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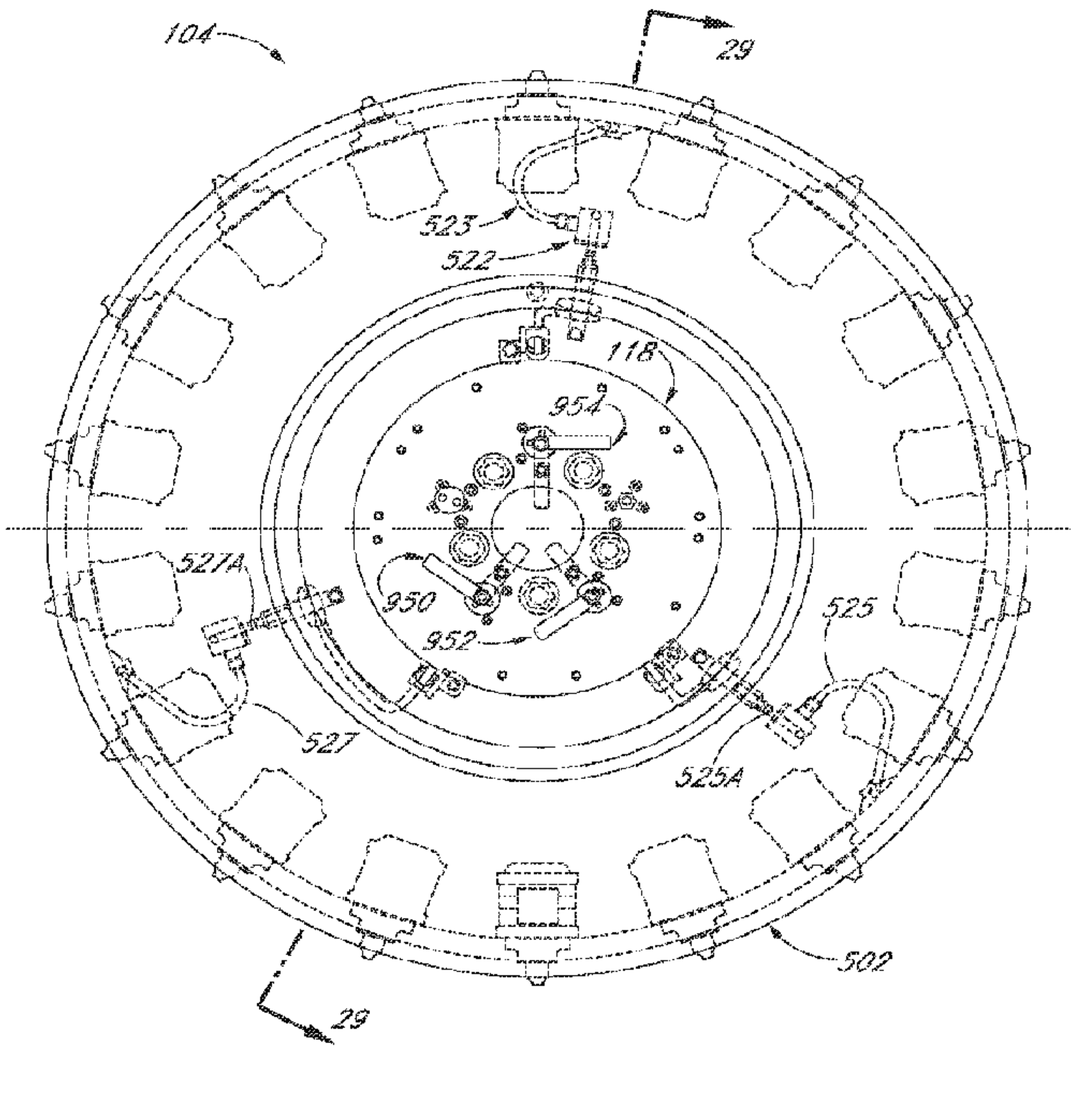
(54) Title: ICE ADAPTIVE TIRE SYSTEM



(57) Abrégé/Abstract:
An adaptive tire system can include retractable and extendable bolts for enhancing traction, for example, on ice-covered roadways. The system can include pneumatically operated bolt assemblies mounted inside a tire. The bolt assemblies can include locking devices configured to be biased towards a locked position so as to lock deployable bolts into extended and/or retracted positions without the need for persistently or continuously applied actuation force or energy. The system can include wheel-mounted, manually operated controls or remote and/or automated controls. The system can include rotary unions for transmitting actuation controls from a vehicle body into an associated wheel. The bolts can also be adjustable and can include removable and replaceable tips.

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[Continued on next page]

(54) **Title**: ICE ADAPTIVE TIRE SYSTEM

(57) **Abstract**: An adaptive tire system can include retractable and extendable bolts for enhancing traction, for example, on ice-covered roadways. The system can include pneumatically operated bolt assemblies mounted inside a tire. The bolt assemblies can include locking devices configured to be biased towards a locked position so as to lock deployable bolts into extended and/or retracted positions without the need for persistently or continuously applied actuation force or energy. The system can include wheel-mounted, manually operated controls or remote and/or automated controls. The system can include rotary unions for transmitting actuation controls from a vehicle body into an associated wheel. The bolts can also be adjustable and can include removable and replaceable tips.

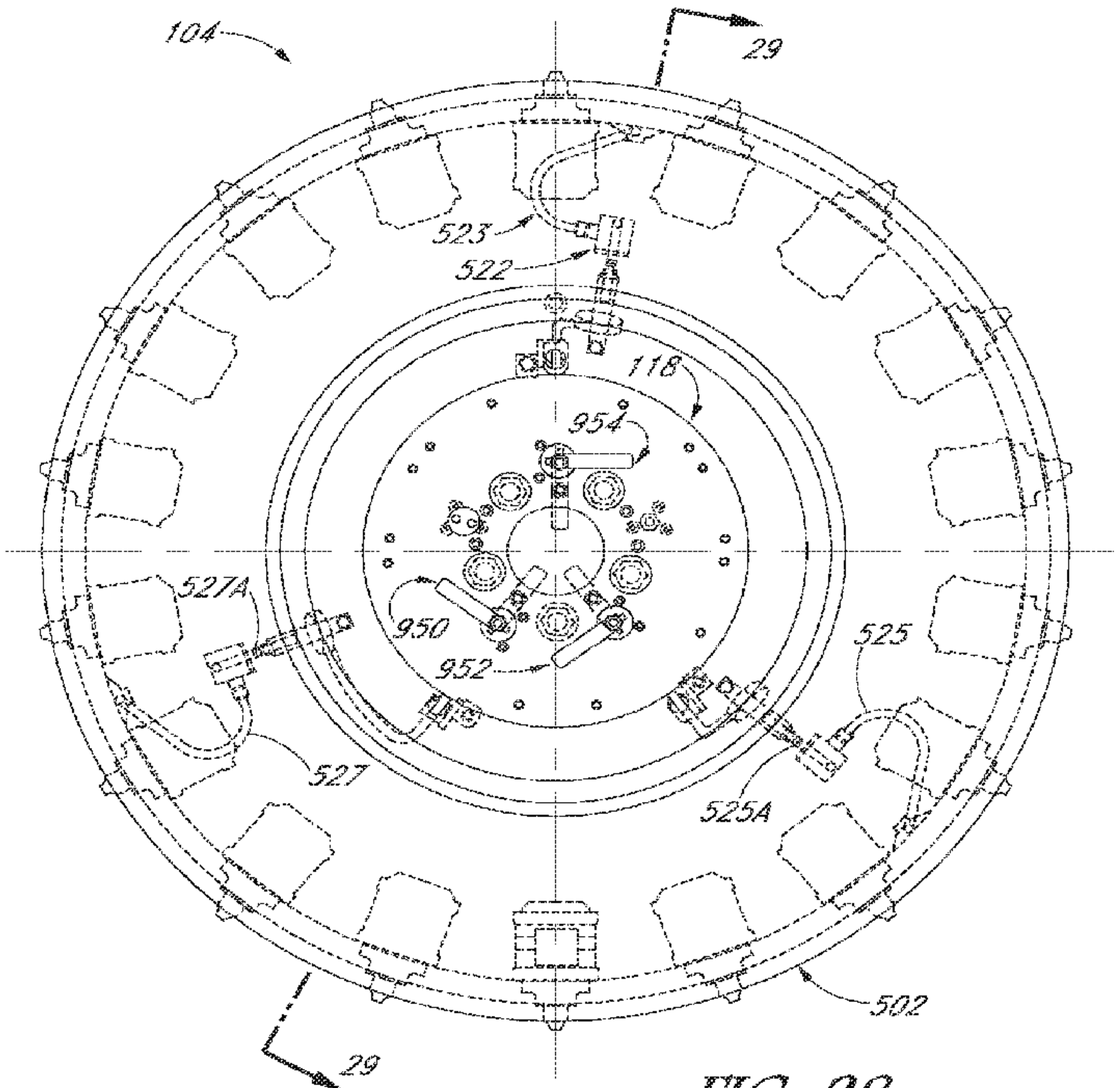

FIG. 28

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ICE ADAPTIVE TIRE SYSTEM

[0001] (This paragraph intentionally left blank.)

FIELD OF THE INVENTIONS

[0002] The inventions disclosed herein relate to adaptive tire systems such as, for example, tire systems designed to adapt to changing road conditions such as road conditions changing from dry road to ice covered roads.

BACKGROUND OF THE INVENTIONS

[0003] Vehicle tires support wheel axle loads on a tread area in contact with a road surface. The sum of contact area of all tires of a vehicle multiplied by inflation pressure of each tire will be equal to the vehicle axle load.

[0004] Coefficients of friction between tread and road surface multiplied by the axle load is the maximum force, parallel to the road surface, that can be applied to the tire contact area by the wheels to stop, accelerate, corner or maintain speed on a grade without tire slippage at the contact between the road and tire. As an example, if a tire tread coefficient of friction is 0.30, and an axle load is 1,000 pounds, the maximum friction force between the tire and road surface before tire slippage will be 300 pounds. If a braking load or an acceleration load, greater than 300 pounds at the tread/road interface is developed, wheel rotation will decrease or increase respectively and when the slippage occurs to some degree, a loss of control may occur.

[0005] Almost all automobiles have brakes and engine capacities sufficient to generate loads that exceed tire friction traction on dry concrete, asphalt, gravel, or dirt. This capacity introduces a responsibility for vehicle operators to use restraint from applying full throttle when accelerating and using maximum braking and steering to maintain safe operation and reasonable service life of tires and vehicle components.

[0006] The coefficient of friction between tires and wet pavement is moderately reduced from dry conditions and requires drivers to use longer stopping distances and lower maximum acceleration values. Driving on wet level, sloped, or curved roads with conventional tires has been found to be manageable by drivers notwithstanding that wet brakes and potential for hydroplaning introduce a need for caution.

[0007] The coefficient of friction between tire tread and ice is so low, however, control of a vehicle on ice covered roads under most conditions at moderate speed is precluded unless surface friction has been increased by sand or chemicals, or unless the tires have been fitted with chains, or studs to develop reactive forces.

[0008] Loss of control on ice is typically evidenced by spinning wheels when initiating motion, locking of wheels when braking, and lack of steering response (e.g. "understeering") due to insufficient friction between the tires and road surface for vehicle traction.

[0009] Tire chains and tire studs function by impressing a fixed-shape chain or stud component into ice by tire tread to develop tractive force which is limited by shear values of ice and geometry of components.

[0010] Some known designs for tires with retractable studs rely on perpetual maintenance of air pressure in order to maintain the associated stud in a deployed position. Additionally, some systems use, and thus can deplete, air within a tire in order to cause movement of a stud, for example, between a retracted and a deployed position.

SUMMARY OF THE INVENTION

[0011] An aspect of at least one of the inventions disclosed herein includes the realization that using a locking mechanism which provides a locking engagement of a retractable ice engagement member can avoid problems associated with prior known systems noted above. For example, in some known designs, as noted above, a deployable tire stud is maintained in a deployed position only with a perpetual maintenance of internal pressure. However, as the associated tire rolls across the ground, the studs are pressed against their actuators and the maintained air pressure as well as the associated seals which can cause leakage. Thus, use of such a tire with studs in a deployed position can deplete the system of air thereby failing to maintain the associated studs in a desired deployed position and or

requiring periodic replenishment of lost air. Further, some systems rely on the air held within a tire for maintaining such deployed positions of studs as well as for retraction of studs. Thus, repeated extension and retraction of studs can cause an associated tire to lose a sufficient amount of air that the tire pressure will fall below a desired level.

[0012] Thus, in accordance with at least some of the embodiments disclosed herein, an adaptive tire can include a retractable bolt for enhancing traction and a lock mechanism for locking the bolt at least in a deployed position without the need for relying on persistently maintained air pressure to keep the bolt in the deployed position. As such, such a tire can avoid the problems associated with the need for persistently maintained air pressure and the associated leakage that can occur. Further, such a system can avoid the depletion of air pressure within a tire that can result from systems which utilize air pressure within the tire for actuation purposes.

[0013] Another aspect of at least one of the inventions disclosed herein includes the realization that an adaptive tire which includes an air actuation system, can avoid the problems of potentially depleting air pressure within a tire with an air actuation system that is independent of the volume of air within a tire. For example, an adaptive tire can include an air actuation system which utilizes compressed air for moving a bolt from a retracted to a deployed position and such an air system can be configured such that the air actuation system is independent of the air utilized for maintaining the tire in an inflated state for supporting axle load. For example, the air actuation system can have air inputs and optionally outputs that are independent from ports used for inflating the tire.

[0014] Another aspect of at least one of the inventions disclosed herein includes the realization that retractable tire bolts can provide better performance where they are adjustable such that their deployed position can be changed. For example, as the tread of a tire wears down and as the tip of the bolt wears down, the effective protruding distance of a bolt changes. More specifically, as tread is worn down, a bolt will protrude farther from the tire tread. On the other hand, as the tip of a bolt wears down, the bolt will protrude less.

[0015] Thus, in accordance with some of the embodiments disclosed herein, an adaptive tire can include retractable and deployable bolts that have an adjustable length. As such, the length of the bolts and thus the magnitude of the protrusion of the bolt can be

adjusted for tread wear, the weight of the vehicle, road conditions including ice type, and other factors.

[0016] Another aspect of at least one of the inventions disclosed herein includes the realization that maintenance, servicing, and repair of adaptive tires which include retractable and deployable bolts can be simplified and reduced in cost by providing such an adaptive tire with replaceable tips for the bolts. For example, when such a tire is used, eventually, the tips of the bolts, regardless of the material, wears down. However, only a small portion of the tip of the bolt is worn down because such systems typically only deploy studs or bolts with a small fraction of an inch of protrusion beyond the surrounding tire tread. Thus, by providing an adaptive tire having bolts or studs with a replaceable tip, the functionality of an adaptive tire can be maintained more easily and at less cost.

[0017] Another aspect of at least one of the inventions disclosed herein includes the realization that an arrangement of valves can be used to control deployment, retraction, and locking of a retractable bolt of an adaptive tire. Further benefits can be achieved by configuring the valves to operate deployment, retraction, and locking with air from a single source.

[0018] Thus, in accordance with at least one of the embodiments disclosed herein, an adaptive tire system includes a plurality of valves mounted on a wheel associated with the tire, wherein the valves of a plurality of tires of an associated vehicle are configured to utilize a single source of compressed air for unlocking, retraction, or deployment of studs which protrude outwardly from an outer surface of the tread of an associated tire.

[0019] Another aspect of at least one of the inventions disclosed herein includes the realization that additional components can be used to automatically control actuation of deployable and retractable tire bolts from a location remote from the wheel, such as from inside the associated vehicle.

[0020] Thus, in accordance with at least one of the embodiments disclosed herein, an adaptive tire system includes a rotary air distribution device configured to guide at least two channels of actuation air from a vehicle body into a spinning wheel of the vehicle. Thus, for example, one such channel could be used for unlocking a tire bolt actuator and the second channel can be used for deploying the bolt.

[0021] In some embodiments, the system includes a remotely operated air supply control device for supplying unlocking and actuating air. For example, such a system can include a user input device, such as a single button or switch disposed in a cockpit of an associate vehicle, the actuation of which is detected by the system and where the system delivers air for unlocking and air for deploying a bolt.

[0022] Another aspect of at least one of the inventions disclosed herein includes the realization that the cost and weight of a system can be beneficially reduced by providing an adaptive tire with a layout of bolts in a configuration such that at least one stud is functionally engaged with a road surface at any one time. In this context, the spacing of the bolts would result in the movement of a tire such that as one bolt becomes functionally disengaged from a road surface, another bolt engages or has been engaged with the road surface. As such, the tire can maintain a functional engagement between a bolt and, for example, an ice covered road surface, while minimizing the number of bolts and actuators and thus the mass and cost of the adaptive tire.

[0023] Another aspect of at least one of the inventions disclosed herein includes the realization that where it is desired to deliver at least two independent channels of actuation energy from a vehicle body to a tire, a multichannel rotary union can be used to deliver actuation energy, for example, pressurized fluid such as air. Thus, in accordance with at least one of the embodiments disclosed herein, an adaptive tire system including retractable and extendable bolts, can include a multichannel rotary union configured to guide at least two independent channels of actuation energy from the vehicle body to the adaptive tire. As such, actuators disposed in the adaptive tire can be controlled from the vehicle for example from within the vehicle without the need to exit the vehicle and or touch the wheel assembly associated with the tire. Further, by providing the actuation energy through a rotary union, there is no need to further connect a source of actuation energy or providing local energy source for the actuators within the tire. Additionally, by providing at least two independent channels of actuation energy, a plurality of different functions can be performed independently of one another.

[0024] Another aspect of at least one of the inventions disclosed herein includes the realization that systems which intermittently use rotary unions for transmitting media

and/or energy from the vehicle body to an adaptive tire can be provided with an enhanced useful life by including retractable seals. For example, known rotary unions typically include fixed seals between a stater body and a rotating shaft for transmitting media such as fluids from the stator body into the rotating shaft. The seals which are designed to provide fluid tight seals between the stator body and the rotating shaft, are worn down during rotation of the shaft relative to the stator body. However, there are some systems that do not require an included rotary union to be functional at all times. For example, some known uses for single channel rotary unions include systems for inflating tires of a vehicle by transmitting pressurized air, through a rotary union, into a vehicle wheel and tire for providing inflation air. Such systems could incorporate appropriate valves such that pressurized air does not need to be provided through the Rotary union at all times. Rather, pressurized air can be used only during and operation of inflating or the inflating tires. Thus, the seals within the Rotary union are only used during the operation of inflation or re-inflation.

[0025] At least some of the embodiments of the adaptive tire systems disclosed herein do not require a continuous supply of actuation energy, such as a working fluid, to be delivered to the tire from the vehicle. Rather, some of the systems disclosed herein only require actuation energy during specific operations, such as unlocking, extending, and optionally retracting bolts used for enhancing traction on compromise road services, such as ice covered road services.

[0026] Thus, in either of the two environments of use noted above, as well as other environments of use, wear of the seals of a rotary union can be reduced or slowed by using retractable seals that can be extended during times of operation. At other times, the seals can be retracted to prevent wear of the seals, while the rotary union is not being used for transmitting media, fluid, or energy.

[0027] Thus, in accordance with at least some of the embodiments disclosed herein, a rotary union can include retractable seals. For example, the seals between a stator body and a rotating shaft can be inflatable and deflatable. As such, for example, the seals can be inflated during periods of operation, thereby causing the seals to press against surrounding surfaces thereby creating seals, such as fluid tight seals. During periods of not operation, on the other hand, the seals can be deflated, thereby allowing the outer services to shrink away

from surrounding surfaces, thereby preventing the outer surfaces of the seals from pressing against surfaces that slide against them during periods of operation. Other configurations can also be used.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] A more complete understanding of the subject matter may be derived by referring to the detailed description and claims when considered in conjunction with the following figures, wherein like reference numbers refer to similar elements throughout the figures.

[0029] Figure 1 is a schematic diagram of an adaptive tire system of a vehicle and illustrating a manual control mechanism mounted on the wheel of the associated tire and an optional automatic control system mounted in the vehicle associated with the wheel.

[0030] Figure 2 is a schematic diagram of a vehicle including four adaptive tires, an air compressor, and compressed air distribution devices for facilitating manual operation of the adaptive tires.

[0031] Figure 2A is a schematic diagram illustrating various pneumatic connections and actuators included in the system illustrated in Figure 2.

[0032] Figure 3 is a schematic diagram of another embodiment of an adaptive tire system of a vehicle incorporating four adaptive tires and external multiple passage rotary unions for providing actuating air to the actuators within each tire.

[0033] Figure 3B is a schematic diagram of the adaptive tire system illustrated in Figure 3.

[0034] Figure 4 is a schematic diagram of a vehicle including four adaptive tires and an automatic actuation system incorporating internal multiple passage rotary unions for delivery of actuation air to the actuators within the adaptive tires.

[0035] Figure 5 is a schematic circuit diagram illustrating a hard-wired circuit that can be incorporated into the systems for Figures 3 and 4 for performing extension and retraction operations.

[0036] Figure 6A is a timing diagram illustrating optional timings for actuation of valves with regard to the methods of retraction and extension that can be performed by the systems of Figures 3-5.

[0037] Figure 6B is a flow chart illustrating a control routine for bolt extension that can be performed by the air supply systems illustrated in Figures 3-3B.

[0038] Figure 6C is a flow chart illustrating a control routine for bolt retraction that can be utilized by the air supply systems illustrated in Figures 3-3B.

[0039] Figure 7 is a front elevational view of a wheel including apertures configured for accommodating hardware of an adaptive tire system such as those of Figures 1-4.

[0040] Figure 8 is a side elevational and partial cross sectional view of the wheel of Figure 6 taken along line 8-8 of Figure 7.

[0041] Figure 9 is a front elevational view of a tire having been modified with a plurality of apertures configured to receive actuators and which extend along two offset circumferential paths along the outer surface of the tire.

[0042] Figure 10 is a cross sectional view of the tire of Figure 9, taken along line 9-9.

[0043] Figure 11 is a side elevational view of the tire of Figure 9.

[0044] Figure 11A is a layout view of an optional configuration of the steel belt layer included in the tire of Figure 9, identified as view 11A-11A in Figure 11D.

[0045] Figure 11B is an enlargement of the plan view identified as a D in Figure 11A.

[0046] Figure 11C is a side view of the steel belt layer of Figure 11A, in the circular configuration used inside a tire.

[0047] Figure 11D is a side elevational view of the belt of Figure 11C.

[0048] Figure 11E is a front elevation view of an alternative configuration of the steel belt illustrated in Figures 11A – 11D, having a radial steel belt configuration.

[0049] Figure 11F is a side elevational view of the radial steel belt of Figure 11E.

[0050] Figure 11G is a plan view of a single section of the radial steel belt of Figures 11E and 11F.

[0051] Figure 12 is a front elevational view of the tire of Figure 9 with base members of actuators being installed in the apertures illustrated in Figures 9 and 11.

[0052] Figure 13 is a side elevational and partial sectional view taken along line 13-13 of Figure 11.

[0053] Figure 14 is a sectional view of the tire in Figure 11 taken along line 14-14.

[0054] Figure 15 is a sectional view of the tire in Figure 11 taken along line 15-15.

[0055] Figure 16 is a cross sectional view of the tire of Figure 11 taken along line 16-16.

[0056] Figure 17 is a cross sectional view of the tire of Figure 11 taken along line 17-17.

[0057] Figure 18 is a cross sectional view of the tire of Figure 11 taken along line 18-18.

[0058] Figure 19 is an exploded and partial cutaway view of an actuator and tire including the unlocking, retraction, and deployment air supply lines.

[0059] Figure 20 is a top plan view of a base member assembly of the actuator of Figure 19 and illustrating connections to three air supply manifolds.

[0060] Figure 21 is a side view of the base member assembly illustrated in Figure 20.

[0061] Figure 22 is a sectional view of the base member illustrated in Figure 20, taken a long line 22-22.

[0062] Figure 23 is a sectional view of the base member illustrated in Figure 20, taken along line 23-23.

[0063] Figure 24 is a sectional view of the base member of Figure 20 taken along line 24-24 of Figure 25.

[0064] Figure 25 is a front view of the base member removed from the base member assembly of Figure 20.

[0065] Figure 26 is a schematic sectional view of the actuator of Figure 19 in an assembled state and illustrating a retracted position of the bolt (solid line) and a deployed position of the bolt (phantom line).

[0066] Figure 27 is another schematic sectional view of the actuator of Figure 19 illustrating a locked position of the locking member with the bolt in a retracted position (solid line).

[0067] Figure 28 is a front elevational view of a combined tire and wheel assembly including actuators shown in phantom and manually operated valves for controlling the supply of actuation air to the actuators for deployment, retraction, and locking which can be incorporated into the systems of Figures 1 and 2.

[0068] Figure 29 is a sectional view of the tire illustrated in Figure 28, taken along line 29-29.

[0069] Figure 30 is a rear elevational view of a control unit at hub of the wheel of Figure 29 illustrating valve bodies and various connections of the air supply system.

[0070] Figure 31 is a front elevational view of a control unit at hub the wheel of Figure 30 showing the levers for manually operating the valves illustrated in Figure 30.

[0071] Figure 32 is a top plan and partial sectional view of an adaptive tire with a non-steered tube bundle support assembly and an external rotary union of the system illustrated in Figure 3 and 3B.

[0072] Figure 33 is a side elevational view of the external rotary union illustrated in Figure 32.

[0073] Figure 34 is a cross sectional view of a portion of the assembly illustrated in Figure 32, taken along the line 34-34.

[0074] Figure 35 is a top plan and partial sectional view of an adaptive tire with a steered tube bundle support assembly (e.g. a front wheel) and including an external rotary union of the system illustrated in Figure 3

[0075] Figure 36 is a side elevational view of the external union illustrated in Figure 35.

[0076] Figure 37 is a top plan view of an internal rotary union unit that can be used with the system of Figure 4.

[0077] Figure 38 is an end view of the internal rotary union of Figure 37.

[0078] Figure 39 is a partial sectional view of the internal rotary union of Figure 37, taken along line 39-39.

[0079] Figure 40 is another sectional view of the internal rotary union of Figure 37, taken along line 40-40.

[0080] Figure 41 is a schematic diagram of the rotary union of Figure 37 for supplying three channels of actuation air to an adaptive tire.

[0081] Figure 42 is a schematic cross-sectional view of a seal that can be incorporated into the rotary unions illustrated in Figures 32 – 41, with the seal in a retracted state.

[0082] Figure 43 is another schematic cross-sectional view of the seal of Figure 42, with the seal in an extended state.

DETAILED DESCRIPTION

[0083] The following detailed description is merely illustrative in nature and is not intended to limit the embodiments of the subject matter or the application and uses of such embodiments. As used herein, the word "exemplary" means "serving as an example, instance, or illustration." Any implementation described herein as exemplary is not necessarily to be construed as preferred or advantageous over other implementations. Furthermore, there is no intention to be bound by any expressed or implied theory presented in the preceding technical field, background, brief summary or the following detailed description.

[0084] "Coupled" – The following description refers to parts, devices, mechanisms or features being "coupled" together. As used herein, unless expressly stated otherwise, "coupled" means that one part/device/mechanism/feature is directly or indirectly joined to (or directly or indirectly communicates with) another part/device/mechanism/feature.

