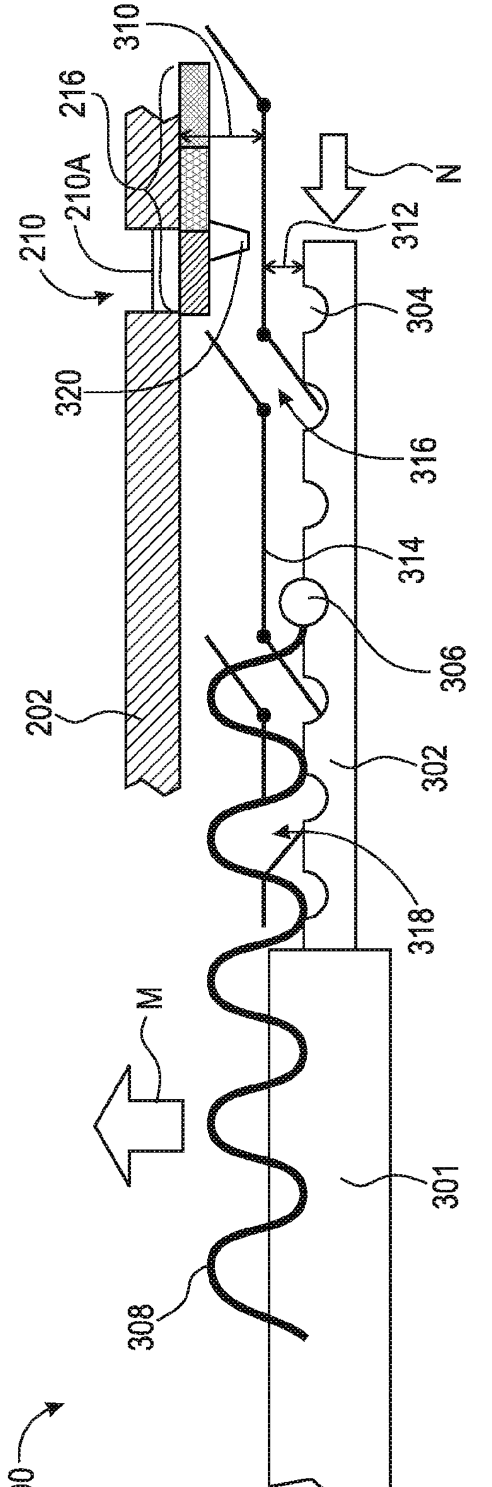
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Fig. 42

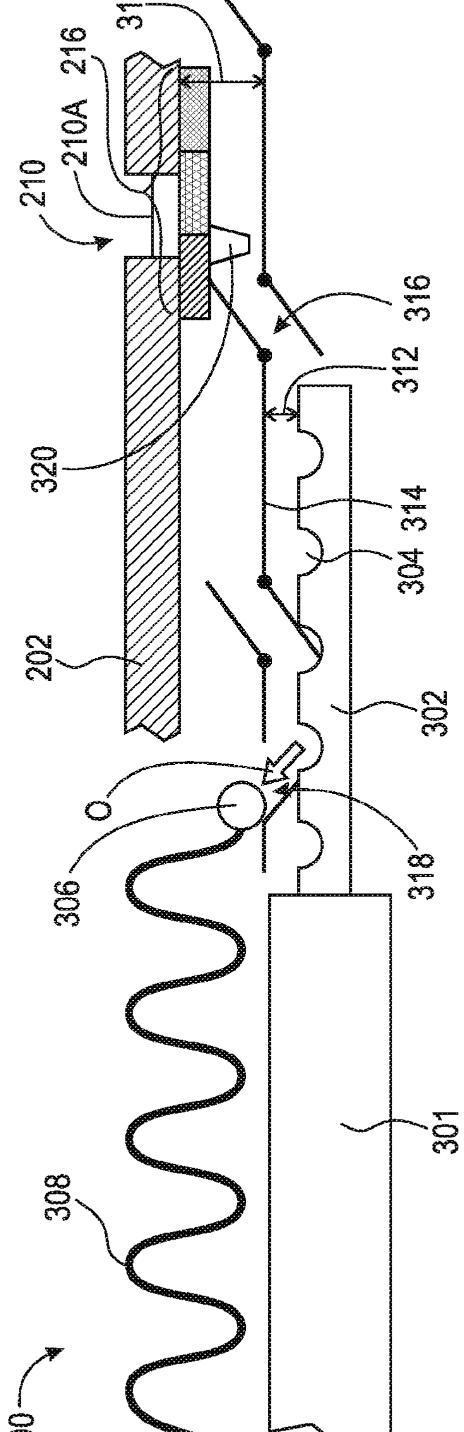
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Fig. 43

REFERENCES CITED IN THE DESCRIPTION

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