[0085] "Adjust" – Some elements, components, and/or features are described as being adjustable or adjusted. As used herein, unless expressly stated otherwise, "adjust" means to position, modify, alter, or dispose an element or component or portion thereof as suitable to the circumstance and embodiment. In certain cases, the element or component, or portion thereof, can remain in an unchanged position, state, and/or condition as a result of adjustment, if appropriate or desirable for the embodiment under the circumstances. In some

cases, the element or component can be altered, changed, or modified to a new position, state, and/or condition as a result of adjustment, if appropriate or desired.

[0086] In addition, certain terminology may also be used in the following description for the purpose of reference only, and thus are not intended to be limiting. For example, terms such as "upper", "lower", "above", and "below" refer to directions in the drawings to which reference is made. Terms such as "front", "back", "rear", and "side" describe the orientation and/or location of portions of the component within a consistent but arbitrary frame of reference which is made clear by reference to the text and the associated drawings describing the component under discussion. Such terminology may include the words specifically mentioned above, derivatives thereof, and words of similar import. Similarly, the terms "first", "second", and other such numerical terms referring to structures do not imply a sequence or order unless clearly indicated by the context.

[0087] The inventions disclosed herein are described in the context of adaptive tire systems used for improving traction of wheeled vehicles on ice covered roads. Some of the embodiments are described in the context of four-wheeled passenger vehicles. However, the inventions disclosed herein can be used in other contexts as well, for example, but without limitation, trucks, multi-wheel axle trucks, tractor trailers, farm vehicles, recreational off road vehicles, robotics, drone vehicles, etc.

[0088] With reference to Figure 1, an adaptive tire system 100 can include a vehicle 102, a vehicle wheel 104 and a bolt actuation system 106.

[0089] The bolt actuation system 106 can include a bolt 108, an extension module 110 and a lock module 112. The bolt 108 can be a generally linear member mounted for reciprocal movement along a radial direction of a tire associated with the vehicle wheel 104. The bolt 108 can be made from any material. However, metals typically provide for reasonable durability. With regard to the reciprocal mounting of the bolt 108, the bolt 108 can be mounted for limited movement within an aperture extending through an outer surface of a tire. More specifically, the bolt 108 can include a distal end and can be mounted such that the distal end of the bolt can be retracted to a position in which it does not protrude beyond an outer surface of a tread of an associated tire and a deployed position in which the distal tip protrudes beyond the outer surface of the surrounding tread.

[0090] The lock module 112 can be configured to move between locked and unlocked positions. Additionally, the locked module can be configured to lock the bolt 108 in a deployed position without the need of persistently maintained actuation force, such as compressed air or another source of force. Rather, the lock mechanism 112 can be configured to mechanically maintain the bolt in the deployed position and optionally without the need for any persistently or continuously applied energy or force.

[0091] Optionally, the lock module 112 can also be configured to lock the bolt 108 in the retracted position. Again, the lock module 112 can be configured to maintain the bolt in a retracted position without the need for persistently or continuously maintained application of energy or air pressure. Additionally, such functionality of the lock module 112 can prevent the bolts from unintentionally being deployed through centrifugal acceleration caused by movement of the wheel 104 and the associated vehicle 102.

[0092] The extension module 110 can be configured to provide an actuation force for moving the bolt 108 from a retracted position to the deployed position noted above. Any type of actuator can be used. In the embodiments described below with reference to the remaining figures, the extension module 110 utilizes compressed air for actuation of the bolt 108. However, other types of actuators can also be used.

[0093] Optionally, the system 106 can also include a retract module 114. The retract module 114 can be configured to provide an actuation force for moving the bolt 108 from the deployed position to a retracted position. In some embodiments, the retract module 114 can be in the form of a spring. Thus, when the lock mechanism 112 is unlocked, and there is no actuation force provided by the extension module 110, the retract module 114 can return the bolt to the retracted position by action of a spring. Optionally, the retract module 114 can also include an active actuator such as a compressed air actuator or other type of actuator for moving the bolt 108 into the retracted position. This can be beneficial where the force of a spring alone is not sufficient to reliably move the bolt fully into the retracted position. In some embodiments, the retract module 114 can be incorporated into the extension module 110.

[0094] The system 106 can also optionally include an adjustment module 116. The adjustment module 116 can be configured to allow the magnitude of protrusion of the

bolt 108 from the surrounding tread surface of an associated tire to be adjusted. For example, the bolt 108 can be made in one or more parts including a threaded engagement with another component thereby allowing the amount by which the bolt protrudes from the surrounding tire tread to be adjusted in or out. Further, the adjustment module 116 can include a mechanism for allowing the tips of the bolt 108 to be removed and replaced. For example, the bolt 108 can be made in a plurality of pieces in which the distal-most tip of the bolt 108 is threaded onto an inner portion of the bolt 108 such that the distal tip can be removed and replaced. In some embodiments, the replaceable tips can be made from any material including, for example, but without limitation, steel, titanium, plastic, aluminum, etc.

[0095] Optionally, the system 106 can include a manual interface 118 configured to allow a user to manually control the supply of air from an air source 120 to the extension module 110, lock module 112 and the retract module 114.

[0096] In some embodiments, the air source 120 can be mounted on the vehicle 102. However, other configurations could also be used.

[0097] Further, in the illustrated embodiment, the manual interface 118 is mounted on the vehicle wheel 104. However, other configurations can also be used.

[0098] In some embodiments, the system 106 can include an automatic control device 122. For example, the automatic control device 122 can control the automatic deployment and retraction of the bolt 108. For example, the device 122 can be configured, with hard-wired circuitry, a microprocessor/microcontroller, or general purpose computer hardware and actuators for controlling a supply of air from the air source 120 to the extension module 110, lock module 112, and retract module 114. In some embodiments, the control device 122 can include a user input device (not shown) configured to allow a user to perform a single input command activate for requesting the lock module 112 to unlock the bolt 108 and the extension module 110 to apply an actuation force to move the bolt 108 from the retracted position to the deployed position. Similarly, and optionally, the device 122 can include a user input device that allows a user to perform a single input command for requesting retraction of the bolt and to activate the lock module 112 and the retract module 114. As such, a user can extend and retract the bolt 108 with single inputs. Other configurations can also be used.

[0099] Figure 2 illustrates a further embodiment of the adaptive tire system 100, identified generally below by the reference numeral 100A. The components of the system 100A that are the same or similar to the adaptive system 100 illustrated in Figure 1 are identified with the same reference numeral, except that "A" has been added thereto. The description set forth above with regard to the system 100 also applied to the similarly designated components of the system 100A.

[0100] In the illustrated embodiment, the vehicle 102A is a four-wheeled passenger vehicle having four vehicle wheels 104A.

[0101] The system 100A includes a vehicle mounted air compressor 130 connected to a vehicle-mounted power supply, such as a 12-volt power supply 132. In some embodiments, the air compressor 130 can be designed to provide at least about 47 psi compressed air. In some embodiments, an inline 30-amp fuse 134 can be included in the circuit connection 136 to the air compressor 130. The air compressor 130 can have a power switch 138 accessible by a user and an air delivery hose 140. The delivery hose 140 can be sized so that it can extend to all of the wheels 104A of the vehicle 102A. The air delivery hose 140 can include an air shut off insert 142 at its distal end for delivering compressed air to the components within the wheels 104A, described in greater detail below. The shut off insert 142 can be any type of shut off insert which are well-known in the art.

[0102] Similarly to the system 100, Figure 1, the system 100A can include a plurality of extendable and/or retractable bolts 108A on each of the wheels 104A. The bolts 108A can be arranged along a single circumferential line around each of the wheels 104A. In the illustrated embodiment, the bolts 104A are arranged around two circumferential lines, parallel to one another, thereby defining two groups of bolts; an inner set of bolt assemblies 150 and an outer set of bolt assemblies 152. The inner and outer bolt assemblies 150, 152 can be configured to be deployed and retracted simultaneously. Additionally, the inner and outer bolt assemblies 150, 152 can be identical or similar to each other. However, other configurations and actuation procedures can also be used.

[0103] Figure 2 schematically illustrates the system 100A including two portions of the wheel 104A; the rigid portion of the wheel 104A referred to herein as wheel 170, also commonly referred to as an "rim" and a tire 172. The wheel 170 can include inputs for a user

to manually control deployment and retraction of the bolt assemblies 150, 152. As illustrated in Figure 2A, several components can extend from the wheel 170 into the tire 172 to provide actuation to the bolt assemblies 150, 152.

[0104] With continued reference to Figure 2A, the wheel 170 can include one or more pipe couplers 174 configured to receive pressurized air from the shut off insert 142. The pipe couplers 174 can be connected to a pressure reservoir 176, which can be in the form of a chamber or loop of pipe or hose. Other configurations can also be used. The reservoir 176 can be connected to three valves 178, 180, 182 which are configured to selectively connect the reservoir 176 with either internal air circuits within the tire 172 or a vent reservoir or vent loop 184. The vent reservoir 184 is connected to a vent discharge port 186, which can optionally include an outlet filter 188 configured to discharge air from the loop 184 to the atmosphere.

[0105] In the orientations illustrated in Figure 2A, all of the valves 178, 180, 182 connect the air circuits internal to the tire 172 to the vent loop 182 and thus to the atmosphere. In this position, none of the bolt assemblies 150, 152 can receive any internal actuation forces. In some embodiments, the bolt assemblies 150, 152 are biased towards a retracted, locked state. Thus, with valves 178, 180, 182 in the positions illustrated in Figure 2A, the bolt assemblies 150, 152 would remain in a retracted, locked state. However, other configurations of bolt assemblies 150, 152 can also be used.

[0106] The valves 178, 180, 182 are movable to at least one other position. For example, the valves 178, 180, 182 are configured to be rotated clockwise by 90 degrees. In that configuration, the valves 178, 180, 182 connect the reservoir 176 with the internal plumbing of the tire 172. Selective actuation in the valves 178, 180, 182 can provide desired locking, unlocking, retraction, and extension of the bolt assemblies 150, 152, described in greater detail below.

[0107] With continued reference to Figure 2A, the tire 172 can include a set of inner actuator manifolds 190 and a set of outer actuator manifolds 192. The manifolds 190, 192 can be in any configuration and can be configured for supplying any type of actuation force to the inner and outer bolt assemblies 150, 152, respectively. In the illustrated embodiments, the manifold sets 190, 192 include three pneumatic reservoirs or loops

corresponding to the three valves 178, 180, 182. More specifically, the manifolds 190, 192 each include an extend manifold 194, a retract manifold 196 and an unlock manifold 198.

[0108] The extend manifolds 194 are connected to the valve 178 with a wheel rim fitting 200. Similarly, the retract and unlock manifold 196, 198 are also connected to valves 180, 182, respectively, with similar wheel rim fittings, unions, and other types of hose or connectors that can be readily applied by one of ordinary skill in the art.

[0109] The manifolds 194, 196, 198 can extend circumferentially within the tire 172, parallel to each other. Further, optionally, each of the manifold sets 190, 192 can be connected to a plurality of bolt assemblies 150, 152 in an aligned or offset configuration. In the illustrated embodiment, each of the manifold sets 190, 192 are connected to nine inner and outer bolt assemblies 150, 152, respectively.

[0110] With continued reference to Figure 2A, the inner and outer bolt assemblies 150, 152 can comprise bolt actuators. Each of these bolt actuators can include a movable bolt 200, an extension actuator device 202, an unlocking device 204 and a retraction device 206.

[0111] Each of the extension manifolds 194 are connected to the respective inner and outer extension devices 202 of the inner and outer bolt assemblies 150, 152. In some embodiments, the extension devices 202 can be diaphragm mechanisms which expand when subjected to pressurized air and thereby generate an actuation force. In the illustrated embodiment, the diaphragms 202 exert a linear, downward force against the movable bolts 200. As described in greater detail below, the movable bolts 200 slideably move within the bolt assemblies 150, 152 and are spring biased towards a retracted (upward) position. Thus, when the valve 178 is rotated 90 degrees from a position illustrated in Figure 2A, thereby guiding pressurized air to the manifolds 194, pressurized air enters the diaphragm mechanisms 202 and thereby urges the bolts 200 toward the extended position (phantom line in Figure 2A). However, the lock mechanism 204, described in greater detail below, must be in an unlocked position before the movable bolts 200 can move.

[0112] The manifolds 196 are connected to the unlock mechanisms 204. Similarly to the extend mechanisms 202, the unlock mechanism 204 can be in the form of a diaphragm device which, when subjected to pressurized air from manifolds 198, generate an actuation force which presses against a movable locking member (described in greater detail

below). In some embodiments, the locking member can be biased towards a lock position. Thus, the unlock mechanism 204 can be configured to, when provided with an actuation force, move the locking member toward an unlock position. Thus, if valve 178 first and then valve 182 are rotated 90 degrees from a position illustrated in Figure 2A, thereby providing pressurized air to the manifolds 194, 198, the locking member within the bolt assemblies 150, 152 would be moved to the unlock position and the extend mechanisms 202 would urge the movable bolts 200 to the extended position illustrated in phantom line in Figure 2A.

[0113] The retract manifolds 196 are connected to a retract device 206 in the bolt assemblies 150, 152. The retract device 206, in some embodiments, can be incorporated into the extend device, for example, utilizing the same diaphragm to provide a retraction force. For example, the retract device 206 can include air passages for communicating air in the retract manifold 196 to the opposite side of the diaphragm used to provide the extension movement performed by the extension device.

[0114] In operation, with removable bolts 200 in either the deployed or retracted position, the valves 178, 180, 182 can be left in the position illustrated in Figure 2A, where all manifolds 194, 196, 198 are vented to the vent reservoir 184. As such, the lock mechanism (described in greater detail below) included in the bolt assemblies 150, 152 lock the movable bolts 200 into an existing position and do not require any continued or persistent application of actuation force or energy.

[0115] If a user wishes to change the position of the movable bolt 200, a user can manually connect the air supply shut off insert 142 to the coupler 174 and rotate valve 182 90 degrees clockwise from the position illustrated in Figure 2A. Such a movement of the valve 182 connects pressurized air within the reservoir 176 with the manifolds 198. Thereafter, pressurized air flows into the unlock mechanisms 204 to thereby unlock the bolts 200 from their position. If the bolts 200 are in the retracted position, the user can rotate the valve 178 90 degrees clockwise from the position illustrated in Figure 2A to thereby provide pressurized air to the manifolds 194. Pressurized air from the manifolds 194 will then flow into the extend mechanisms 202 and thereby urge the bolts 200 from retracted to deployed positions. Thereafter, the user can then rotate the valve 182 counter-clockwise to the position illustrated in Figure 2A, thereby allowing the pressurized air to vent from the unlock

mechanisms 204 and thereby allowing the lock mechanism to return to its locked position towards which it is biased. The user can then return the valve 178 to the position illustrated in Figure 2A and disconnect the shut off insert 142.

[0116] On the other hand, if the bolts 200 are in the deployed position or extended position and the user desires to retract the bolts 200, the user can move the valve 182 to the unlock position (90 degrees clockwise from the position illustrated in Figure 2A) and also rotate the valve 180 90 degrees clockwise from the position illustrated in Figure 2A. As such, pressurized air will flow into both the unlock manifolds 198 and the retract manifolds 196, thereby urging the bolt 200 towards its retracted position. As noted above, the bolt assemblies 150, 152 can optionally include springs to bias the bolts 200 toward a retracted position. Thus, in some embodiments, or under certain circumstances, it may not be necessary to use the retract valve 180 to retract the bolts. Friction between the bolt assembly and lock cams during pressure retraction is minimized by sloped surfaces of bolt assembly and lock cam, described in greater detail below with reference to Figure 27. Finally, in order to maintain the bolts 200 in the retracted position, the user can return the lock valve 182 to the position illustrated in Figure 2A, thereby allowing the pressurized air to bleed out of the unlock mechanisms 204 allowing the lock member (described below) to return to a locked position.

[0117] Figure 3 illustrates a further modification of the systems 100, 100A, identified generally by the reference numeral 100B. The components of the embodiment 100B set forth below that are the same or similar to the corresponding components of the embodiments 100, 100A described above, are identified with the same reference numeral except that a "B" has been added thereto. The components of the system 100B that are not described in detail below can be assume to be the same or similar to those described above with reference to the systems 100, 100A.

[0118] With continued reference to Figure 3, the system 100B can include an automated air delivery subsystem 300. The system 300 can include a compressed air source 138 (Figure 2) or another type of source of actuator forces.

[0119] The system 100B also includes rotary union assemblies 302 associated with each of the wheels 104B. The rotary union assemblies 302 are configured to divert

actuation forces from the system 300 to the wheels 104B by using pivotable actuator lines mounted on the exterior side of the wheels 104B guiding the actuator forces through a rotary union disposed at the hub of the wheels 104B. More specifically, with continued reference to Figure 3, the rotary union assemblies 302 include flexible pneumatic hose bundles 304 which are connected to the system 300, and the source of compressed air disposed therein. The pivotable tube bundles304 associated with the rear axle of the vehicle 102B can include proximal ends 306 that are fixed to the vehicle frame or body. The distal ends 308 of the flexible hose bundles 304 can be fixed to rotary union units 310 disposed at the outer sides of each of the wheels 104B. During operation, as the wheels 104B move up and down, the flexible tube bundles 304 pivot, twist and bend to accommodate movement of the wheels 104B.

[0120] The flexible tube bundles 304 associated with the front wheels can include proximal ends 310 mounted to a portion of the suspension of the vehicle 102B near the inner side of the hub of the wheel 104B. These flexible tube bundles 304 can extend around the wheels 104B to rotary union devices 312 disposed on the outer sides of the wheels 104B associated with the front of the vehicle 102B. An additional fixed mount 314 can be provided for each side of the vehicle associated with the front wheels for fixing additional lengths of flexible lines connecting the flexible bundles 304 with the system 300. In this configuration, the flexible tube bundles 304 pivot left and right with steering movements of the wheels 104B, and the additional lengths of hose 316 can flex to accommodate the up-and-down movements of the front wheels 104B.

[0121] As shown in Figure 3B, the system 300 (Figure 3) can include an air compressor 138B and a plurality of valves 178B, 180B, 182B, configured for controlling the supply of air for extension, retraction, and unlocking, respectively. The subsystem 300 can include actuators (not shown) configured to electronically operate the valves 178B, 180B, 182B. Any type of actuator known in the art can be used for such actuation. For example, the subsystem 300 can include a hard-wired controller, a microprocessor controller, a programmable logic controller, or a general purpose computer and processor with an appropriate operating system and software coding for performing any of the functions described above or below. In some embodiments, the valves 178B, 180B, 182B, are linear

sliding-type valves which rely on linear actuators for creating and cutting off connections between the various supply and discharge lines.

[0122] As reflected in Figure 3B, the subsystem 300 includes four parallel bundled outputs for feeding actuation air to the rotary unions 310.

[0123] With continued reference to Figure 3B, the subsystem 300 can be configured to sequentially operate the valves 178B, 180B, 182B, to perform the functions of retraction and extension. For example, the subsystem 300 can be programmed (and/or hard-wired) to respond to a user input, for example, user input device 330 (Figure 3). The user input device 330 can include, for example, two or more positions; a first position for requesting retraction and a second position for requesting extension.

[0124] The subsystem can be programmed, as is well within the skill of one in ordinary skill in the art, to perform the following steps upon detection of retraction and extension.

[0125] When the user input 330 is actuated to request extension, the subsystem 300 can sequentially move valve 182B to connect the high-pressure source 176B to the unlocked manifold 198B. This will, as described above, unlock the bolt assemblies 150B, 152B. With the value 182B maintained in the activated position noted above, the subsystem 300 can then activate valve 178B to connect the extension manifolds 194B to the bolts 150B, 152B. As such, the movable bolts 200B would then be urged to the extended position (phantom line in Figure 3B).

[0126] The subsystem 300 can then sequentially deactivate the valves 182B, 178B. More specifically, the subsystem 300 can, with the movable bolts 200B held in the extended position through the continued application of high-pressure air from the compressor 138B through the loop or source 176B, the valve 182B can then be deactivated, i.e., moved to the position illustrated in Figure 3B, so as to allow pressurized air from the unlocking manifold 198B to be vented through the vent 186B and, optionally, filter 188B. Thus, the locking mechanisms within the bolts 150B, 152B, will move, under their bias, to the locked position. After the bolts 150B, 152B, change state to the locked state, the valve 178B can be deactivated, i.e., moved to the position illustrated in Figure 3B, to allow high-pressure air to vent through the vent 186B and, optionally, filter 188B.

[0127] On the other hand, if the bolts 150B, 152B, are in the extended position and a retraction request is detected at the user input 330, the subsystem 300 can sequentially operate valves 182B, 180B, to unlock and then retract the moveable bolts 200B. More specifically, upon detection of the retraction request at the user input 330, the subsystem 300 can activate valve 182B, as noted above, to unlock the bolt assemblies 150B, 152B. With the bolt assemblies 150B, 152B, maintained in an unlocked position, the subsystem 300 can then activate valve 180B to thereby connect the retraction manifolds 196B with the loop 176B so as to drive the moveable bolts 200B toward the retracted position.

[0128] After the moveable bolts 200B have been moved to the retracted position, the subsystem 300, while maintaining valve 180B in the activated state, can move the valve 182B back to the deactivated state, thereby connecting the unlocked manifolds 198B to the vent 186B so as to vent the pressurized air to the atmosphere, optionally through the filter 188B.

[0129] As such, the bolt assemblies 150B, 152B, will move to the locked positions, as noted above, under the bias of the locking mechanisms included in the bolt assemblies 150B, 152B.

[0130] Thereafter, the subsystem 300 can optionally deactivate the valve 180B to thereby connect the retraction manifolds 196B with the vent 186B.

[0131] With regard to the function of extension of the moveable bolts 200B, the subsystem 300 can be activated during operation of the vehicle, i.e., during rotation of the wheels 104B. As such, during operation, large centripetal accelerations are generated and act on the moveable bolts 200B. Thus, such centripetal acceleration can be utilized to assist or entirely perform or apply the necessary actuation forces for moving the moveable bolts 200B from the retracted position to the extended position.

[0132] The use of the rotary unions 310 allow the system to be configured to be operated by an operator of the vehicle from inside the vehicle, without the need to attach exterior pressure lines. Thus, the rotary unions 310 provide a highly desirable mode of operation which minimizes the need for user manual manipulation of valves, or application of pressurized air.

[0133] Figure 4 illustrates yet another modification of the systems 100, 100A, 100B, and is identified generally by the reference numeral 100C. The components of the system 100C, which are the same or similar to the components of the systems 100, 100A, or 100B, are identified below with the same reference numeral, except that a "C" has been added thereto.

[0134] With continued reference to Figure 4, the system 100C includes internal, hub-mounted rotary unions 310C. The rotary unions 310 and 310C are both configured to provide a plurality of compressed air connections through a spinning joint. Additionally, the use of the internal rotary unions 310C avoids the additionally and potentially undesirable appearance of the unions on the outside of the wheels 104C that results from the configuration of the system 100B.

[0135] With reference to Figure 5, the subsystems 300 and 300C can include a hard-wired controller 350 configured for activating the valves and performing the methods described above. Some of the components are identified with functional block representations and such components' construction, and operation thereof, is well understood by those of ordinary skill in the art. Additionally, a more detailed description of the components and operation of the controller 350 of Figure 5 is set forth in U.S. Provisional Patent Application No. 61/691,076 filed August 20, 2012 and U.S. Provisional Patent Application No. 61/691,222 filed August 20, 2012, the entire contents of both of which is noted above.

[0136] As shown in Figure 5, the controller 350 can include a power switch 382 connecting the controller 350 with a power source 354. Wired in the configuration illustrated in Figure 5, the power switch 352, when closed, powers on the air compressor 130 and the air compressor light 356. Otherwise, the remainder of the controller 350 remains off, until a user activates the button 330.

[0137] The circuit of the controller 350 also includes a flip-flop relay 358. The relay flip-flop 358 allows for the controller 350 to automatically switch between retract and extend modes. In the position illustrated in solid line in Figure 5, the flip-flop relay 358 is in the retract mode. Thus, when the button 330 is depressed, the retract relay "RR" as well as the unlock valve "UV", the unlock timer "UT", and the timing relay "TR" are connected to

the power supply 354. As such, the controller 350 sequentially operates the valves 182B and 180B to perform a bolt retraction operation, as described in greater detail below. At the end of the retraction operation, the flip-flop relay 358 moves to the downward position illustrated in phantom line in Figure 5.

[0138] When the button 330 is depressed with the flip-flop relay 358 in the down position (phantom line), the extend relay "ER" is connected to the power supply along with the unlocked valve "UV", the unlock timer "UT", and the timing relay "TR". As such, the controller 350 sequentially operates the valves 182B and 178B to perform an extend operation, described in greater detail below.

[0139] With regard to Figure 5, the timing diagrams for unlocking and operating the valves described above with regard to the retraction and extension methods, is set forth therein. These timings are examples of timings that can be used with the systems 300, 300C. However, other timing schemes and scenarios can also be used. As reflected in the timing diagram of Figures 6A, during operation, the controller 350 initially energizes the unlock valve "UV" which corresponds to valve 182B (Figure 3B). Some time elapses as the air flows through the valve 182B and into the unlock manifold 198B before the bolt assemblies 150B, 152B are fully unlocked. Thus, the controller 350 waits until t1 seconds has elapsed after the unlocked valve 182B has been energized before energizing either the extend or retract valves 178B, 180B. This allows the lock mechanisms within the bolt assemblies 150B, 152B to reach a fully unlocked state before an attempt is made to move the bolts 200B. Additionally, the controller 350 waits until the extend or retract valves have been energized for at least t2 seconds before de-energizing the lock valve 182B. This ensures that the bolt has made the desired movement before the locking device within the 150B, 152B moves back into a locked position. Finally, the controller 350 waits until t3 seconds has elapsed before venting the extend or retract manifolds 194B 196B. The controller 350 accomplishes the delays associated with the durations T1, T2, T3 noted above by using the unlock timer "UT", and the timing relay "TR". These types of devices are well known in the art and can include adjustment screws for changing the magnitudes of the times t1, t2, and t3 noted above. The appropriate magnitudes of the times t1, t2, and t3 can be determined through routine optimization. The magnitudes of the times t1, t2, and t3 may be in the range of approximately

600 ms to 2 full seconds. These magnitudes can vary depending on the geometry of different components within the system and thus one set of magnitudes of the times t1, t2, and t3 may not be appropriate for all embodiments. Additionally, methods of operation of the systems 300, 300C are further described with reference to the control routines illustrated Figures 6B 6C.

[0140] Figures 6B and 6C illustrate control routines that can be utilized by the air supply systems 300, 300C illustrated in Figures 3 and 4 where such systems include microprocessor or general purpose computer control. Additionally, the flow charts set forth in Figures 6B and 6C can represent methods of operation that are performed by hard-wired embodiments, such as that illustrated in Figures 5 and 6A above.

[0141] Figure 6B illustrates a subroutine 550 which is configured to extend the moveable bolts 200. The subroutine can start operation block S10. After the operation block S10, the subroutine 550 can move on to decision block S12.

[0142] In the decision block S12, it is determined whether an extension request has been detected. For example, the system 300 can monitor the user input 330, 330C (Figs. 3 and 4) to determine if a user or operator of the associated vehicle 102B, 102C has activated the user input 330, 330C to request an extension operation. If it is determined that an extension request has not been detected, the control routine 550 can return to start block S10.

[0143] On the other hand, if it determined, in the decision block S12, that a user has requested an extension operation, the control routine 550 can move on to operation block S14.

[0144] In the operation block S14, an unlock operation can be activated. For example, the system 300, 300C can activate valves 182B, to provide pressurized air to the unlock manifolds 198B to thereby begin an unlock operation. After the operation block S14, the control routine 550 can move on to decision block S16. In the operation block S16, it can be determined if the unlock operation has been performed for at least a minimum amount of time, for example, t1 seconds. For example, the systems 300 can determine if the valves 182B have been energized or activated for at least the predetermined number of seconds ("t1"). If it is determined that the unlock operation has not been performed for at least the threshold amount of time, the control routine 550 can return to operation block S14 and

continue. On the other hand, if it is determined in decision S16 if the unlock operation has been performed for the minimum amount of time, the control routine 550 can move on to operation block S18. This portion of the control routine 550 is reflected in the timing diagram of Figure 5B where it is indicated that an unlock begins "(UV energized)", subsequently, the unlock operation reaches 100% and then after a time B, an extension operation begins.

[0145] Thus, in operation block S18, an extension operation can be activated. For example, the systems 300, 300C can activate valves 178B to thereby provide pressurized air to the extend manifolds 194B. As such, the moveable bolts 200, 200B will begin to move toward an extended configuration. After the operation block S18, the control routine 550 can move on to decision block S20.

[0146] In the decision block S20, it can be determined if the extend operation has been performed for a threshold amount of time, such as "t2" seconds. If it is determined that the extend operation has not been performed for at least t2 seconds, the control routine 550 can return to operation block S18 and continue. On the other hand, if it is determined that the extend operation has continued for at least t2 seconds, the control routine 550 can move on to operation block S22.

[0147] In the operation block S22, a lock operation can begin. For example, but without limitation, the systems 330 can deenergize valves 178B and then 182B so as to allow locking manifolds 198B to vent to the atmosphere through the vent 186B and optionally the filter 188B. As such, the lock mechanism (described in greater detail below) can move back to the locked position towards which it is biased. However, other locking mechanisms can also be used. After the operation block S22, the control routine 550 can move on to decision block S24.

[0148] In the decision block S24, it is determined if the block activate function has been performed for at least t3 seconds. If it is determined that the activate lock operation has not been performed for at least t3 seconds, then the control routine 550 can return to operation block S22 and continue. On the other hand, if it is determined in operation block S24 that the activate lock operation has not continued for at least t3 seconds, the control routine 550 can move on to operation block S26.

[0149] In the operation block S26, the extend operation can be deactivated. For example, the systems 300 can deenergize valves 178B so as to allow the extend manifolds 194B to vent to the atmosphere. As such, the moveable bolts 200, 200B will remain in the locked extended position, however, the pressure will be vented out of the extend manifolds 194B.

[0150] After the operation block S26, the control routine 550 can move on to end block S28, and optionally return to start block S10 and run continuously in that fashion.

[0151] Figure 6C illustrates a control routine 552 which can be utilized by the control systems 300, 300C to retract the moveable bolts 200B. The operations and decisions performed within the control routine 552 are essentially the same as those set forth in the control routine 550, except that instead of the extend valves 178B and extend manifolds 194B being pressurized and vented to the atmosphere, the retract valves 180B and retract manifolds 196B are activated and charged with pressurized air then vented to the atmosphere in the same manner that the extend valves and manifolds are operated in the control routine 550. Thus, the steps S50, S52, S54, S56, S58, S60, S62, S64, S66, and S68 are not described in greater detail herein. Rather, one of ordinary skill in the art can fully understand how the control routine 552 can operate.

[0152] The above circuit and timing diagram of Figures 5A and 6A and control routines of Figures 6B and 6C provide advantageously smooth operation of retract and extend operations for the moveable bolts 200, 200B. This is because these mechanical components need some time to move, as does the pressurized air in the systems 300, 300B. Thus, by allowing for detecting or determining whether certain minimum threshold amounts of time have passed before moving on to subsequent operations, sufficient time is allowed for these mechanical components and air to move into and pressurize the previously vented passages and manifolds so that the subsequent steps can be completed smoothly and without colliding components into one another or causing unnecessarily large friction among moving components.

[0153] Figures 6 and 7 illustrate a sample wheel or "rim" 400 that can be used as a center rigid portion of any of the wheels 104, 104A, 104B, 104C.

[0154] The wheels 400 can include a plurality of apertures for accommodating the air circuit tubing and hardware illustrated in Figures 1-4. For example, the wheels 400 can include apertures 402 for accommodating connections from the manual user interface 118 (Figure 1), 170 (Figure 2A), or the rotary unions 300, 300C, into the interior of the wheels 104. As described in greater detail below, appropriate seals would be used in conjunction with the apertures 402 to maintain an air-tight seal for the wheel 104 for inflation purposes. The wheel 400 can include various other apertures not described in greater detail herein, for accommodating other components described below.

[0155] With reference to Figures 9-11, a tire 500 is illustrated therein as including a tread surface 502, a sidewall 504, and a plurality of apertures 506 for accommodating bolt assemblies 150, 152. The apertures 506, in some embodiments, extend through steel belts, commonly used on tires, and vulcanized rubber used on tires. Additionally, the apertures 506 extend through the tread pattern tread surface 502 of the tire 500 so as to provide a clearance for the moveable bolts 200 to retract and extend from the bolt assemblies 150, 152.

[0156] As shown in the schematic diagram of Figure 9, apertures 506 can be spaced apart so as to be positioned at locations which result in continuous engagement of a bolt 200 with a road surface meaning an ice or snow covered; during operation, as the tire 500 rolls over the road surface 501, individual bolts 200 of the bolt assemblies 150 (Figure 28) will come into contact with the road surface 501, then be pulled away from the road surface 501 as a subsequent bolt assembly 150 moves into contact with the road surface 501. In the illustrated embodiment, the tire 500 includes only eighteen apertures 506 for receiving bolt assemblies 150. However, other numbers, greater or fewer, can also be used.

[0157] Optionally, the steel belt 602 within the tire 500 can be provided with apertures prior to being calendered with the rubber that also forms the outer and inner surfaces of the tire 500. For example, as shown in Figures 11A-11D, the steel belt 602 can be in the form of an axial single ply steel belt, optionally including additional fiberglass layers, which may be biased. The belt 602 can have thin steel discs or rings 603 welded to the belt at the desired locations of the apertures 504 (Figure 9). For example, the rings 603 can be welded to the belt 602 using precision-timed electric welds, for example at a plurality of weld spots 630 to provide an adequate connection between the wires of the belt 602 and the rings

603. Subsequently, the discs 603 can be punched with an aperture of the desired size for mounting the bolt assemblies 150, 152. Punching the discs 603 also cuts the wires forming the underlying belts. Thus, the welded connection between the belts 602 and the ring-shaped portions of the discs 603 remaining after punching, help compensate for the interruption of the wires caused by punching, thereby routing forces between the ends of interrupted wires of the belt 602. In some embodiments, the discs 630 are about 1 ¾" in diameter and they are punch with a 1" diameter hole. After such reinforcement, the belt 602 can be calendered with rubber to form a component of the tire 500.

[0158] With reference to Figures 11E-11G, the belt 602 can also be in the form of a radial belt. Figure 11G shows a punched disc 630 welded to a segment 632 of a radial belt configuration of the belt 602.

[0159] Figures 12-18 illustrate further modifications of the tire 500 that can be made to accommodate the bolt mechanisms 150, 152, as well as the manifolds 194, 196, 198, 194B, 196B, 198B.

[0160] Figure 11 illustrates 18 installation sites 520 around the tire 500. Additionally, Figure 12 illustrates three connection assemblies 522, 524, 526 for connecting the air interface 118 for control system 122 (Figure 1) as well as the air supply systems 300, 300C to the various manifolds within the tire 500.

[0161] Figures 11 and 12 also illustrate an optional configuration of the manifolds 194, 196, 198, 194B, 196B, 198B within the tire 500. For purposes of simplicity, references to the various manifolds set forth below will only reference the manifolds 194, 196, 198 but it is understood that the statements apply equally to the manifolds 194B, 196B, 198B.

[0162] As illustrated in Figures 11-18, the manifolds 194, 196, 198 extend around an inner surface of the tire 500 circumferentially around the tire forming a complete loop therein. However, other configurations can also be used.

[0163] Additionally, as is reflected in Figures 2A and 3A, each tire includes an inner set of manifolds 196, 194, 198, and an outer set of manifolds 194, 196, 198. The two sets of manifolds allows the installation sites 520 to be staggered along a path along the circumference of the tire 500, alternating between the inside and outside sets of manifolds.

Otherwise, each of the installation sites for the bolt assemblies 150, 152, can be identical and are supplied with pressurized air by the two sets of manifolds in the same manner.

[0164] Further benefits can be achieved by dividing the air distribution points to each of the three manifolds with three different assemblies 522, 524, 526. This provides an inherent balance to the tire. For example, because there three assemblies 522, 524, 526 they can be offset from each other by 120°. Additionally, each of the three distribution assemblies 522, 524, 526 can be configured to receive pressurized air from the air distribution system 170 or 300, 300C, or the interface 118 (Figure 1) and to split the air supply so as to provide air both to the inner and outer corresponding manifolds. For example, with reference to Figures 12 and 16 the air distribution assembly 522 provides a connection to the inner and outer locking manifolds 198, thereby allowing pressurized air to be supplied to and vented from the manifolds 198.

[0165] Figures 12 and 17 illustrate how the air distribution assembly 524 is connected to inner and outer retract manifolds 196. Finally, Figures 12 and 18 illustrate how the distribution assembly 526 is connected to the inner and outer extension manifolds 194. Other arrangements of the manifolds can also be used.

[0166] With continued reference to Figures 12 and 16, in the illustrated embodiment, the air distribution assembly 522 includes an air supply line 523 that extends downwardly from an output of air distribution coupler 530. The coupler 530 can be secured to the side wall of the tire 500 in a through hole of the side wall of the tire 500. This provides for secure fixation of the coupler 530 and for support of the supply line 523 within the tire. For example, during rotation of the tire 500, centripetal acceleration causes large forces on the line and coupler 530. The fixation of the coupler 530 to the side wall of the tire 500 also provides for accommodation of bends in the tube assemblies 523, 525, and 527 about an axis parallel to the rotational axis of the wheel 104 as well as bends in tube assemblies 523A, 525A, 527A about an axis transverse to the rotational axis of the wheel 104. These bends allow the hoses to flex appropriately as the wheel rotates which causes the tread surface and the bolt assemblies 150, 152 to deflect toward the hub of the wheel 104 and as the wheel is distorted during cornering. Other configurations can also be used.

[0167] As shown in Figures 12-18, the manifolds 194, 196, 198 can be formed along the inner circumferential surface of the tire 500 on the opposite side of the outer tread surface 502. For example, the tire 500 can include a vulcanized rubber portion 600 disposed on the inner side of the steel belt 602. In some embodiments, the vulcanized rubber portion 600 can be formed monolithically with the remaining portions of vulcanized rubber forming the side walls 604, steel belt layer 602, and outer tread 502. In other embodiments, the portion 600 can be made from one or more separate pieces of material adhered to the inner circumferential surface of the tire 500. In some embodiments, the portion 600 is also made from vulcanized rubber and bonded to the inner circumferential surface of the tire. Other configurations can also be used.

[0168] Further, in some embodiments, the manifolds 194, 196, 198 can be further defined by tube members 604 extending along the inside of the manifolds 194, 196, 198. In some embodiments, the tube members 604 are all made from the same material such tubing made from polyethylene. Other materials and configurations can also be used.

[0169] Optionally, the distribution assemblies 522, 524, 526 can be connected to the appropriate corresponding manifolds 194, 196, 198 through the use of manifold connector members 606, 608, 610. The three connector blocks 606, 608, 610 can have generally the same configuration except for their corresponding connections to different manifolds. Specifically, connector member 606 is configured to connect the supply line 523 to manifolds 198. The connector member 608 is configured to connect the supply line 525 with the manifolds 196. Finally, connector member 610 is configured to connect the air supply line 527 with the manifolds 194.

[0170] With continued reference to Figure 16, the connector member 606 includes a transverse cross passage 620 that connects with the supply line 523. The cross passage 620 extends transversely across the top (as viewed in Figure 16) of the manifolds 194, 196, 198. More specifically, the passage 620 is spaced above the manifolds 194, 196, 198 and is separated therefrom by a thickness of the connector member 606. Additionally, the connector member 606 includes cylindrical sections622 which are aligned over the overlap between the passage 620 and the manifolds 198. The cylindrical sections622 can facilitate a connection procedure between the cross passage 620 and the manifold 198. For

example, in the orientation illustrated in Figure 16, a drill can be passed into the cylindrical section622, through the cross passage 620, and into the manifold 198. Then, a separate fastener or plug can be inserted into the cylindrical sections622, thereby creating a closed, fluidic connection between the cross passage 620 and the manifold 198. Sealed as such, the supply line 523 can supply pressurized air to the manifold 198 but remain isolated from the other manifolds 194, 196. However, other configurations can also be used.

[0171] As shown in Figures 17 and 18, connection member 608 and 610 include similar features for providing isolated connections between the supply lines 525, 527 and the manifolds 196, 194, respectively.

[0172] Figure 19 illustrates an exploded view of a bolt assembly design which can be utilized for the bolt assemblies 150, 152. Other configurations can also be used.

[0173] In the illustrated embodiment, the bolt assemblies 150, 152 can include an extension actuator assembly 700, a locking actuator assembly 702 and a retraction actuator assembly 704. The moveable bolt 200 is mounted in a bolt carrier 710. In some embodiments, to provide for adjustability of the magnitude at which the moveable bolt 200 extends outwardly from the outer tread surface 502 of the tire 500, the moveable bolt 200 can be threadedly engaged with the bolt carrier 710. Thus, rotational movement of the moveable bolt 200 relative to the bolt carrier 710 allows the moveable bolt 200 to change its axial position relative to the bolt carrier 710, described in greater detail below.

[0174] The actuator 700 can include a flexible diaphragm member 711 fixed between a cap member 712 and an upper portion of the main body 714 of the bolt assemblies 150, 152. The diagram member 711 can be made from any material typically used with diaphragm actuators. A central portion 716 of the diaphragm member 711 is vertically deflectable (as viewed in Figure 19) relative to the cap member 712, the body portion 714, as well as the outer periphery 718 of the diaphragm member 711. The central portion 716 of the diaphragm member can be fixed to the upper end 720 of the bolt receiver 710.

[0175] The main body 714 can also include two springs 722, 724 aligned with lateral projections 726, 728 of the bolt receiver 710. Additionally, the bolt receiver 710 is configured to be slideably moveable within the main body 714. The springs 722, 724 can be configured and sized to bias the bolt receiver 710 into a retracted position, i.e., an upper-most

position within the main body 714. One or more passages within the main body 714 can connect the extend and retract manifolds 194, 196 to opposing sides (i.e. above and below) of the diaphragm member 711. More specifically, as noted above, the extend manifold 194 is provided with pressurized air when it is desired to cause the bolts 200 to extend outwardly from the tire. Thus, internal passages through the base member 520 and the main body 714 can be provided for connecting the extend manifold 194 to the upper side (as viewed in Figure 19) of the diaphragm member 711. As such, when pressurized air is provided into the space between the upper surface of the diaphragm member 711 and the cap 712, the central portion 716 of the diaphragm member 711 is pushed downwardly away from the cap 712, thereby pressing on the upper portion 720 of the bolt receiver 710, thereby pushing the moveable bolt 200 downwardly into the extended position, against the bias of the springs 722, 724. Similarly, other internal passages can connect the retract manifold 196 with an area within the assembly 150, 152 below the diaphragm member 711 (as viewed in Figure 19). Thus, when compressed air from the retraction manifold 196 is applied to the area beneath the diaphragm member 711, the portion of the diaphragm member 11 surrounding the central portion 716 is pressed upwardly toward the cap 712, thereby pulling the upper portion 720 of the bolt receiver 710 upwardly into the retracted position thereby moving the bolt 200 upwardly as well.

[0176] The lock actuator 702 can include a moveable lock member 750 including a piston end 752 and a locking projection 754. The lock actuator 702 can also include a spring 756 configured to bias the lock member 750 toward a locked position, described in greater detail below. In the locked position, the projection 754 can engage one of two recesses 758, 780 so as to lock the bolts 200 in an extended position (when projection 754 engages recess 780) or a retracted position (when projection 754 engages recess 758).

[0177] The lock actuator 702 can also include a diaphragm assembly 782. The diaphragm assembly 782 includes diaphragm member 784 and a cap member 786. A locking actuator passage 788 disposed in the main body 714 provides for communication and a reciprocal sliding motion of the lock member 750 relative to the main body 714. Air passages 790 in the main body 714 allow for actuation air from the unlock manifold 198 to be guided to a space between the diaphragm member 784 and the cap 786. When air is guided

as such, a central portion 792 of the diaphragm member 784 is pressed away from the cap member 786 toward the piston head 752 of the lock member 750. Thus, such pressurized air causes the lock member 750 to slide laterally away from the cap 786 thereby moving the projection 754 away from the recesses 758, 780. In that position, the bolt receiver 710 is unlocked from any position and can reciprocate within the main body 714. The bias of the spring 722, 724, would normally bias the bolt receiver 710 towards a retracted position. However, centripetal acceleration generated during operation and rolling movement of the tire 500 can cause sufficient force on the bolt receiver 710 to overcome the bias of the spring 722, 724, thereby allowing the bolt 200 to extend outwardly. In some embodiments, the lock member 750 is configured to move along a direction transverse or perpendicular to the radial direction of the tire 500. As such, the movement of the lock member 500 is isolated from the centripetal accelerations generated during rotation of the tire 500 during operation of an associated vehicle. This can help prevent movement of the lock member 750 caused by rotation of the tire 500 during operation. Other configurations can also be used.

[0178] The spring 756, the other hand, in the absence of air pressure between the diaphragm member 784 and the cap 786, is sufficient to cause the bolt member 750 to remain in a locked position, in a position in which the projection 754 engages one of the recesses 758, 780.

[0179] The bolt assemblies 150, 152 can also include various brackets 800, 802 and flanges 804, 806 for securing the main body 714 to the tire 500. In some embodiments, the brackets 800, 802 cooperate with the flanges 804, 806 and threaded fasteners 808 to secure the bolt assembly 150 to a mounting block member 810 which provides for communication between the manifolds 194, 196, 198 and various passages on the base member 520 (described in greater detail below with reference to Figures 20-24). The brackets 800, 802 can be identical to each other. Additionally, a reinforcing member 812 can be disposed between the steel belt layer 602 and the outer tread layer 502 for enhancing the securement of the bolt assembly 150, 152 to the tire 500. The reinforcing member can be made from a thin sheet of Kevlar. In some embodiments, four layers of Kevlar can be used, for example, oriented so that their fibers extend in different directions. Other materials can

also be used. Additionally, additional rings and retainers 814 can be used to further secure the bolt assemblies 150, 152 to the tire 500.

[0180] Figures 20-24 illustrate, in greater detail, the base member 520 and the connection block 810, which together can form a base member assembly. The connection block 810, as illustrated in Figure 19, is designed to fit around the tubes 604 which partially define the manifolds 194, 196, 198. The tubes 604 can extend partially into or completely through the block 810 to provide for secure airtight engagement. Additionally, the block 810 includes internal circular recess 812 into which the base member 520 can fit. The base member 520 also includes internal passages 814, 816 and 818 for communication with the manifolds 194, 196, 198.

[0181] The base member 520 also includes a central passage 820 into which the lower portion of the main body 714 of the bolt assemblies 150, 152 engages the base member 520 for facilitating communication of compressed air in and out of the bolt assemblies 150, 152. As shown in Figure 23, air passages 814 provide communication between the manifold 198 and the unlock actuator 702. Similarly, the body 520 includes passages 816 for providing communication between the manifold 196 and the actuator 700. Further, similarly, the base member 520 includes passages 818 for providing communication of compressed air in and out of the actuator 700 for extending the bolts 200.

[0182] Optionally, the base member 520 can include anti-rotation features for preventing rotation of the base member 520 relative to the tire 500. For example, the base member 520 can include external splines or serrations 830 engaged with corresponding internal splines or serrations on the block member 810. With the serrations engaged as such, the block member 810 and the base member 520 can be securely rotationally coupled. Thus, with the block member 810 bonded or otherwise fixed to the inner surface of the tire 500, the base member 520 is rigidly fixed in place and will resist torques that may be applied, for example, when bolts 200 are turned within the bolt receivers 710.

[0183] Additionally, the base member 520 can include a peripheral lip with an under cut 842 which can be configured to provide enhanced engagement with connectors used to connect the remainder of the bolt assembly 150,152 to the base member.

[0184] For example, with reference to Figure 19, the bolt assemblies 150, 152 can include brackets 800, 802 which include ramped inner lips 801, 803 configured to engage the undercut 842 on the base member 520. More specifically, the ramped inner lips 842 can have a shape that is complementary to the undercut 842 to thereby provide a more secure attachment between the main body 714 and the base member 520.

[0185] Figures 26 and 27 further illustrate the components of the bolt assemblies 150, 152 shown in Figure 19. With reference to Figures 26 and 27, the bolt assemblies 150, 152 can also include a seal assembly 900 which can include a plurality of gland seals and gaskets for providing a sliding airtight seal between the main body 714 of the bolt assemblies 150, 152 and the moveable portions of the bolt itself, which includes the moveable bolt 200 and the bolt receiver 710. Thus, as the bolt receiver 710 moves upward and downwardly (as viewed in Figure 26), the gland seal assembly 900 maintains an airtight seal. Optionally, the gland assembly can include an ice wiper device 901 so as to scrape off ice that may accumulate on the outer surface of the bolt 200 as the bolt 200 is retracted, thus protecting the glands disposed within the gland seal assembly 900. Additionally, as noted above, the moveable bolts 200 can include a bolt body 902, and a replaceable tip portion 904. The bolt body 902 can include external threads and the inner surface of the bolt receiver 710 can include internal threads so that the bolt body 902 can be axially adjusted relative to the bolt receiver 710. Additionally, the bolt body 902 can further include a lower recess 906 with internal threads which cooperate with external threads on the removable tip portion 904. As such, the removable tip portion 904 can be conveniently removed and replaced. As such, maintenance of such an adaptive tire system can be reduced by providing for inexpensive replacement tips 904.

[0186] Additionally, the bolt assemblies 150, 152 can include one or more passages 903 configured to aid in maintenance and are particularly useful in adding lubrication. For example, the bolt receiver 710 can include one or more apertures 903 connecting the inner recess having internal threads for receiving the external threads of the bolt 200 to the outer surface of the bolt receiver 710. Thus, if the bolt is unscrewed or otherwise removed from the bolt receiver 710, lubricants can be disposed in the recess or on an upper end of the bolt 200 and thereafter the bolt 200 can be threaded into the recess of the

as such, lubricant can be pressed through the aperture 903 and into the space within the main body 714 and onto the outer surface of the bolt receiver 710, which can thereby assist in lubricating the glands in the gland assembly 900, as well as other services within the main body 714. This can be particularly beneficial because such removal and addition of lubrication can be performed from the exterior of the wheel 500. In other words, it is not necessary to remove the tire 500 from its associated rim in order to remove the bolts 200 or add lubricant to the inside of the bolt assembly 150, 152.

[0187] Further benefits can be achieved by providing the within additional internal passage 910 extending upwardly from the bolt receiving recess and opening into the ends of the recesses 758, 780 of the bolt receiver. For example, if the bolt receiver 710 or the lock mechanism 702 becomes stuck, the bolt 200 can be removed from the bolt receiver 710 in the tool can be inserted into the passage 910 and into contact with a tip of the projection 754 so as to dislodge the lock member 750. Thus, such a feature enhances the serviceability of the bolt assemblies 150, 152.

[0188] With continued reference to Figure 27, the recess 758 and the projection 754 can include complementarily sloped faces to aid in smooth operation and prevent excessive friction. For example, the recess 758 can include opposing lateral faces 757, 759 which are sized and shaped to cooperate with faces 753, 755 of the projection 754. The faces 757, 759 are sloped such that the faces 757, 759 are splayed away from each other such that the recess 758 is slightly trough shaped. Similarly, the faces 753, 755 of the projection 754 are sloped such that the projection 754 is slightly wedge-shaped. The faces 757, 759 and faces 753, 755 can be selected generally the same angle for example, but without limitation about 7°. Other angles can also be used. Such sloping of the faces 757, 759, 753, 755, as noted above, helps prevent excessive friction between the faces so as to better ensure smooth operation and movement of the lock member 750 between locked and unlocked positions. Additionally, if the lock member 750 becomes stuck with the bolt 200 in the extended position, the tire can be rolled over a road surface (e.g., by moving the associated vehicle), such as to provide some axial force in the retraction direction of the bolt 200, will help exert some lateral force on the lock member 750 through the sloped faces 753, 755, 757, 759 in the unlocking direction of movement of the lock member 750.

[0189] Figures 28 and 29 illustrate a fully assembled adaptive wheel 104 (described in more general terms with reference to Figure 1). The wheel 104 includes the manual interface 118 which incorporates manual valve lever 950 for operating the extend valve 178, lever 952 for operating the valve 180 (Figure 1) and lever 954 for operating the unlock valve 182 (Figure 1).

[0190] With continued reference to Figures 2A, 11, 12, 28 and 29, the levers 950, 952, 954 can be used to control the flow of compressed air in and out of the bolt assemblies 150, 152. As noted above with regard to Figure 11, certain components such as the supply lines 523, 525, 527 are secured in place partially by the coupling members 522, 524, 526.

[0191] Figures 30 and 31 show a more detailed view of the valves 178, 180, 182 and their connections to the high-pressure reservoir 176, which is in the form of a loop and the vent reservoir 184 which is also in the form of a loop. Each of the loops 176, 184 can be formed with a plurality of tubes and connectors, as is within the skill of one of ordinary skill in the art.

[0192] Figures 32-34 illustrate more detailed views of the flexible pivoting bundles 304 initially described above with reference to Figure 3 of the external unions 310. As shown in Figure 32, the unit 310 can include a rotary union output assembly 950 and a rotary union input assembly 952. The rotary union output assembly 950 is connected to three pneumatic lines within the bundle 304. A rotary union output assembly 950 includes three internal channels for politically communicating the pneumatic lines within the bundle 304 to the input assembly 952.

[0193] The input assembly 952 is fixed to the rim of the vehicle wheel 104B and is rotatable relative to the rotary union output assembly 950. The structure and operation of rotary unions is well known in the art. Thus, further detail about the internal construction of the rotary union 310 is not described in greater detail herein. However, one of ordinary skill in the art understands that the manifolds 194, 196, 198 are connected to the vehicle wheel 104B through three fluidic channels that extend from the rotary union output assembly 150 into the rotary union input assembly 952 and can operate whether the vehicle and thus the vehicle wheel 104B is moving or stationary.

[0194] Figures 35 and 36 illustrate more detailed views of the flexible bundles 304 used for the front steerable wheels, initially described above with reference to Figure 3.

[0195] Finally, Figures 37-40 illustrate additional more-detailed views of the internal rotary union units 310C initially described above with reference to Figure 4. Similarly to the rotary union unit 310, the rotary union unit 310C includes a rotary union output assembly 950C and a rotary union input assembly 952C. As with the above described rotary union unit 310, the rotary union unit 310C also connects the manifolds 194, 196, 198 with the various components within the vehicle wheel 104C through three fluidic channels extending from the rotary union output assembly 950C into the rotary union input assembly 952C.

[0196] Optionally, the rotary union units 300 or 300C can include retractable/expandable seals. For example, known rotary unions include seals that are in continuous contact with sliding surfaces within the union. In the illustrated environment of use, the rotary union units 300 and 300C are used infrequently; only during extension and retraction operations. The rotary union units 300 and 300C are not used when the bolts 200 are held in either the retracted or extended positions. Thus, there is no need for the rotary union units 300, 300C to achieve the air seals that are necessary for their operation when no extension or retraction operations are being performed. By retracting the seals when the rotating union units 300 300C are not being used reduced the wear that would normally occur, thereby dramatically increasing the useful life of the seals.

[0197] The rotary union units 300 or 300C can include any type of actuators for expanding and retracting the seals. In some embodiments, the seals can be pneumatically or hydraulically operated. Additional benefits can be achieved where the seals are controlled by the same pressurized air used for operating the bolt assemblies 150, 152. Optionally, the units 300 300C can include a pressure intensifier device to expand the seals more rapidly when air pressure is applied to the seals.

[0198] As is well known in the art, rotary unions include seals sized to fit and seal the stator grooves to the rotary union rotor. The rotary union units 300, 300C can include an expandable seal unit configured to be selectively expandable.

[0199] For example, with reference to Figure2 41-43, the rotary union 300C includes three inputs for connections to the manifolds 178B, 180B and 182B which open into three circumferential stator grooves 961, 962, 964, respectively. Seals 966, 968, 970, and 972 surround each of the three grooves 961, 962, 964 and press against both the stator body 974 and the rotor 976 which rotates with the wheels of an associated vehicle. Seal 966 is illustrated in Figures 42 and 43, but it is to be understood that the illustrations and descriptions of seal 966 also apply to seals 968, 970, 972.

[0200] The seals 966, 968, 970, 972 can be configured to be expandable. For example, the seals 966, 968, 970, 972 can be in the form of hollow, internal cylindrical cross section donuts made of low friction inert plastic PTFE, sized to fit and seal stator groove, and a few thousandths of an inch larger than rotary union rotor diameter. Optionally, the seals 966, 968, 970, 972 can have a rectangular or square-shaped cross-section. Additionally, the seals 966, 968, 970, 972 can be configured to be inflatable such that the surface 965 at the inner diameter of the seal 966 decreases with inflation, at least enough to make a functional seal against the outer surface 967 of the rotary union rotor. Optionally, the seals 966, 968, 970, 972 can include a molded, threaded metal hollow stem 990 extending beyond the stator external surface when passed through an opening from the stator grooves sufficient for a gasket seal washer (not shown), metal washer 992, and nut 994. The seals 966, 968, 970, 972 can also include a metal blade spring 996, which can extend 60 degrees to either side of hollow metal threaded stem 990 to support the seals 966, 968, 970, 972 in the stator seal groove and to reduce contact with the rotor 976 when the seals 966, 968, 970, 972 are not pressurized. The blade spring 996 can be within the molded doughnut seal 966, which can have a square or rectangular cross-section. Additionally, the blade spring 996 can be biased so as to press the outer surface 998 of the seal 966 against the inner surface of the stator seal groove 999.

[0201] Optionally, the units 300, 300C can include a common seal manifold 978 which can be disposed at the stator body 974. The manifold can include an input side connected to the manifolds 194B, 196B, 198B with check valves 980, 982, 984, respectively. Thus, when any of the manifolds 194B, 196B, 198B are pressurized, then the seals 966, 968, 970, 972 are also pressurized and thereby inflated. The seals 966, 968, 970, 972 can be

appropriately and timely inflated even if only the unlock and extend manifolds (198B, 194B) are connected to the seal manifold 978.

[0202] During operation, the seals 966, 968, 970, 972 can be initially pressurized by a flow of compressed air in the unlock manifold 198B. This manifold 198B should always be pressurized first since the bolts 200 should be unlocked first before movement is attempted. Pressure to the manifold 978 can be maintained after unlock manifold 198B is vented, by the extend manifold 194B for example, at the end of an extend operation.

[0203] Optionally, the rotary union units 300, 300C can also include a pressure intensifier 986 configured to intensify the pressure discharged from the check valves 980, 982, 984. Output pressure from the intensifier 986 is designed to cause a pressure adequate to pressurize the seals 966, 968, 970, 972 with a typical 8 % to10 % material compression.

[0204] When unpressurized, the inside diameters of the seals 966, 968, 970, 972 are a few thousandths of an inch larger than the outer diameter of the rotor 976. Optionally, an embedded flat steel spring, as noted above, can be attached to threaded hollow metal seal stem and can extend 60 degrees either side of seal stem, at the outer diameter of seal internal passage cross section so as to provide support for the seals 966, 968, 970, 972 in the stator grooves 961, 962, 964.

[0205] Pressurized seals are thus exposed to other than minor rotational wear only when one or more of three incoming manifolds 194B, 196B, 198B are pressurized, which being a small (low single digit) percentage of time allows for an inverse increase of seal useful life compared to a continuously functioning compressed seal along with an associated increase in seal and rotary union functional reliability.

[0206] Optionally, a bleed valve 1000 can be connected to the outputs of check valves 980, 982, 984 so as to slowly bleed pressure from the seal manifold 978. As such, after all operations have ceased such that no pressurized air is provided to the check valves 980, 982, 984, pressurized air can bleed from the manifold 978 to allow the seals 966, 968, 970, 972 to deflate and thus retract, as described above.

[0207] Also optionally, a back pressure device 1002 can be provided on the upstream side of the check valves 980, 982, 984 so as to provide additional back pressure

during initiation of an operation, to thereby speed the inflation of the seals 966, 968, 970, 972.

[0208] While at least one exemplary embodiment has been presented in the foregoing detailed description, it should be appreciated that a vast number of variations exist. It should also be appreciated that the exemplary embodiment or embodiments described herein are not intended to limit the scope, applicability, or configuration of the claimed subject matter in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing the described embodiment or embodiments. It should be understood that various changes can be made in the function and arrangement of elements without departing from the scope defined by the claims, which includes known equivalents and foreseeable equivalents at the time of filing this patent application.

CLAIMS:

1. A tire system comprising:

a tire having a tread surface and a sidewall;

a retract module

a bolt mounted to the tire so as to be movable along a radial direction relative to the tread surface between a retracted position and an extended position, the bolt being retracted within the tire when in the retracted position and extending through the tread surface when in the extended position, the tire being configured such that the bolt is moved from the extended position to the retracted position by a first actuation force generated using the retract module and applied to the bolt from within the tire;

a lock mechanism movable between a locked position and an unlocked position in response to a second actuation force, the lock mechanism being configured to mechanically lock the bolt in the retracted position and in the extended position, wherein the lock mechanism is biased toward the locked position with a biasing device such that the lock mechanism remains in the locked position.

2. The tire system according to claim 1 additionally comprising an extension actuator configured to apply a third actuation force to the bolt so as to move the bolt from the retracted position to the extended position.

3. The tire system according to claim 1 additionally comprising a retraction actuator configured to apply the first actuation force to the bolt so as to move the bolt from the extended position to the retracted position.

4. The tire system according to claim 1 additionally comprising at least first and second manifolds extending along an inner circumferential surface of the tire, the first and second manifolds being isolated from an interior volume of the tire.

5. The tire system according to claim 4 additionally comprising an actuator configured to move the bolt from the retracted position to the extended position, wherein the first manifold is connected to the lock mechanism and the second manifold is connected to the actuator.

6. The tire system according to claim 5 additionally comprising a third manifold connected to the actuator and configured to either provide the first actuation force for moving the bolt from the extended position to the retracted position or to provide a vent to atmosphere from the actuator interior.

7. The tire system according to claim 4 wherein the first and second manifolds are disposed on a first side of a centerline of the tire, a third manifold and a fourth manifold extending circumferentially around the inner surface of the tire and disposed on a second side of the centerline of the tire, opposite the first side.

8. The tire system according to claim 7 additionally comprising a fifth manifold extending parallel to the first and second manifolds and disposed on the first side of the centerline and additionally comprising a sixth manifold extending parallel to the third and fourth manifolds and disposed on the second side of the centerline.

9. The tire system according to claim 1, wherein the bolt comprises at least a bolt carrier portion and a bolt body partially enclosed by the bolt carrier portion, the bolt carrier portion being disposed proximally to a radial center of the tire and the bolt body being disposed distally from the radial center of the tire, the bolt body being connected with the bolt carrier portion so as to provide for effective adjustment of the overall length of the bolt.

10. The tire system according to claim 1, wherein the bolt comprises at least a bolt body portion and a bolt tip portion releasably engaged with the bolt body portion.

11. The tire system of claim 1, wherein the bolt is mounted to a bolt carrier partially enclosing the bolt and configured to move with the bolt along the radial direction between the retracted

position and the extended position, the bolt being mounted to the bolt carrier by an adjustable connection enabling the bolt to be connected to the bolt carrier in at least a first position and a second position relative to the bolt carrier.

12. The tire system of claim 11, wherein the bolt protrudes a first distance from the bolt carrier in the first position, and by a second distance lesser or greater than the first distance in the second position.

13. The tire system of claim 11, wherein the adjustable connection comprises internal threads on the bolt carrier, and external threads on the bolt.

14. The tire system of claim 11, wherein the adjustable connection is further configured to enable removal of the bolt from the bolt carrier from the outside of the tread surface.

15. The tire system of claim 11, wherein the bolt comprises a bolt body disposed proximally to a radial center of the tire and a bolt tip disposed distally from the radial center of the tire, the bolt tip being removable from the bolt body.

16. The tire system of claim 1, further comprising at least one reinforcing belt, the at least one reinforcing belt including a plurality of apertures and a corresponding plurality of reinforcing rings attached to the at least one reinforcing belt, each of the plurality of apertures being surrounded by a respective one of the corresponding plurality of reinforcing rings.

17. The tire system of claim 16, wherein the at least one reinforcing belt comprises steel wires, each of the plurality of apertures interrupting some of the steel wires and resulting in interrupted steel wires having terminal ends disposed at a periphery of each of the plurality of apertures.

18. The tire system of claim 17, wherein the corresponding plurality of reinforcing rings are configured to route forces between the terminal ends of the interrupted steel wires.

19. The tire system of claim 17, wherein the corresponding plurality of reinforcing rings are welded to the steel wires.

20. The tire system of claim 16, further comprising another plurality of reinforcing sheet members corresponding to the plurality of apertures, each of the plurality of apertures being surrounded by a respective one of the another plurality of reinforcing sheet members.

21. The tire system of claim 20, wherein the another plurality of reinforcing sheet members are disposed between the at least one reinforcing belt and the tread surface.

22. The tire system of claim 20, wherein each of the another plurality of reinforcing sheet members comprise multiple layers of a fiber material.

23. The tire system of claim 20, wherein each of the another plurality of reinforcing sheet members comprises multiple layers of a fiber material, each layer of the multiple layers having its fibers oriented in a different direction from other layer of the multiple layers.

24. The tire system of claim 20, wherein each of the another plurality of reinforcing sheet members comprises strands of material oriented radially, axially, bias to the right, and bias to the left, and wherein the another plurality of reinforcing sheet members is bonded into the tire.

25. The tire system of claim 20, wherein each of the another plurality of reinforcing sheet members comprises strands of KEVLAR® material oriented so that their fibers extend in different directions, and wherein the another plurality of reinforcing sheet members is bonded into the tire.

26. The tire system according to claim 1, wherein the lock mechanism remains in the locked position without a need for a continuous application of any other force.

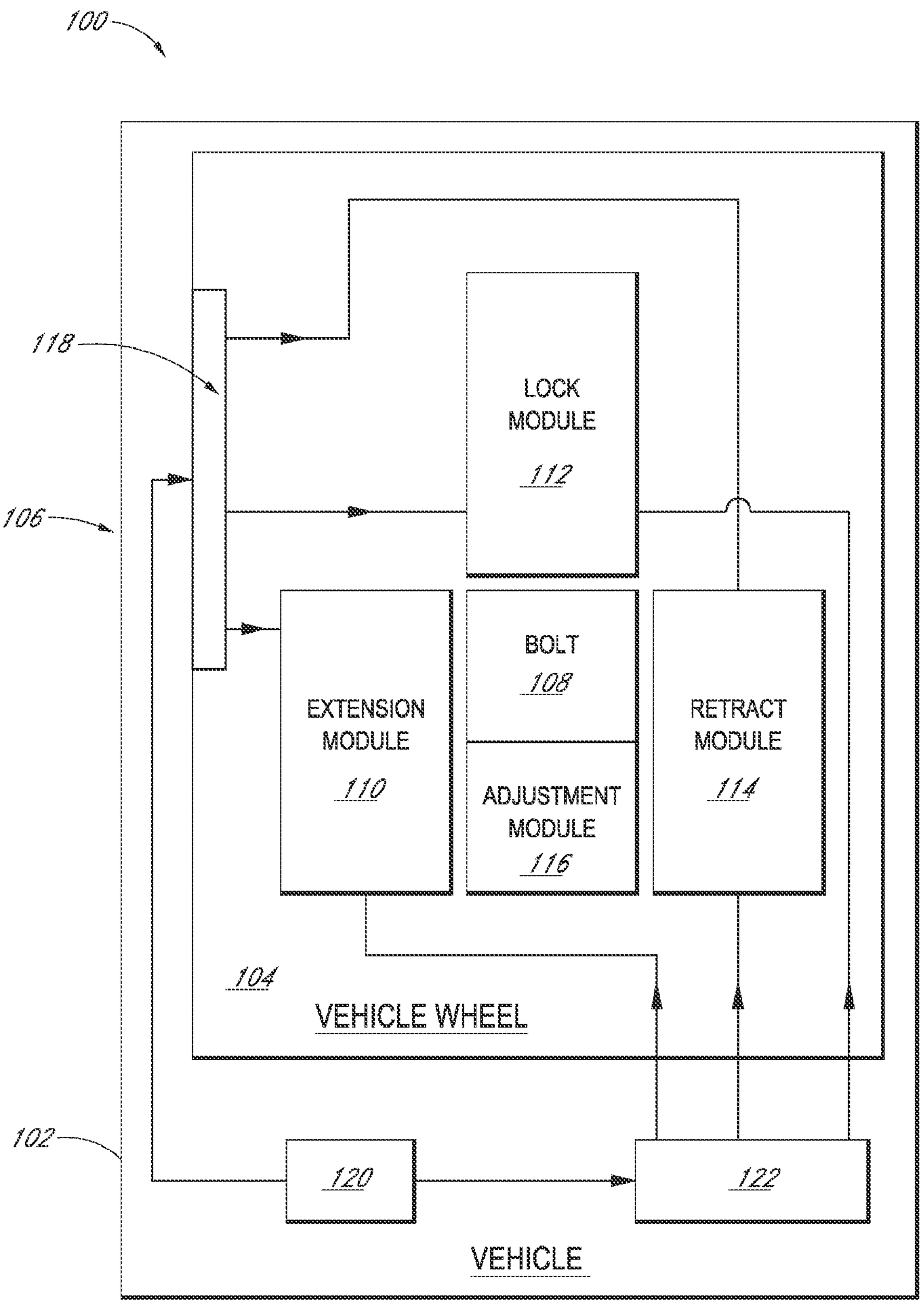
100
118
106
LOCK MODULE
112
EXTENSION MODULE
110
BOLT
108
ADJUSTMENT MODULE
116
RETRACT MODULE
114
104
VEHICLE WHEEL
102
120
122
VEHICLE

FIG. 1

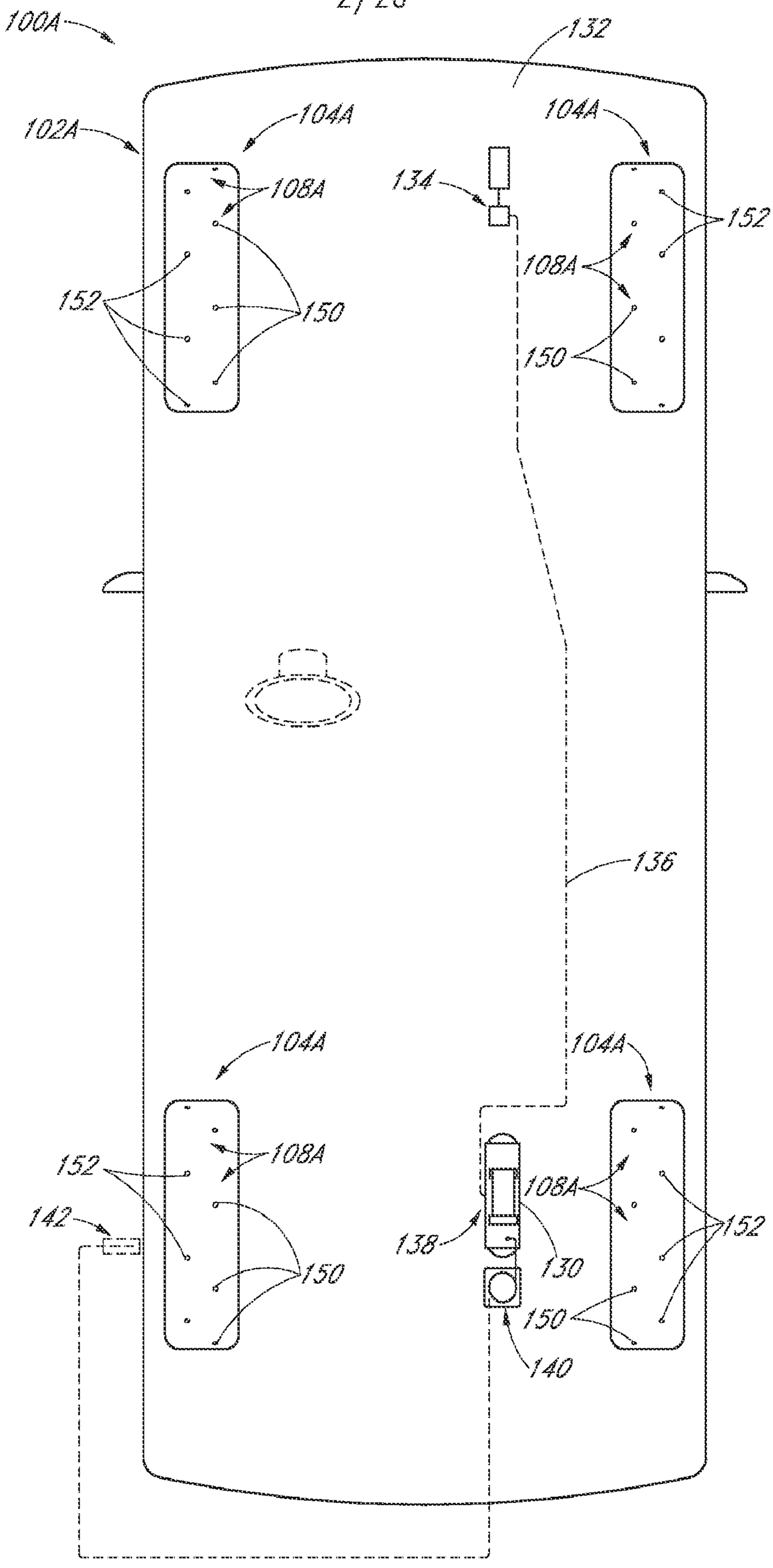
100A
132
102A
104A
104A
108A
134
152
152
108A
150
150
136
104A
104A
108A
108A
152
142
138
130
150
150
140

FIG. 2

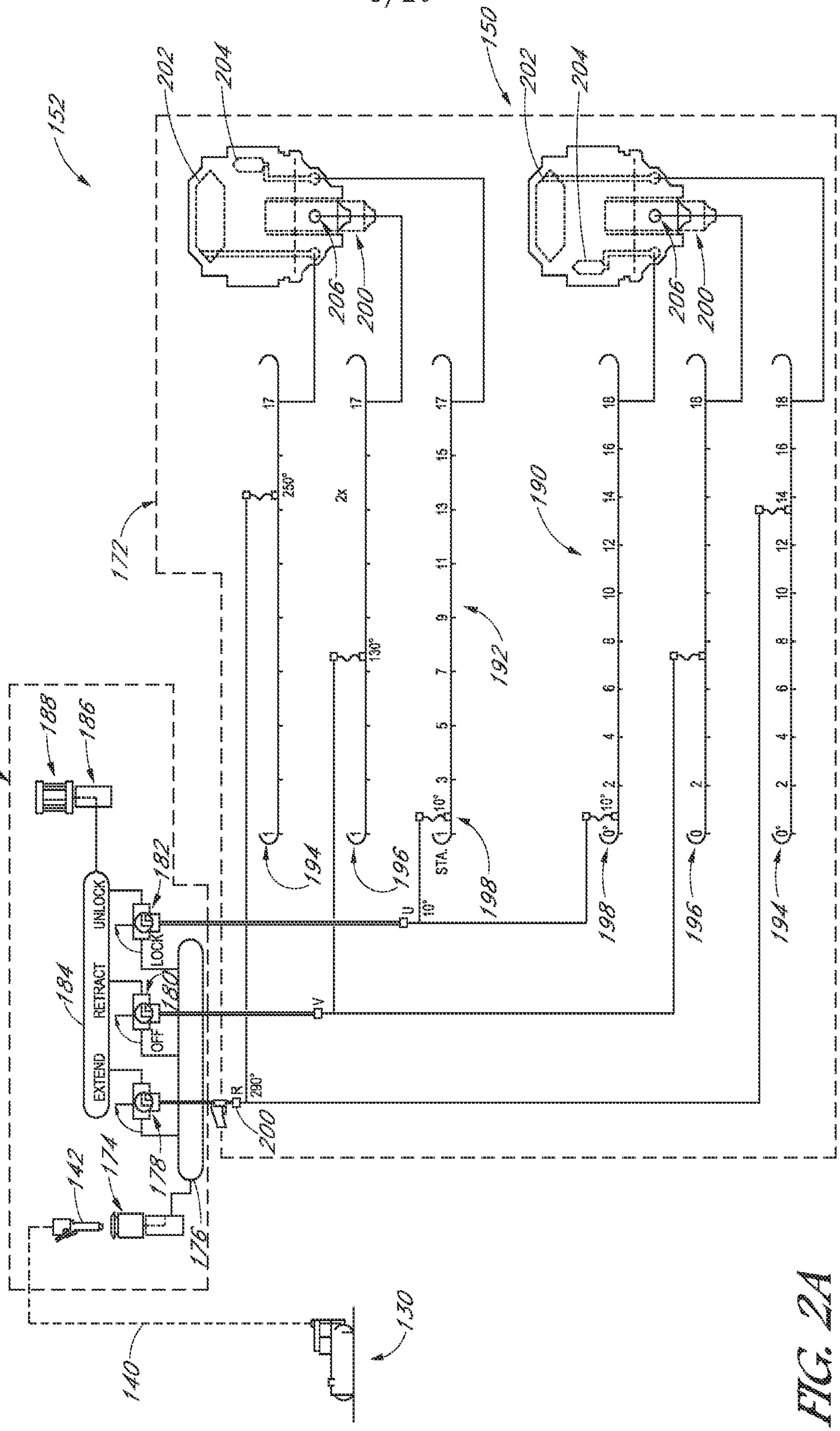
152
150
202
204
206
200
172
190
192
194
196
198
170
118
188
186
182
184
180
174
142
178
176
140
130
EXTEND
RETRACT
UNLOCK
LOCK
OFF
STA.
250°
290°
130°
10°
2x

FIG. 2A

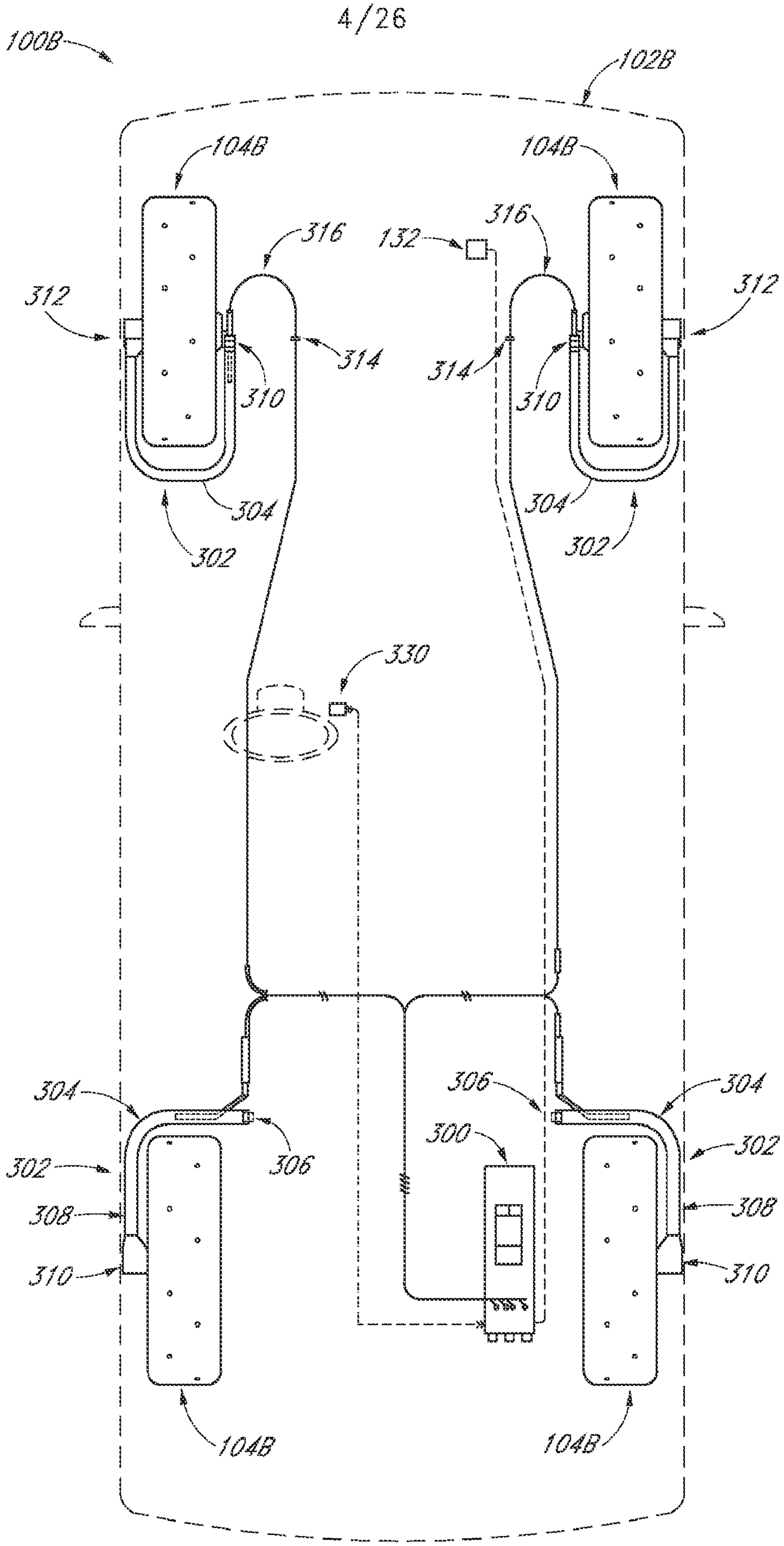
100B
102B
104B
104B
316
316
132
312
312
314
314
310
310
304
304
302
302
330
304
306
306
304
300
302
302
308
308
310
310
104B
104B

FIG. 3

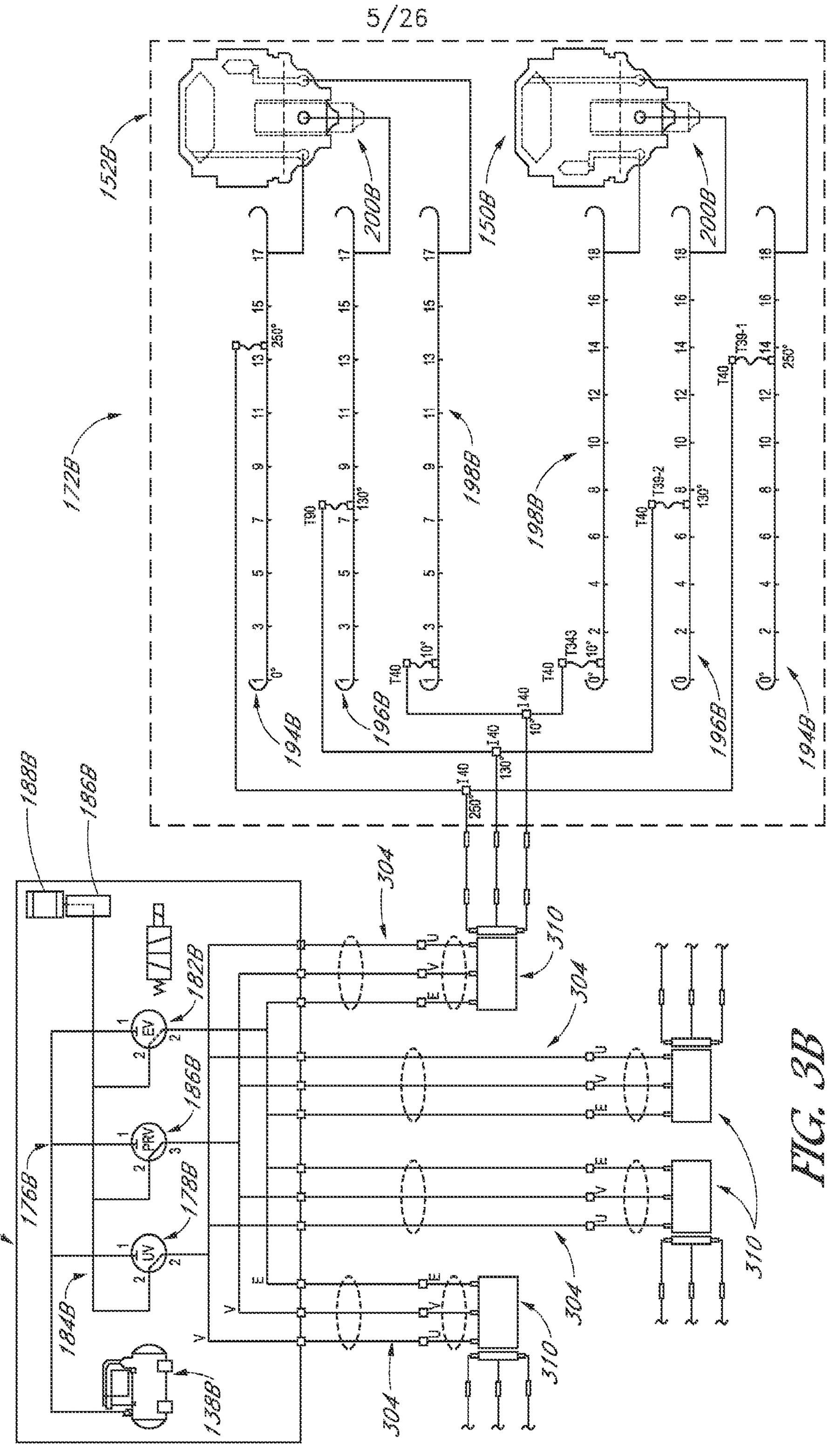
152B
150B
200B
200B
172B
198B
198B
194B
196B
196B
194B
188B
186B
304
310
182B
186B
304
310
176B
178B
184B
138B
304
310
300

FIG. 3B

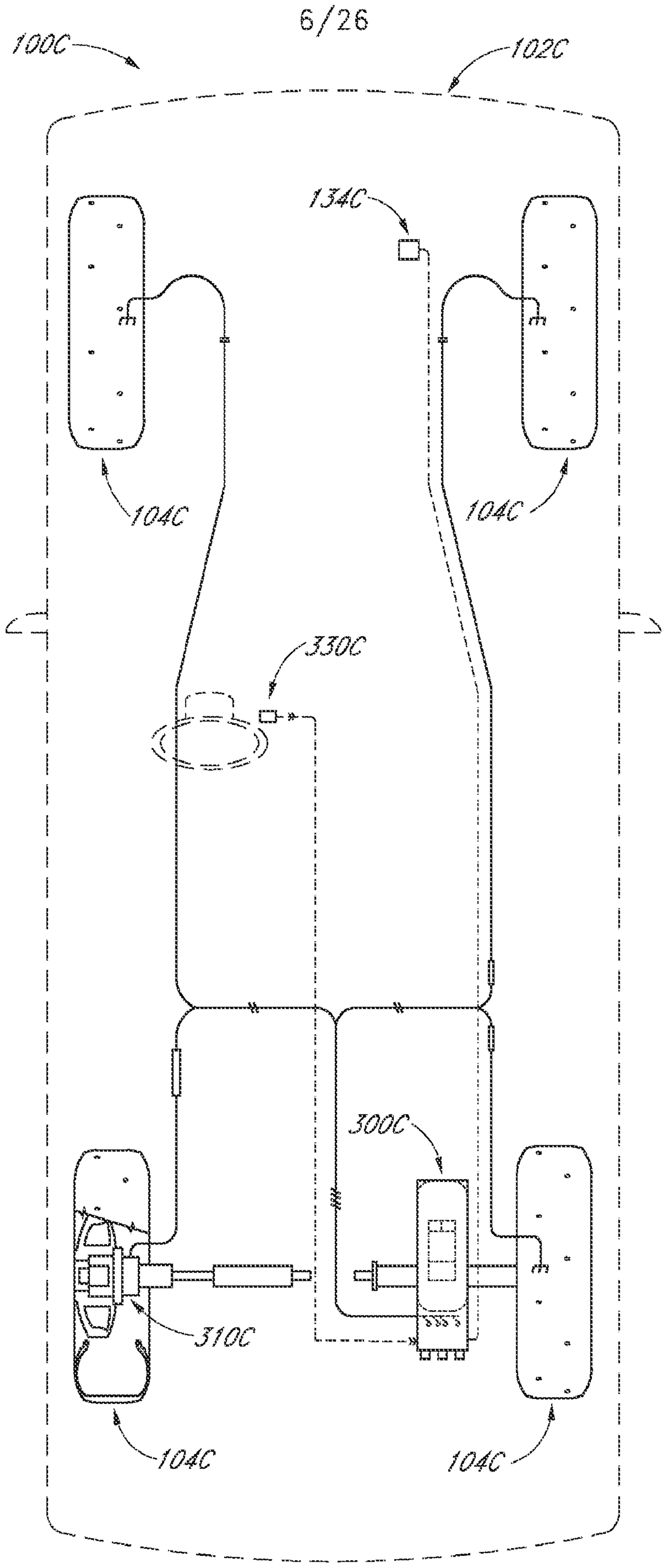

FIG. 4

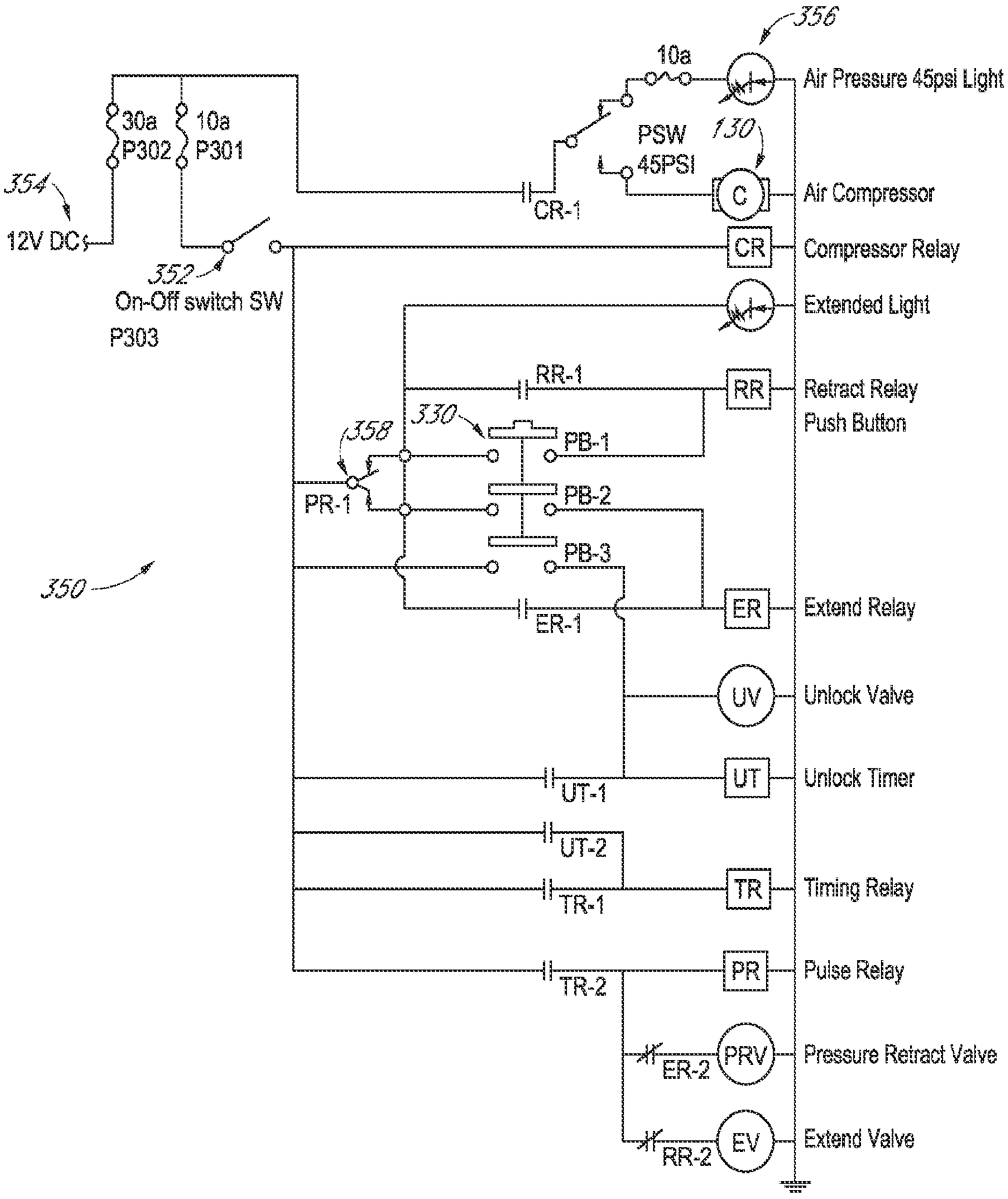
356
10a
Air Pressure 45psi Light
30a
P302
10a
P301
PSW
45PSI
130
354
12V DC
CR-1
C
Air Compressor
CR
Compressor Relay
352
On-Off switch SW
P303
Extended Light
RR-1
RR
Retract Relay
330
Push Button
358
PB-1
PR-1
PB-2
PB-3
350
ER
Extend Relay
ER-1
UV
Unlock Valve
UT
Unlock Timer
UT-1
UT-2
TR
Timing Relay
TR-1
PR
Pulse Relay
TR-2
PRV
Pressure Retract Valve
ER-2
EV
Extend Valve
RR-2

FIG. 5

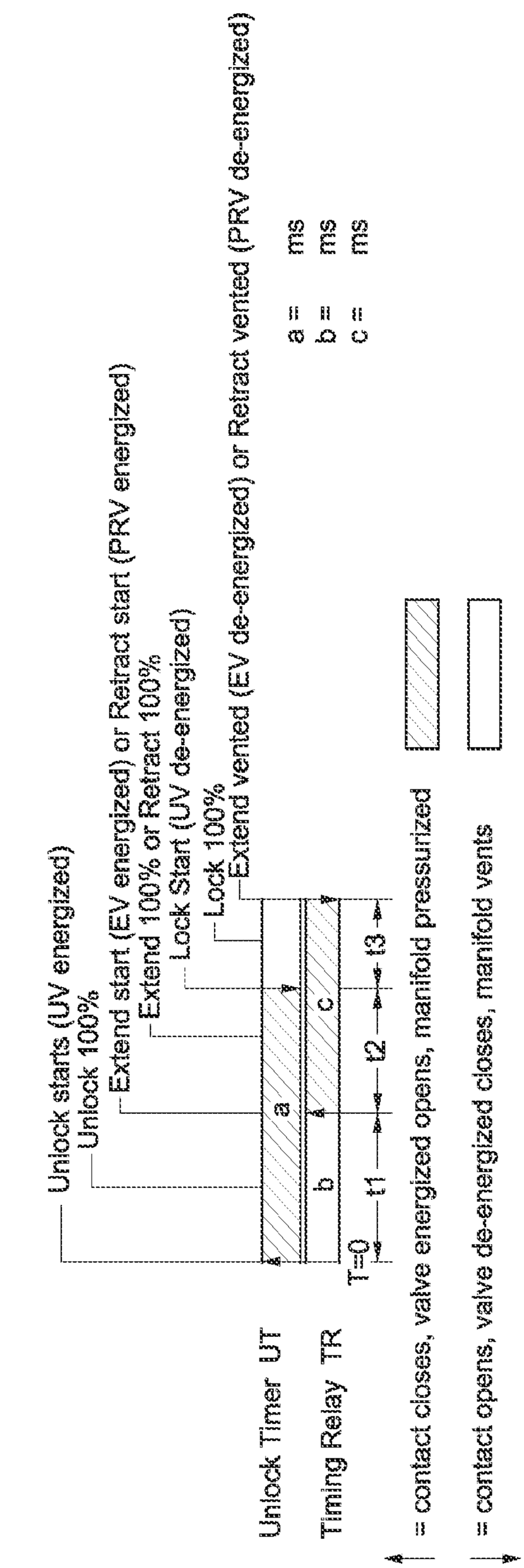
Unlock starts (UV energized)
Unlock 100%
Extend start (EV energized) or Retract start (PRV energized)
Extend 100% or Retract 100%
Lock Start (UV de-energized)
Lock 100%
Extend vented (EV de-energized) or Retract vented (PRV de-energized)
a
b
c
T=0
t1
t2
t3
UT
TR
a = ms
b = ms
c = ms
Unlock Timer UT
Timing Relay TR
= contact closes, valve energized opens, manifold pressurized
= contact opens, valve de-energized closes, manifold vents

FIG. 4

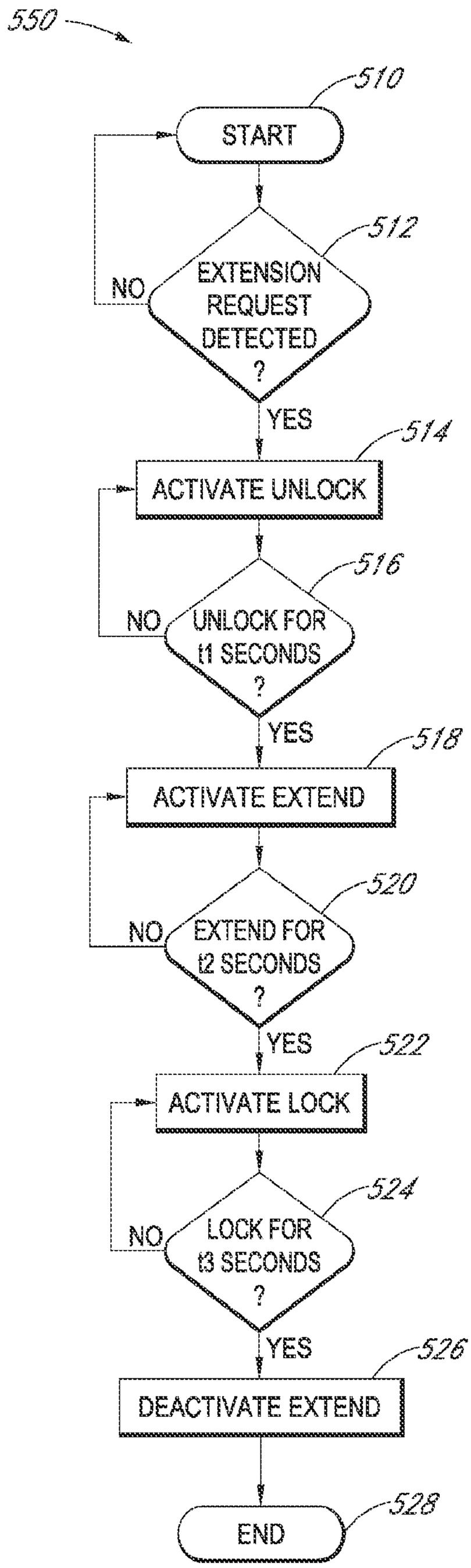
550
510
START
512
EXTENSION REQUEST DETECTED ?
NO
YES
514
ACTIVATE UNLOCK
516
UNLOCK FOR t1 SECONDS ?
NO
YES
518
ACTIVATE EXTEND
520
EXTEND FOR t2 SECONDS ?
NO
YES
522
ACTIVATE LOCK
524
LOCK FOR t3 SECONDS ?
NO
YES
526
DEACTIVATE EXTEND
528
END

FIG. 6B

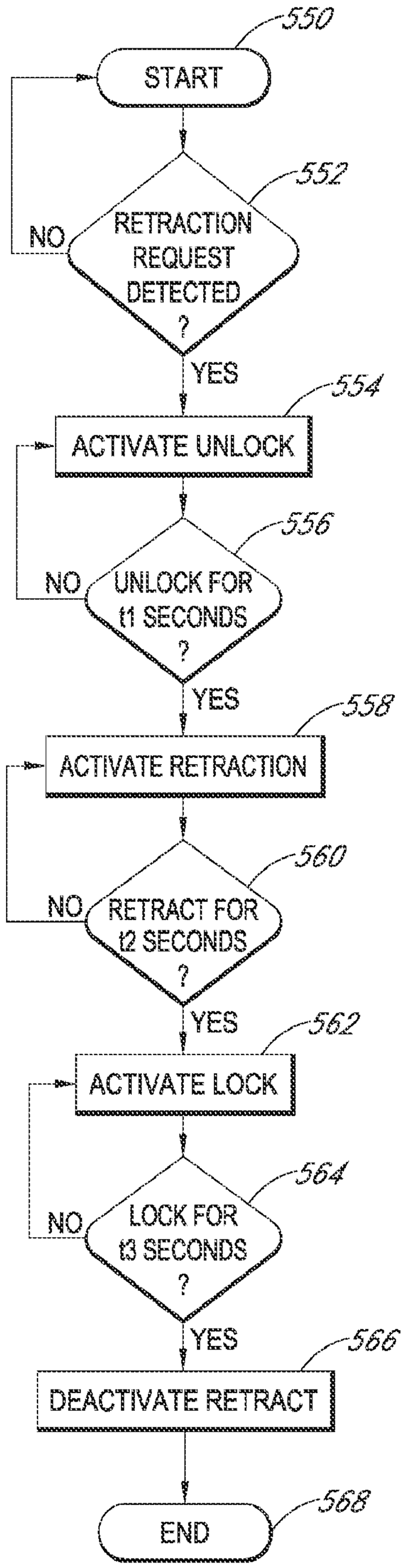
550
START
552
RETRACTION REQUEST DETECTED ?
NO
YES
554
ACTIVATE UNLOCK
556
UNLOCK FOR t1 SECONDS ?
NO
YES
558
ACTIVATE RETRACTION
560
RETRACT FOR t2 SECONDS ?
NO
YES
562
ACTIVATE LOCK
564
LOCK FOR t3 SECONDS ?
NO
YES
566
DEACTIVATE RETRACT
568
END

FIG. 6C

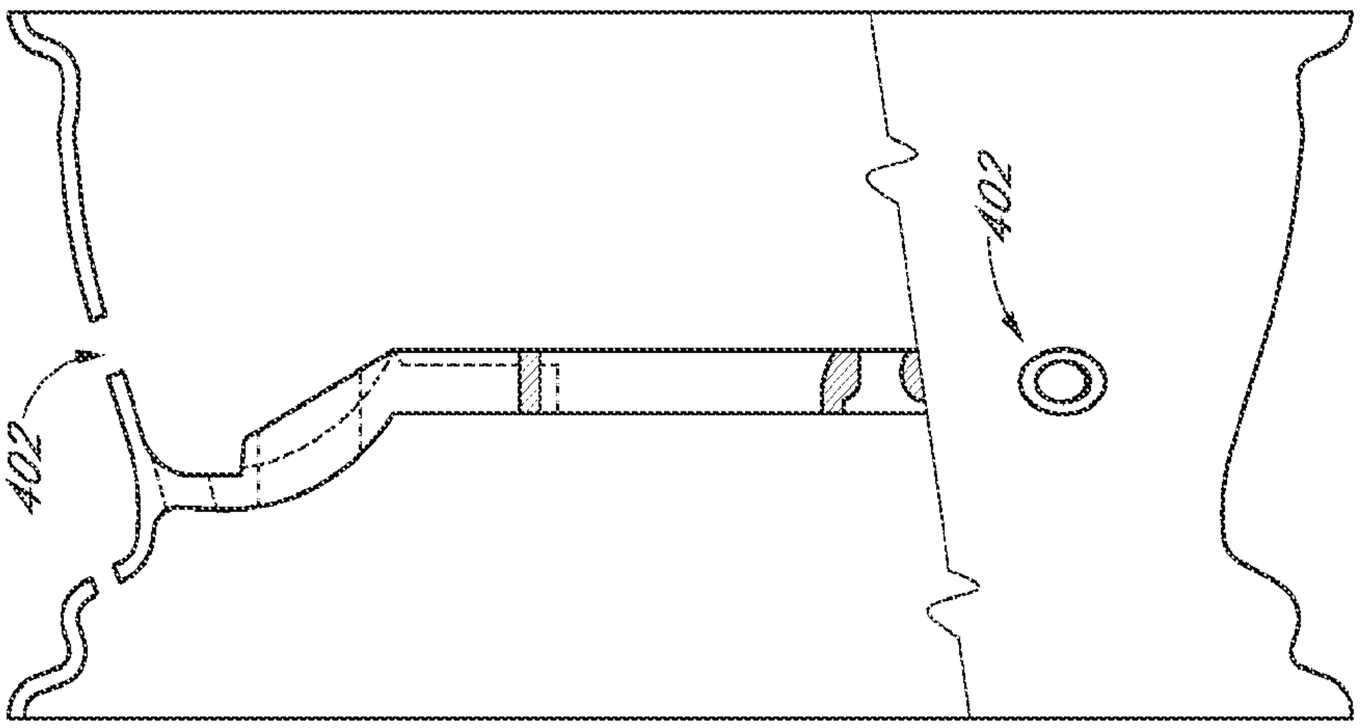

FIG. 8

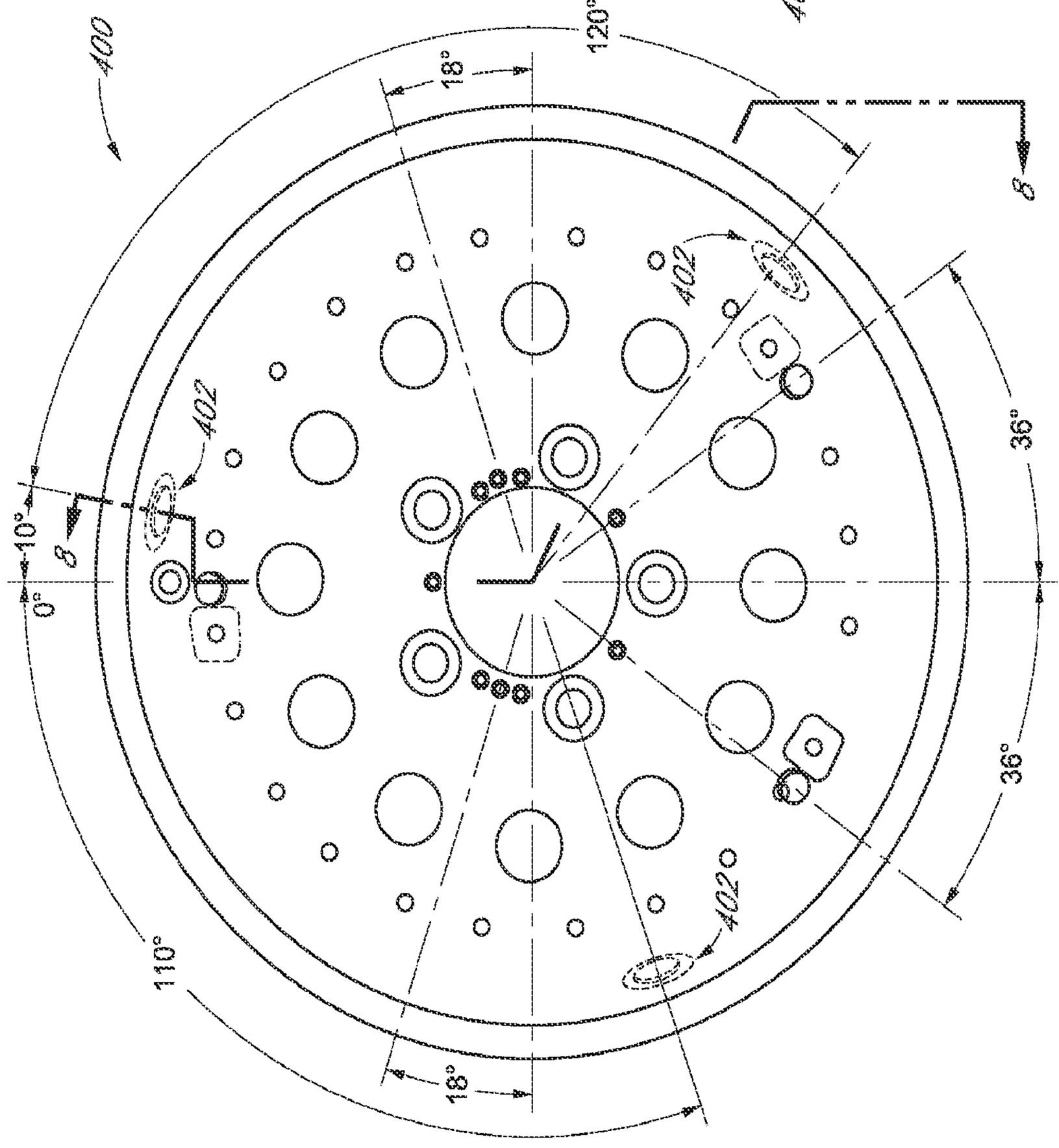

FIG. 7

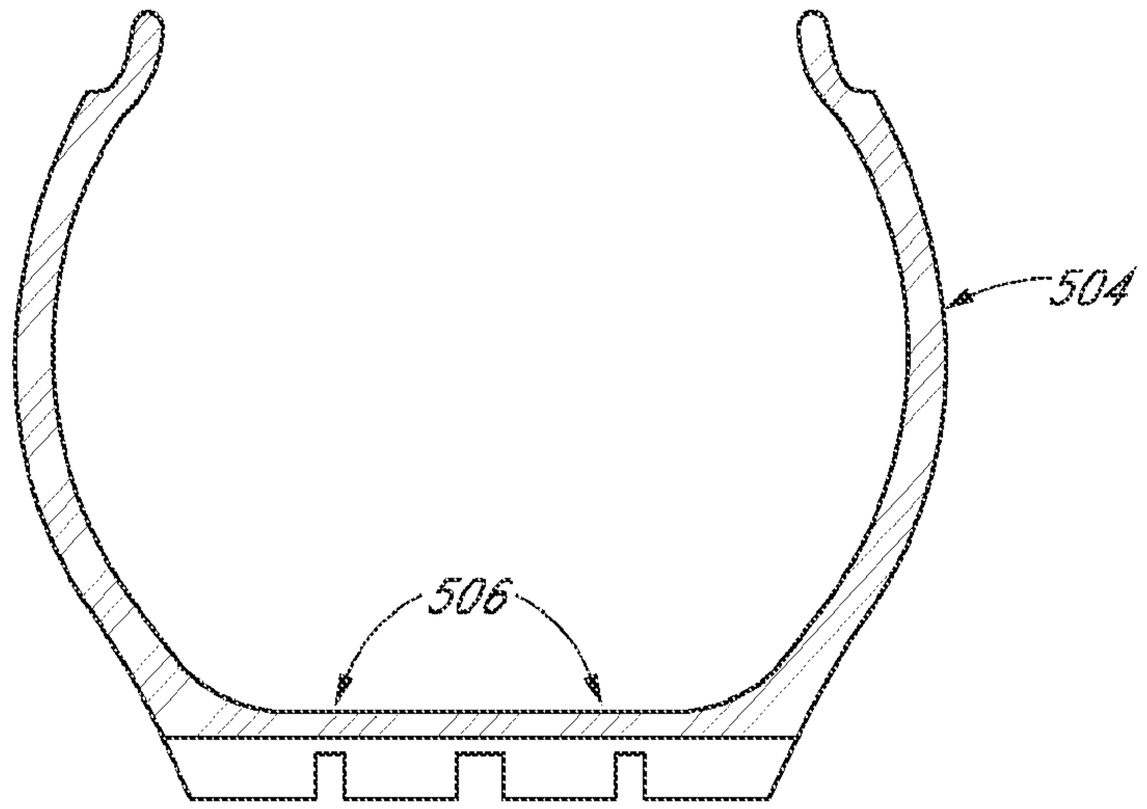

FIG. 10

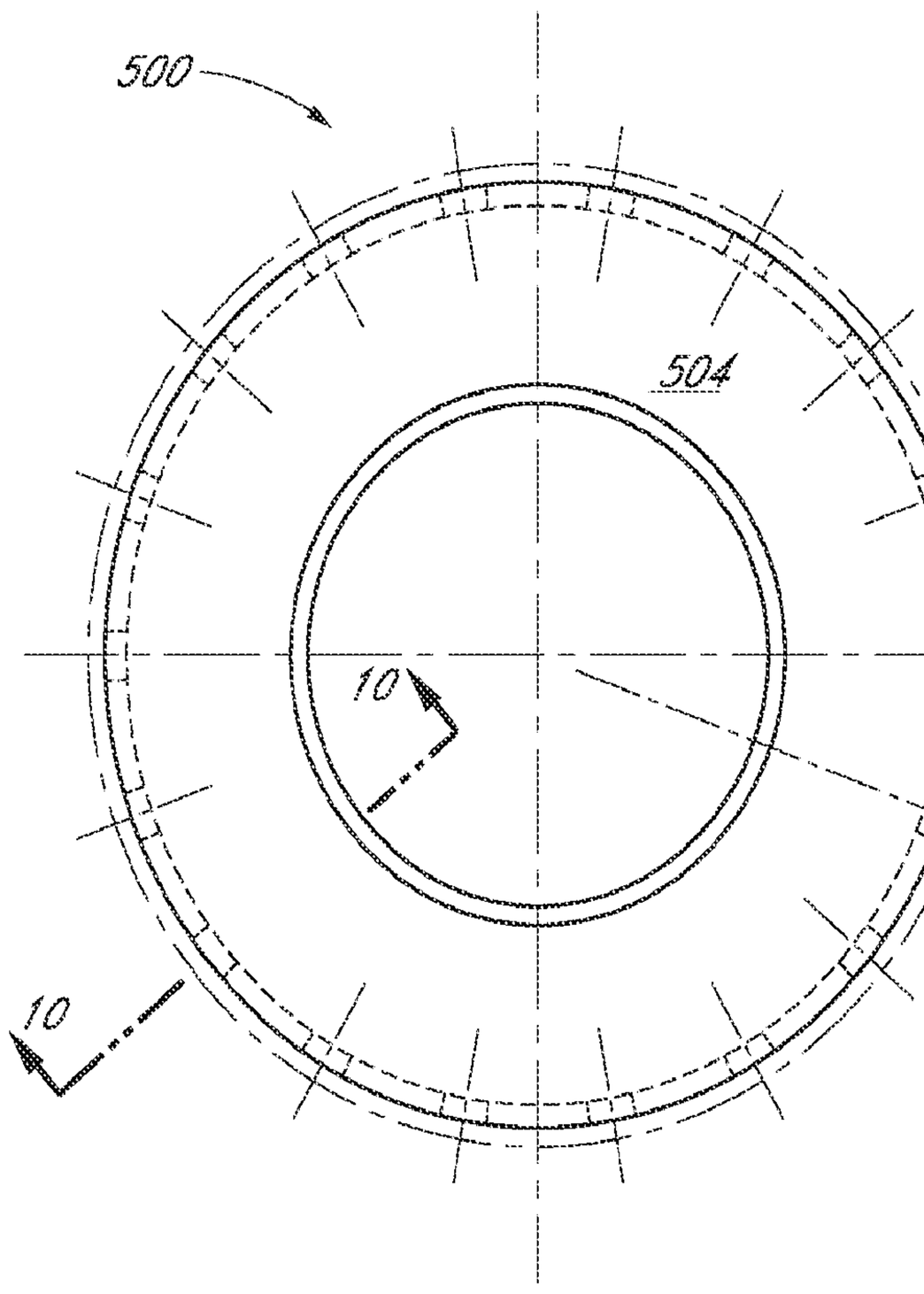

FIG. 9

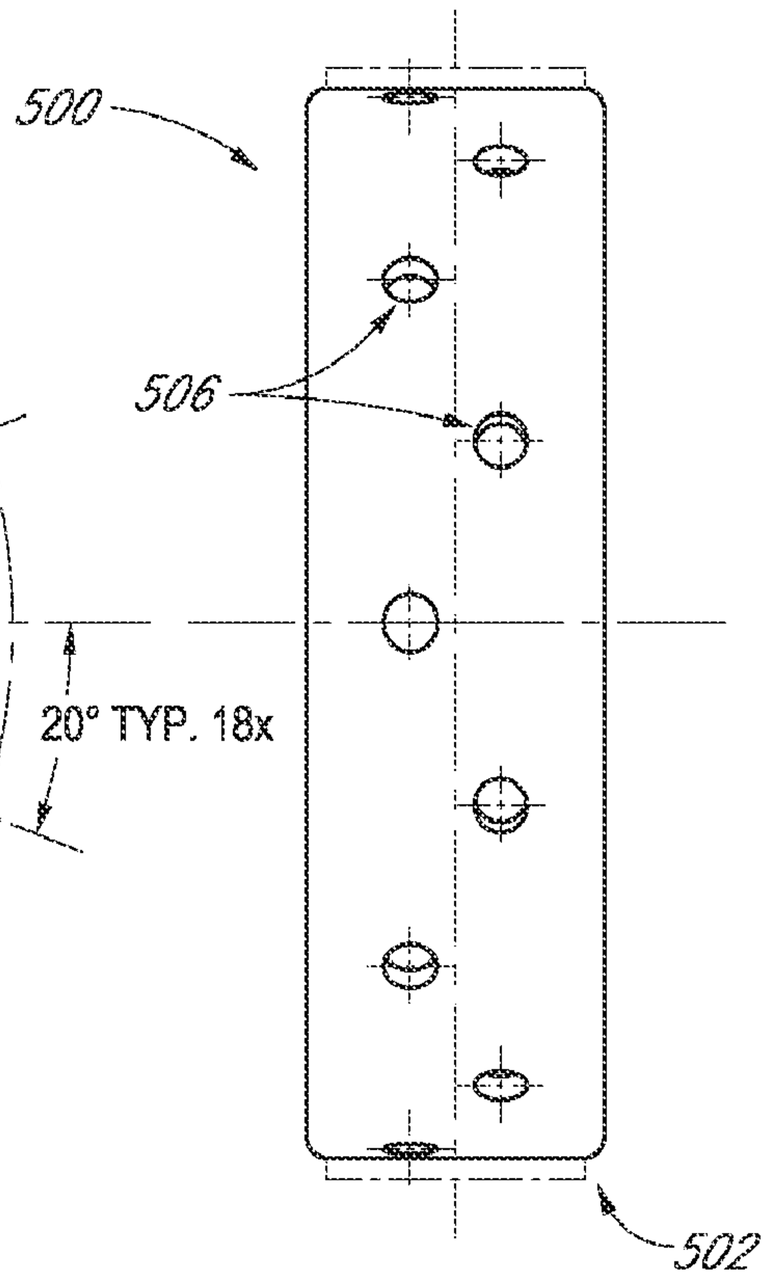

FIG. 11

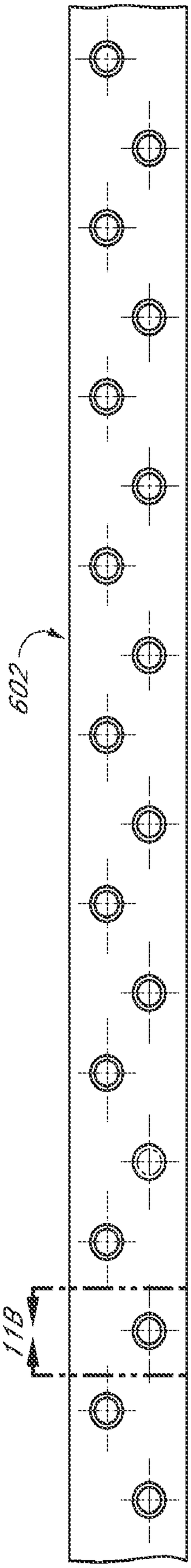

FIG. 11A

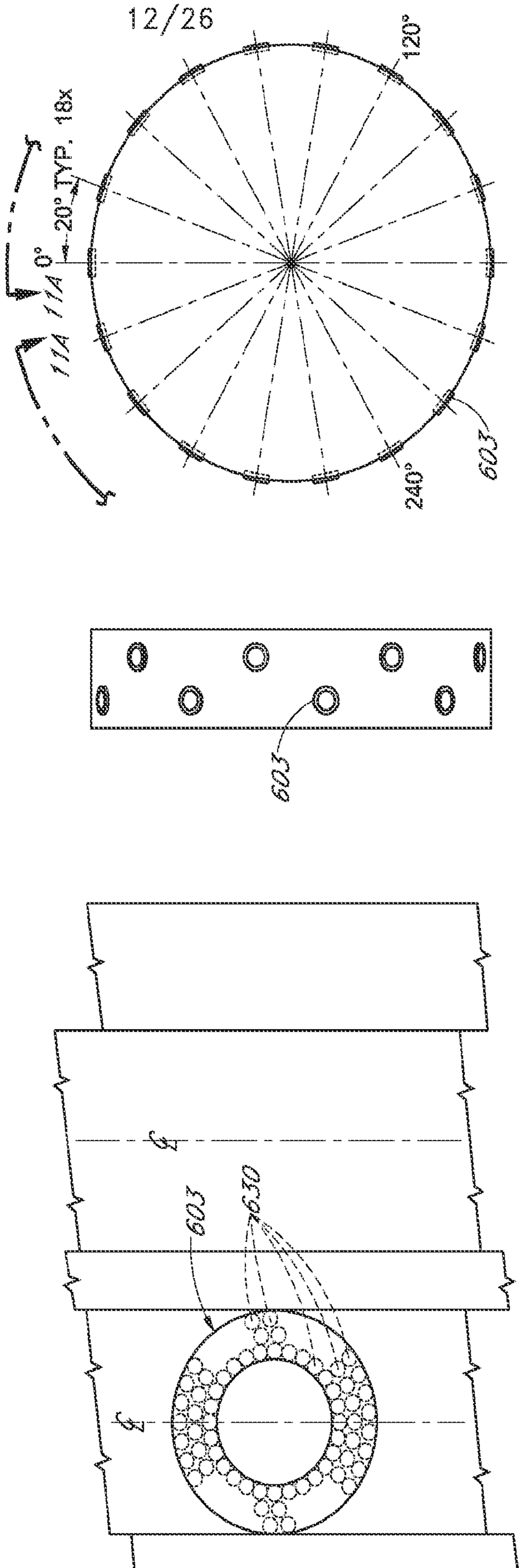

FIG. 11C

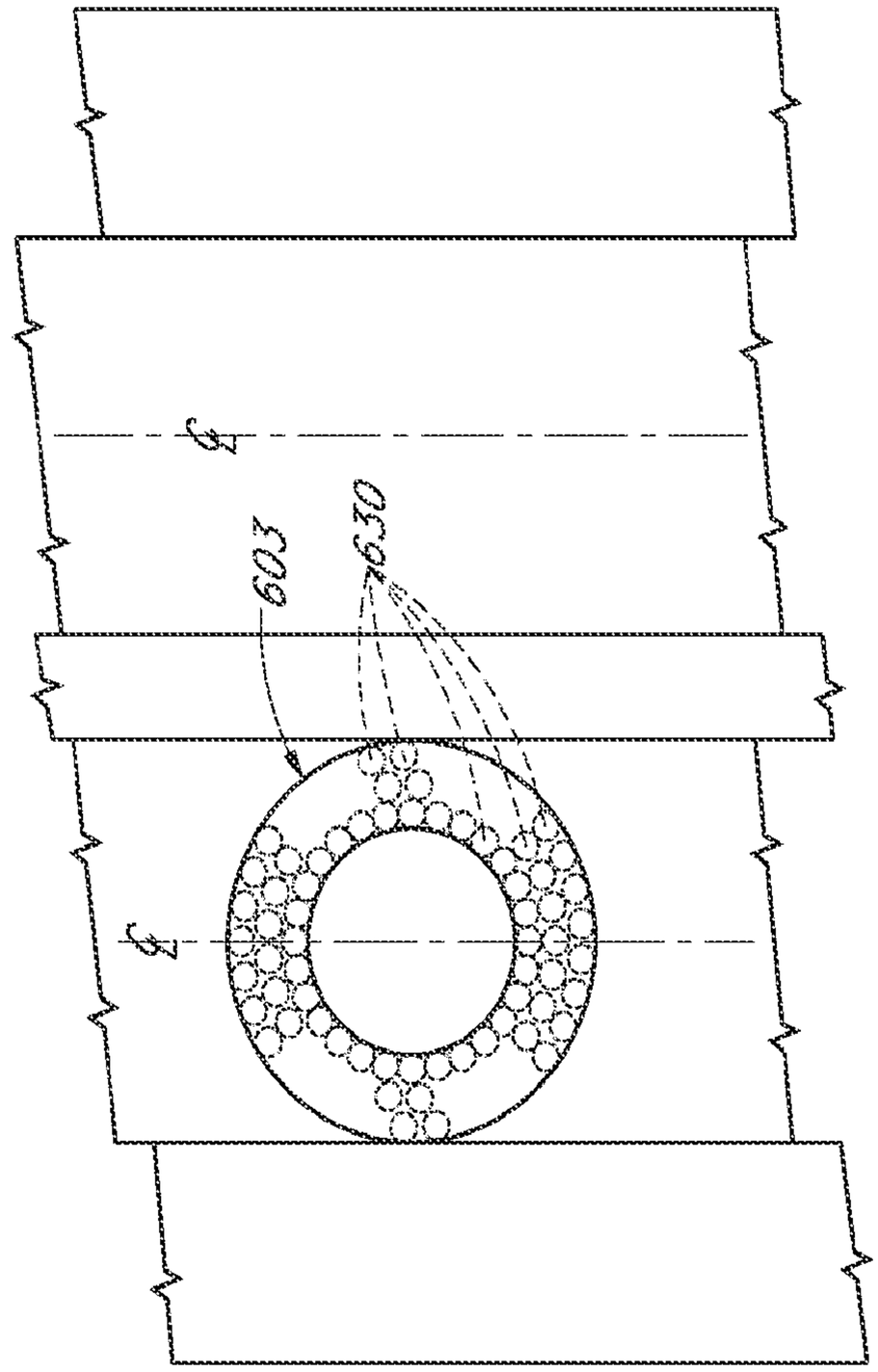

FIG. 11B

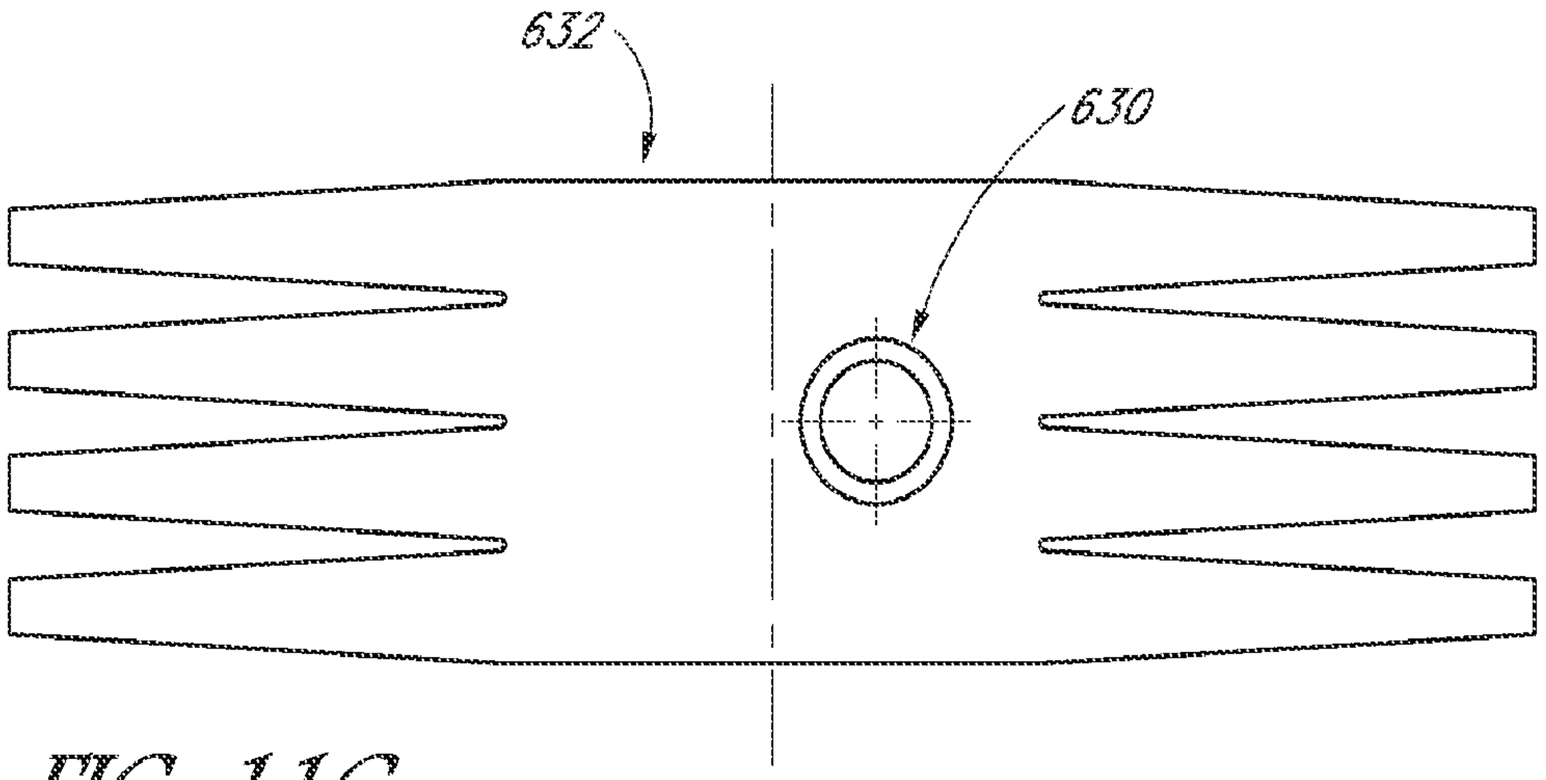

FIG. 11G

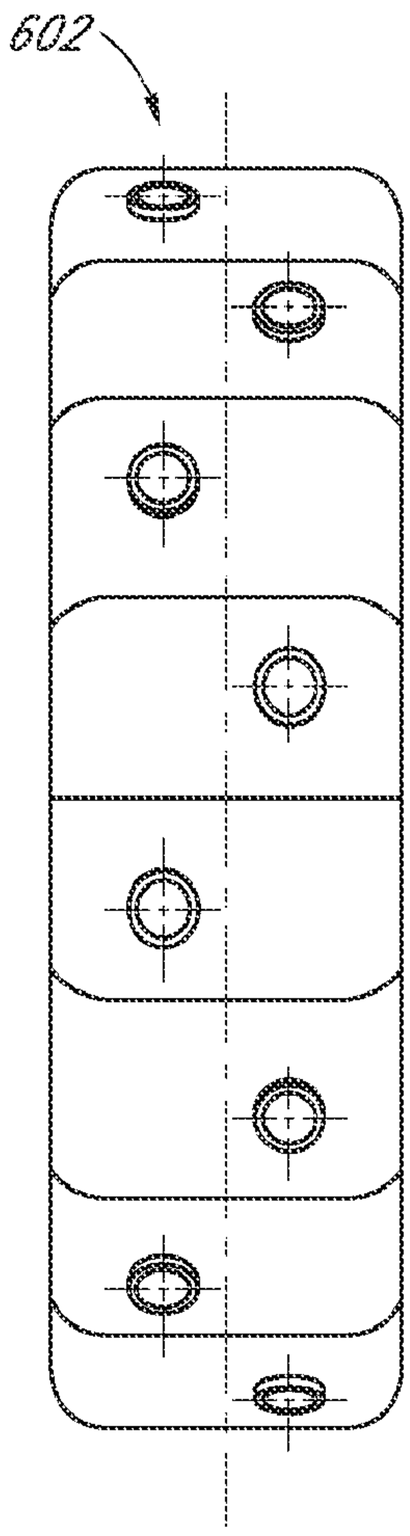

FIG. 11F

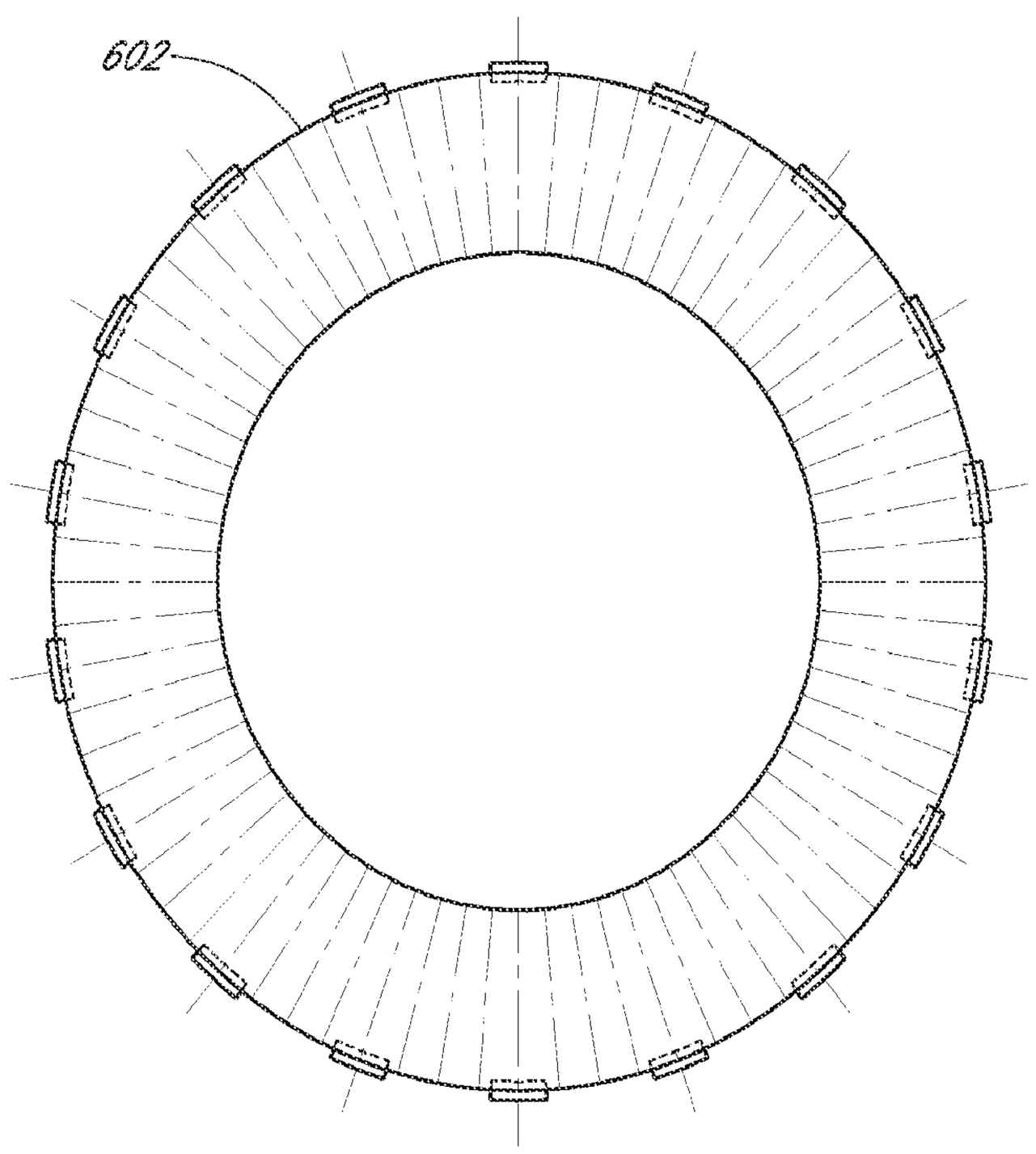

FIG. 11E

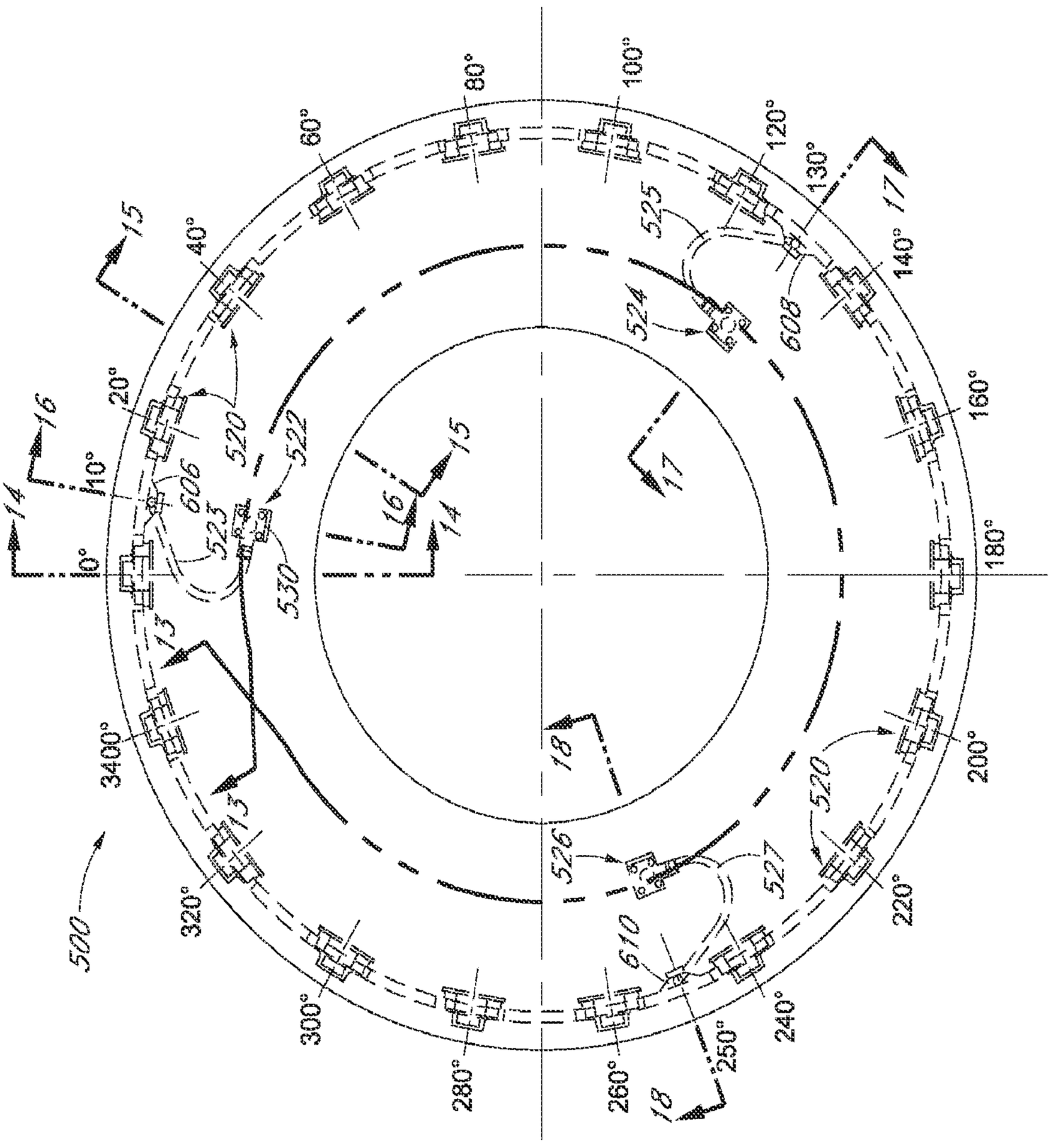
0°
10°
20°
40°
60°
80°
100°
120°
130°
140°
160°
180°
200°
220°
240°
250°
260°
280°
300°
320°
340°
500
520
522
523
524
525
526
527
530
606
608
610
12
13
14
15
16
17
18

FIG. 12

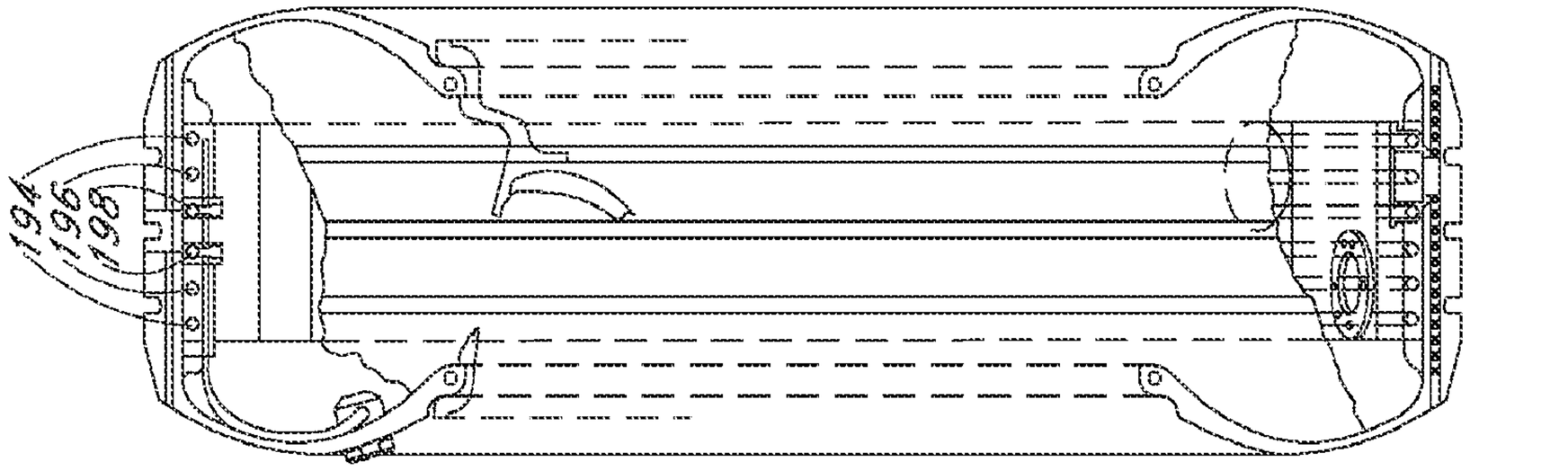
194
196
198

FIG. 13

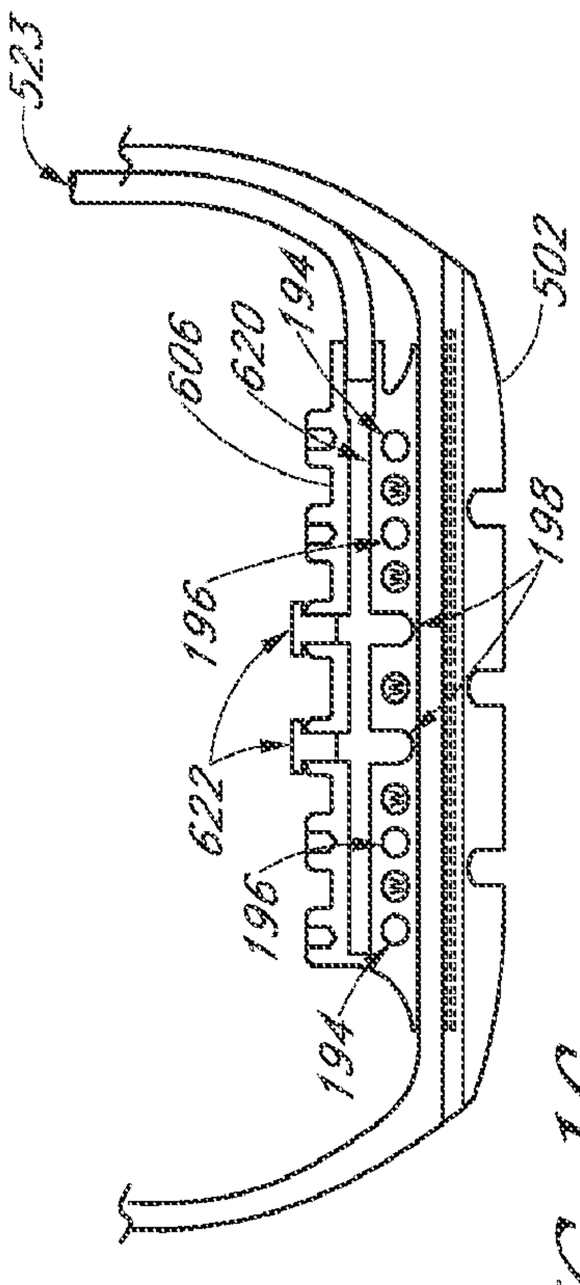

FIG. 16

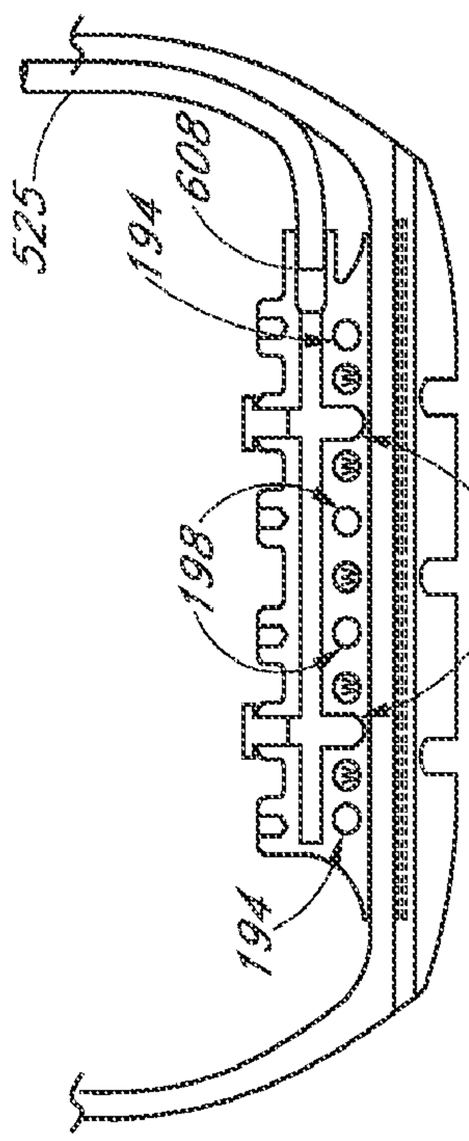

FIG. 17

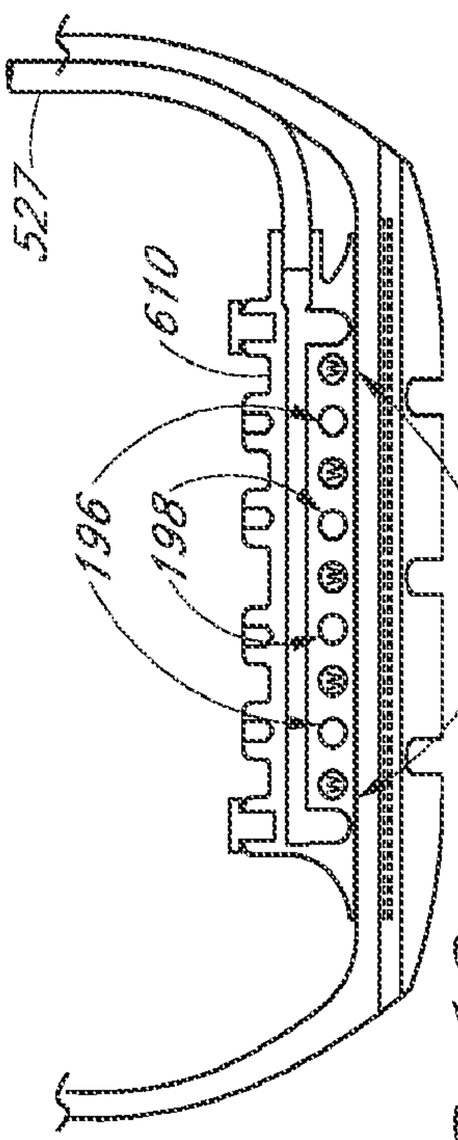

FIG. 18

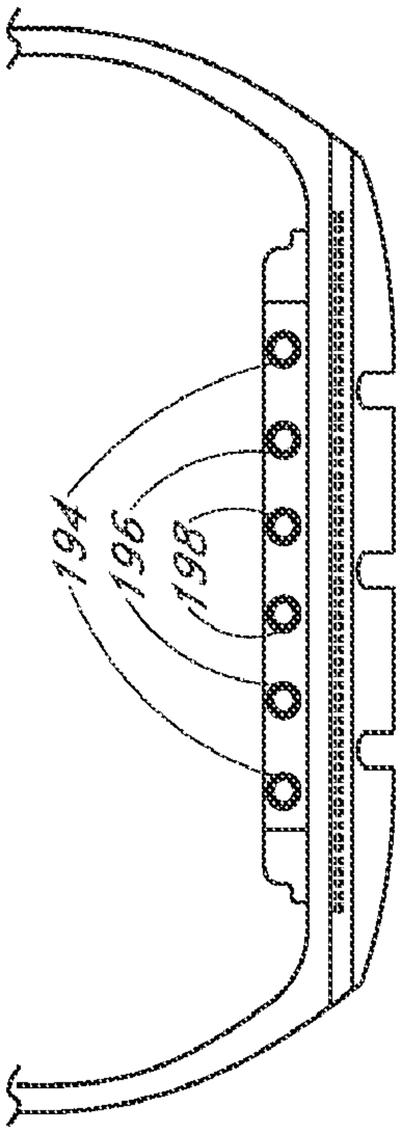

FIG. 15

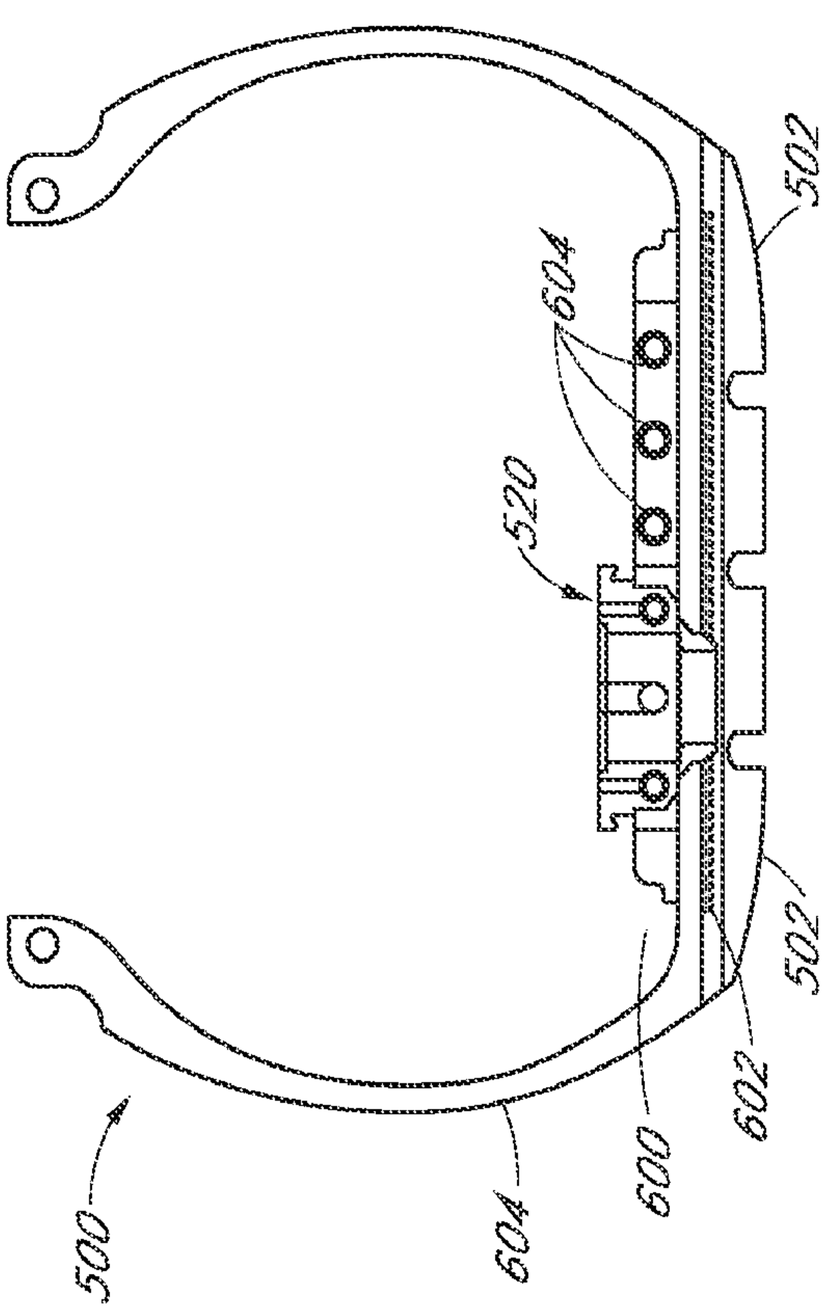

FIG. 14

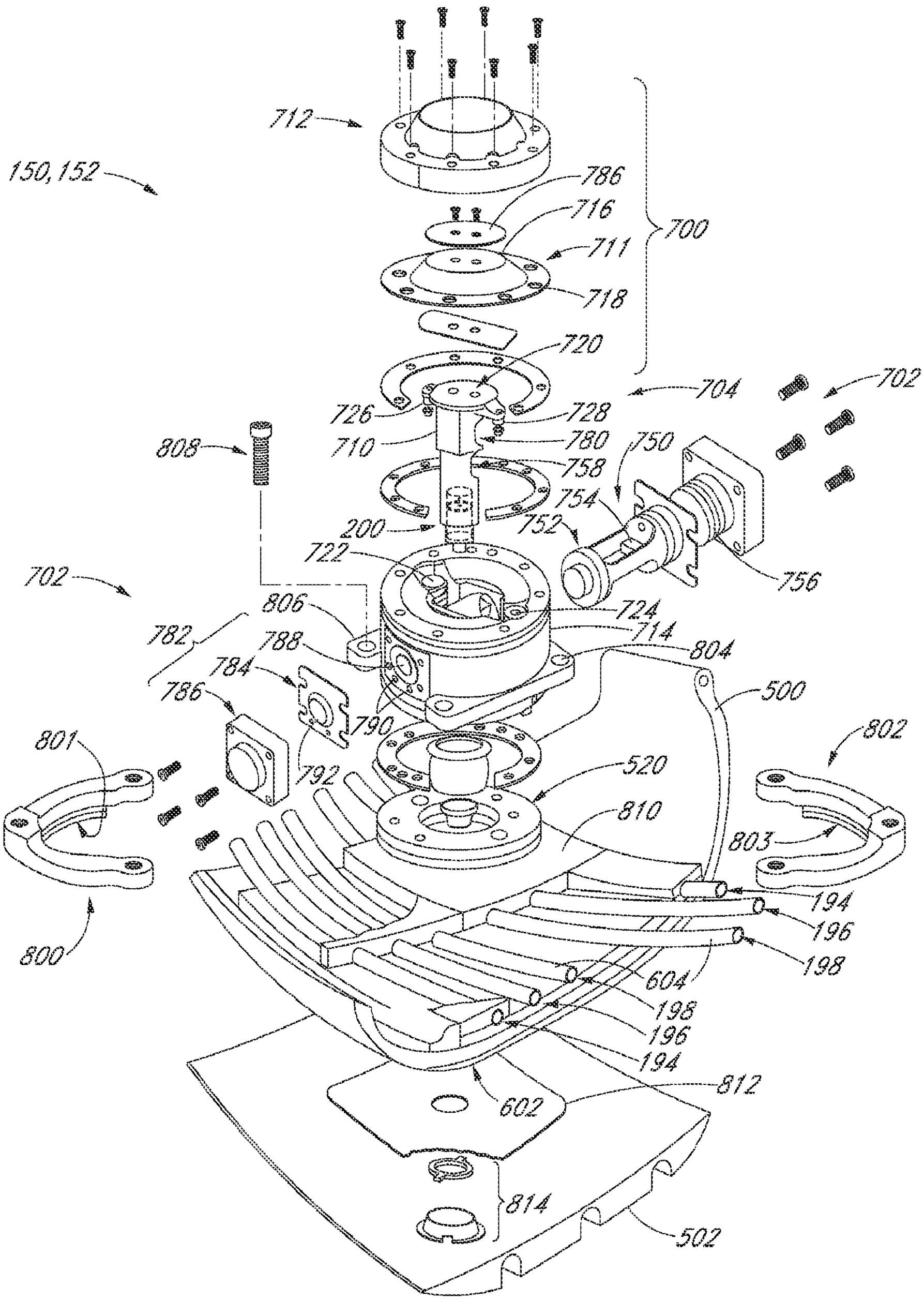
712
150, 152
786
716
711
700
718
720
704
702
726
728
710
780
750
808
758
754
200
752
722
756
702
724
806
714
782
788
804
784
500
786
790
801
802
792
520
810
803
194
196
198
604
195
196
194
812
602
800
814
502

FIG. 19

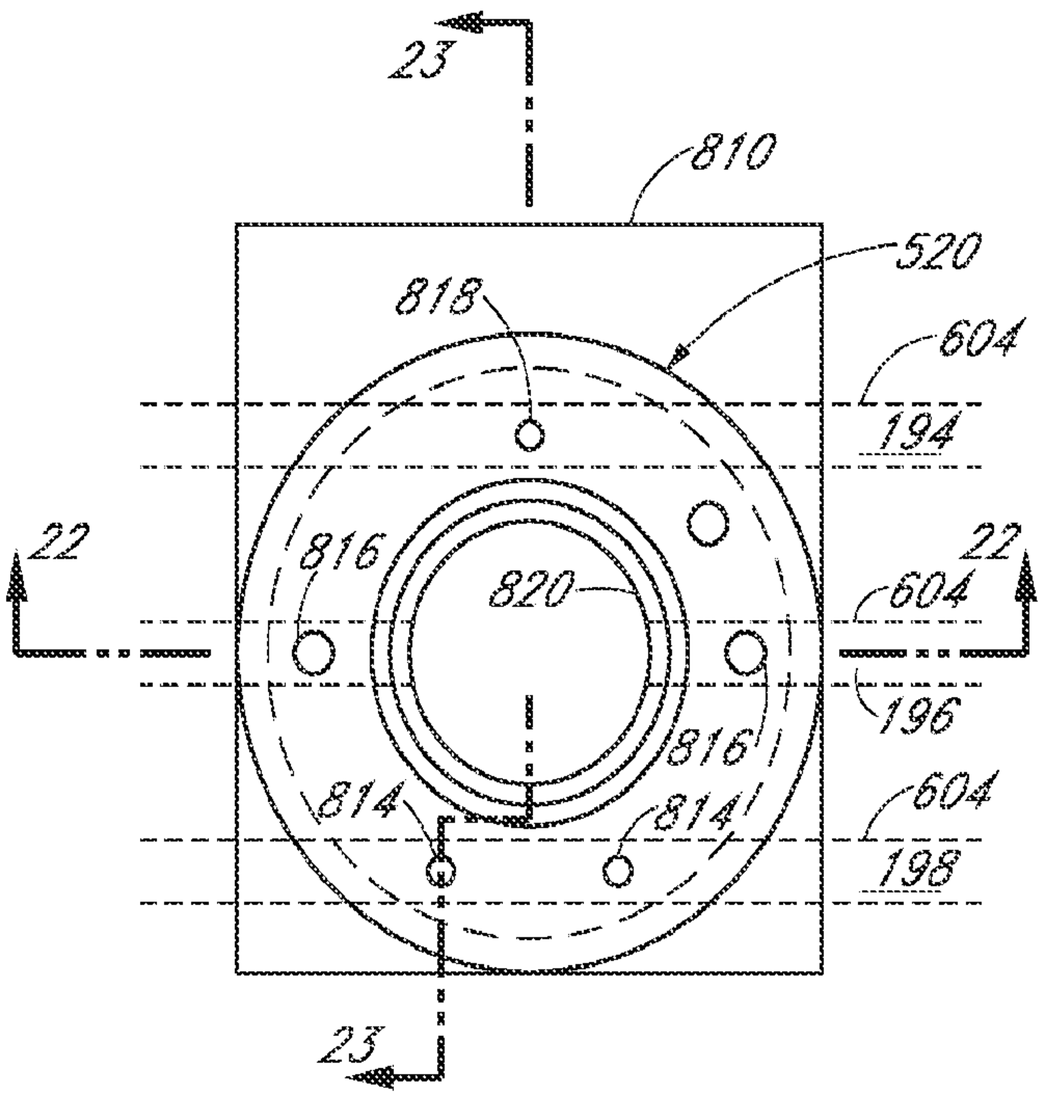

FIG. 20

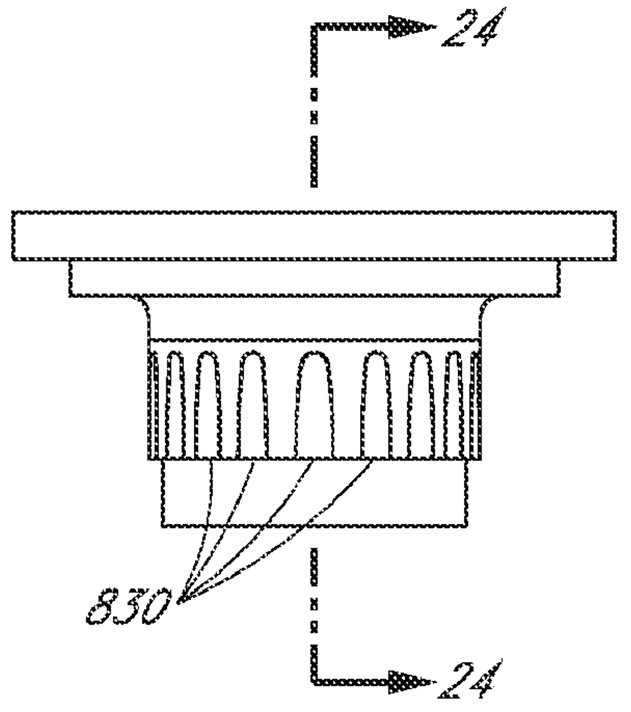

FIG. 25

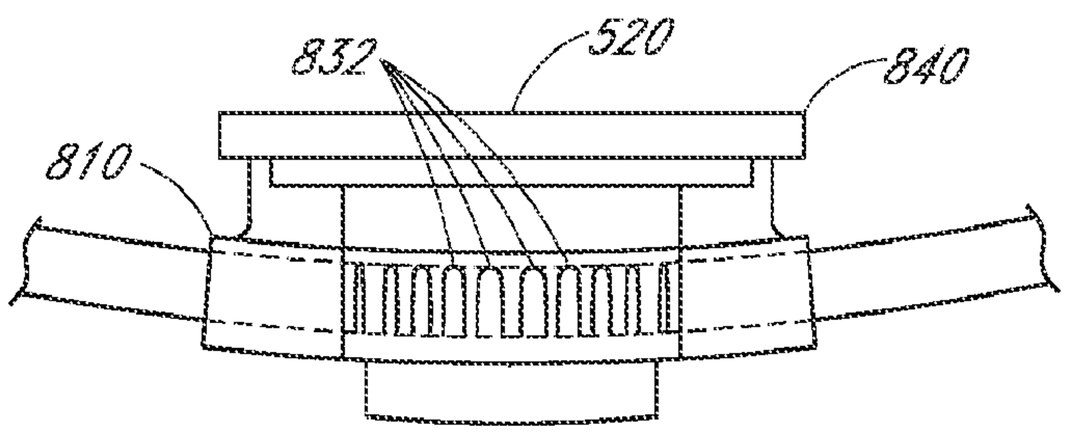

FIG. 21

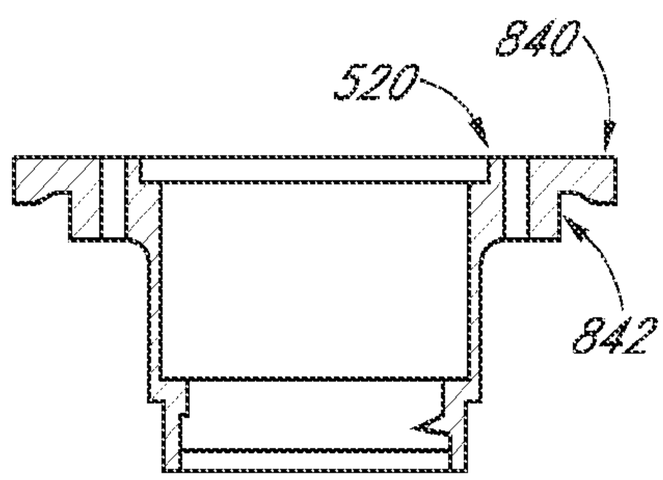

FIG. 24

FIG. 22

FIG. 23

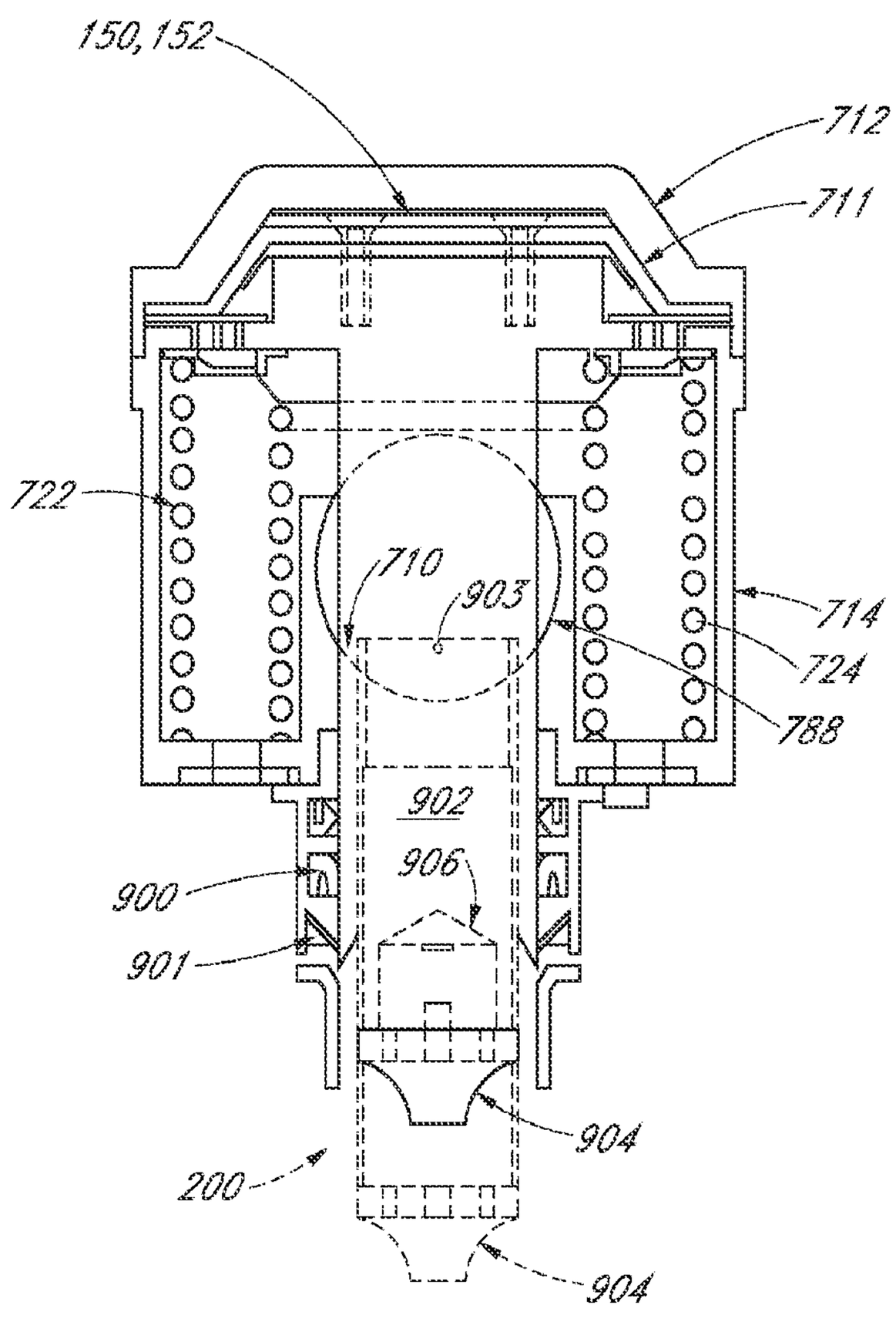
150, 152
712
711
722
710
903
714
724
788
902
906
900
901
904
200
904

FIG. 26

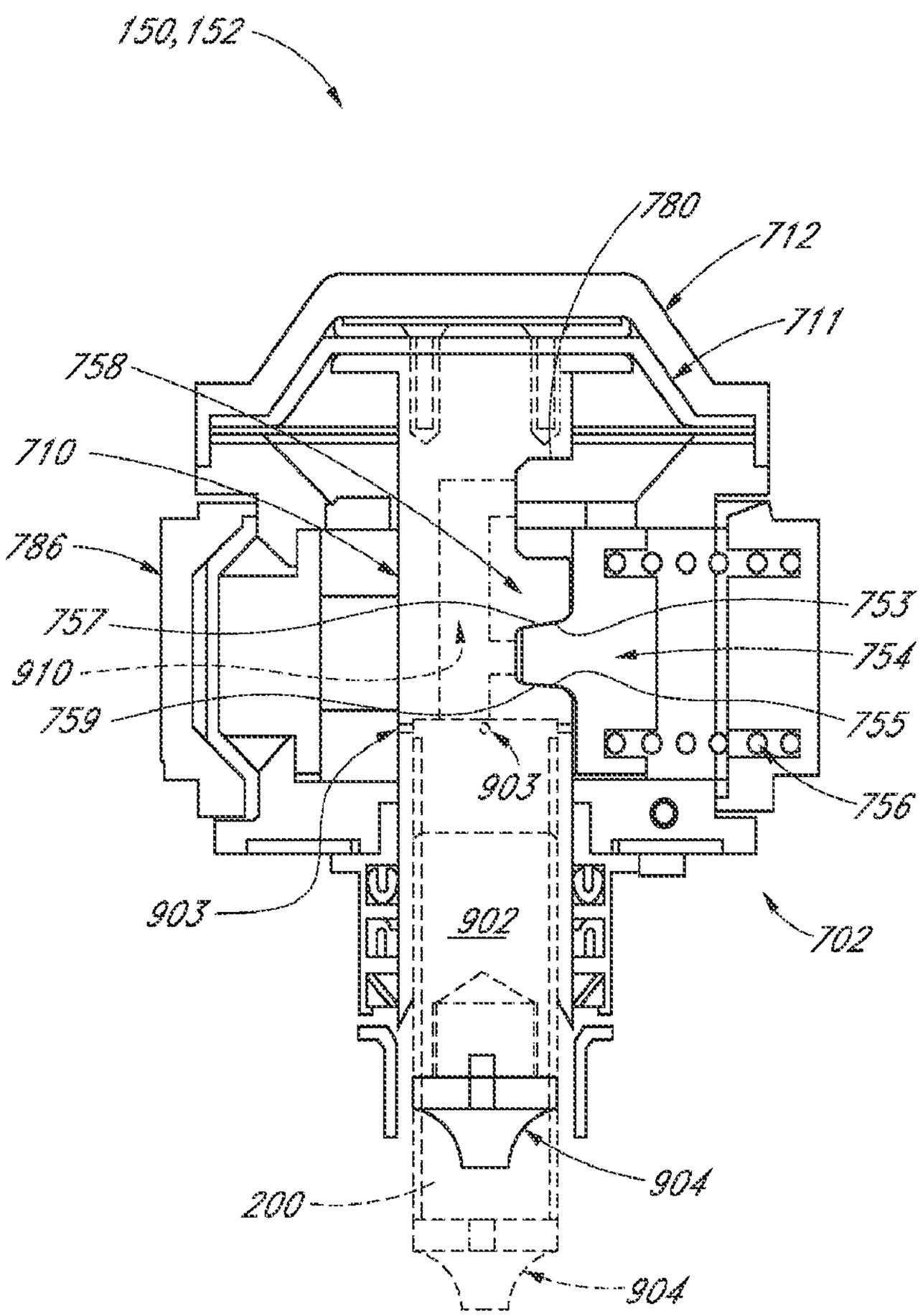
150, 152
780
712
711
758
710
786
757
910
759
753
754
755
756
903
902
702
200
904
904

FIG. 27

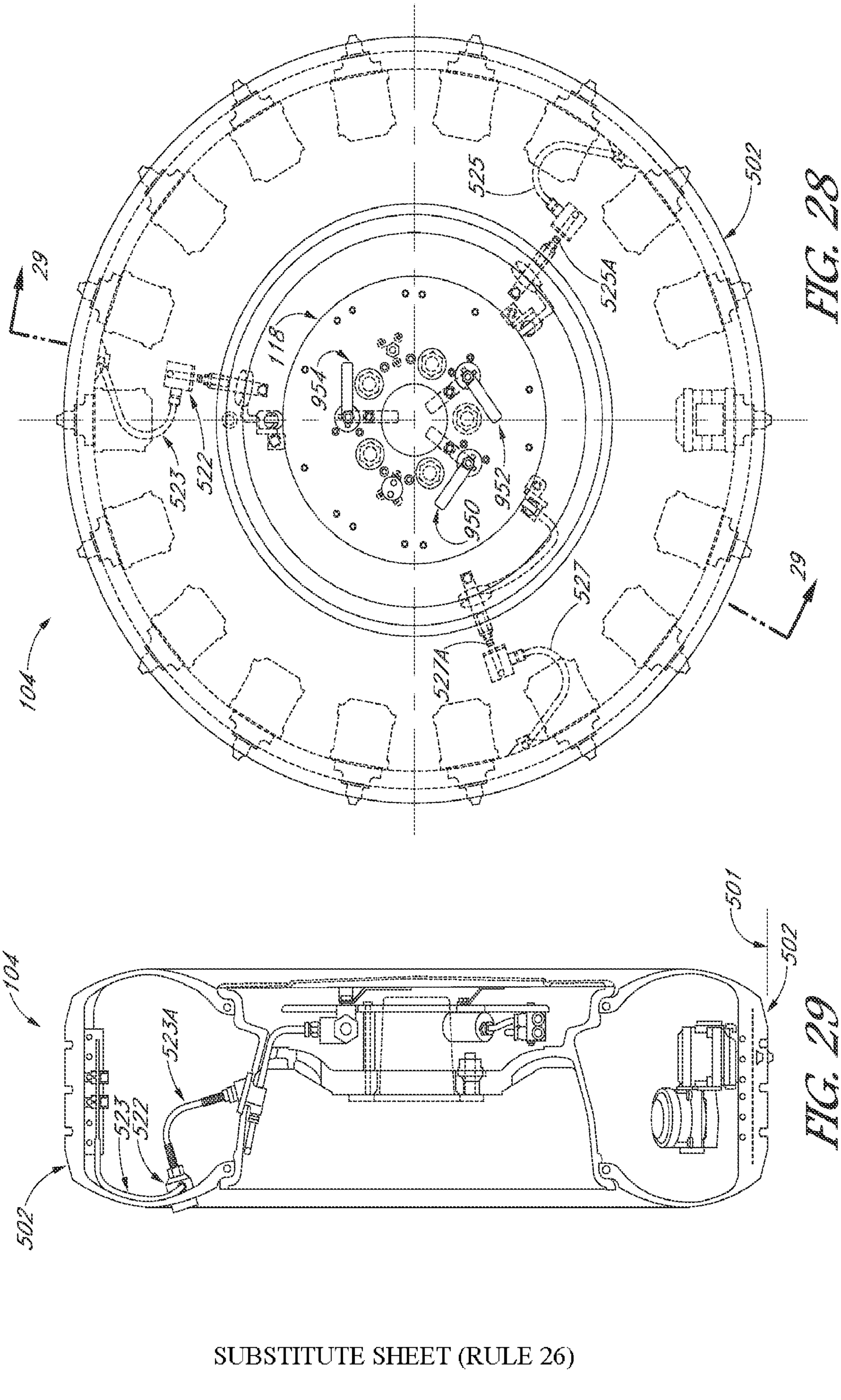
29
525
502
525A
118
954
523
522
952
950
527
527A
29
104
501
502
104
523A
523
522
502

FIG. 28

FIG. 29

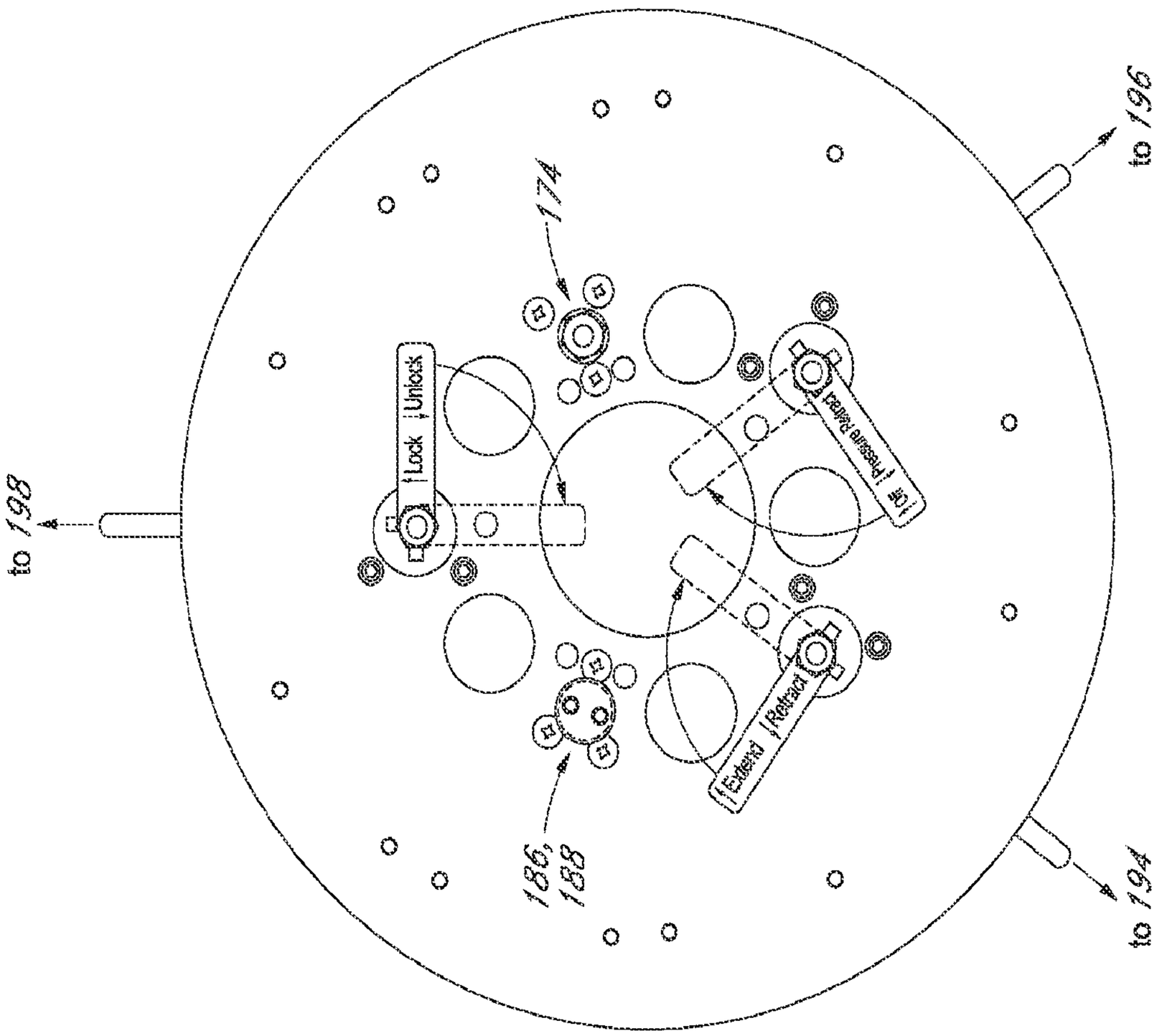
to 196
174
Lock
Unlock
Release
Hold
Extend
Retract
to 198
186, 188
to 194

FIG. 31

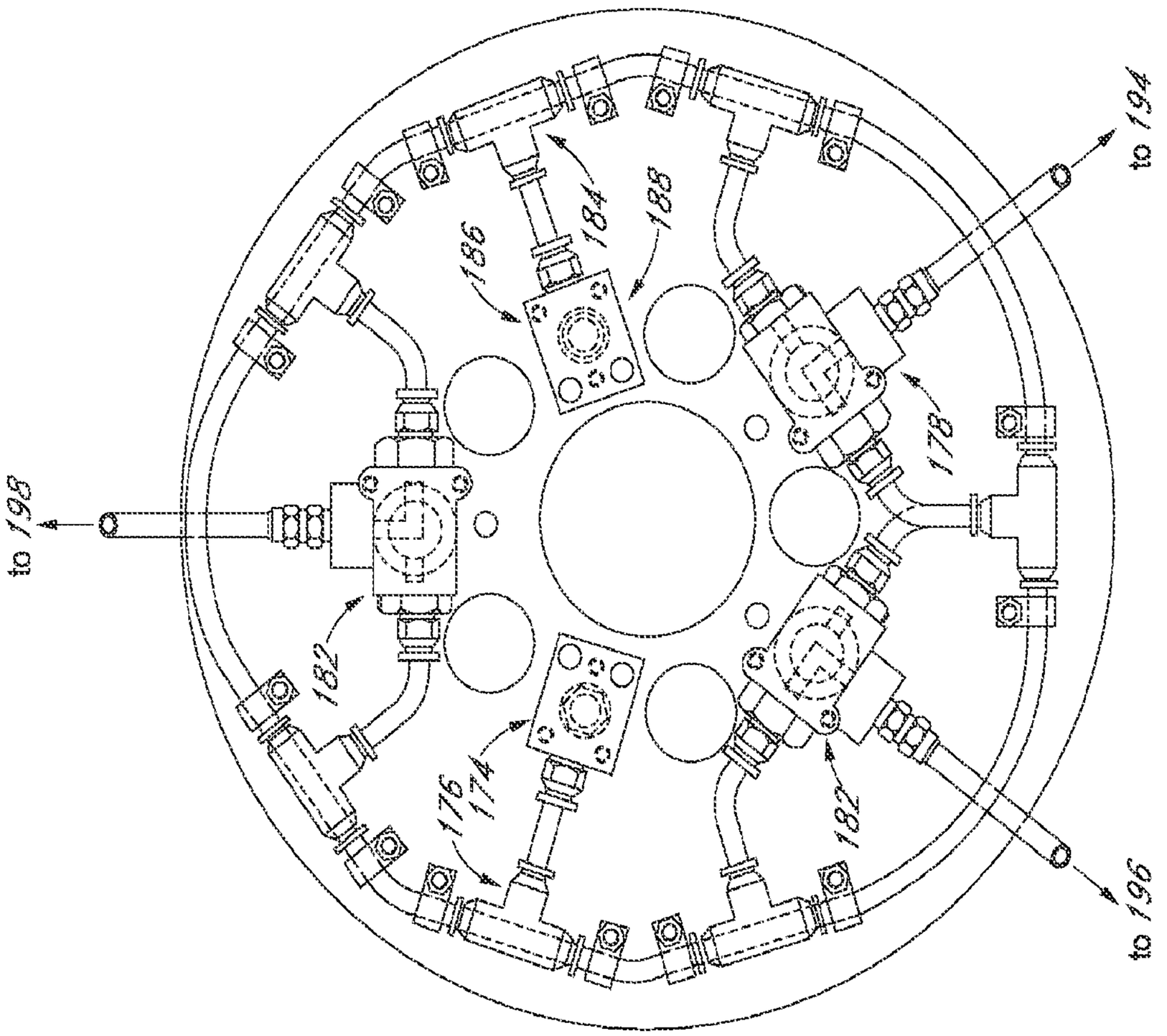
to 194
186
184
188
178
to 196
182
176
174
182

FIG. 30

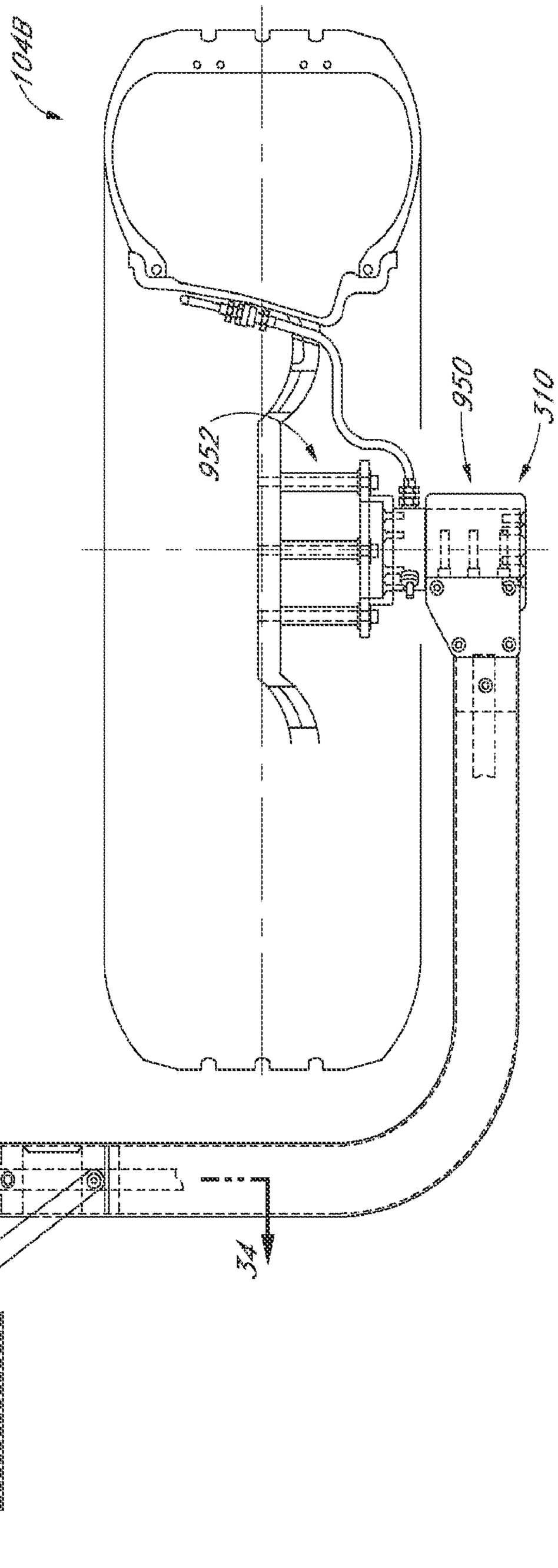

FIG. 32

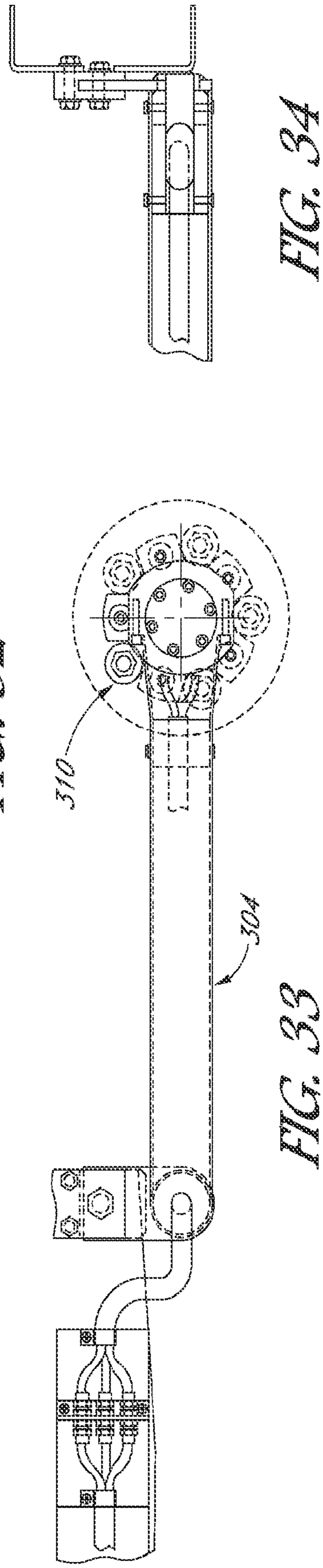

FIG. 33

FIG. 34

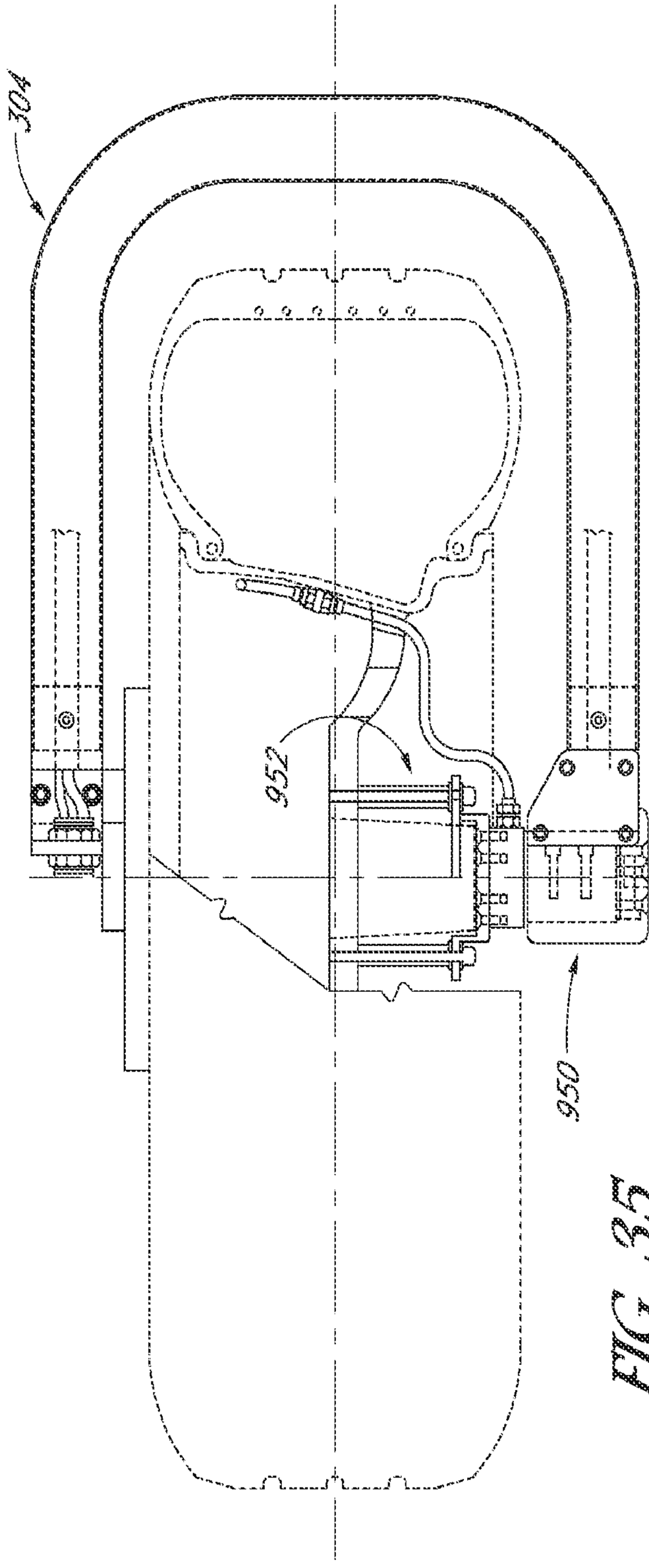

FIG. 35

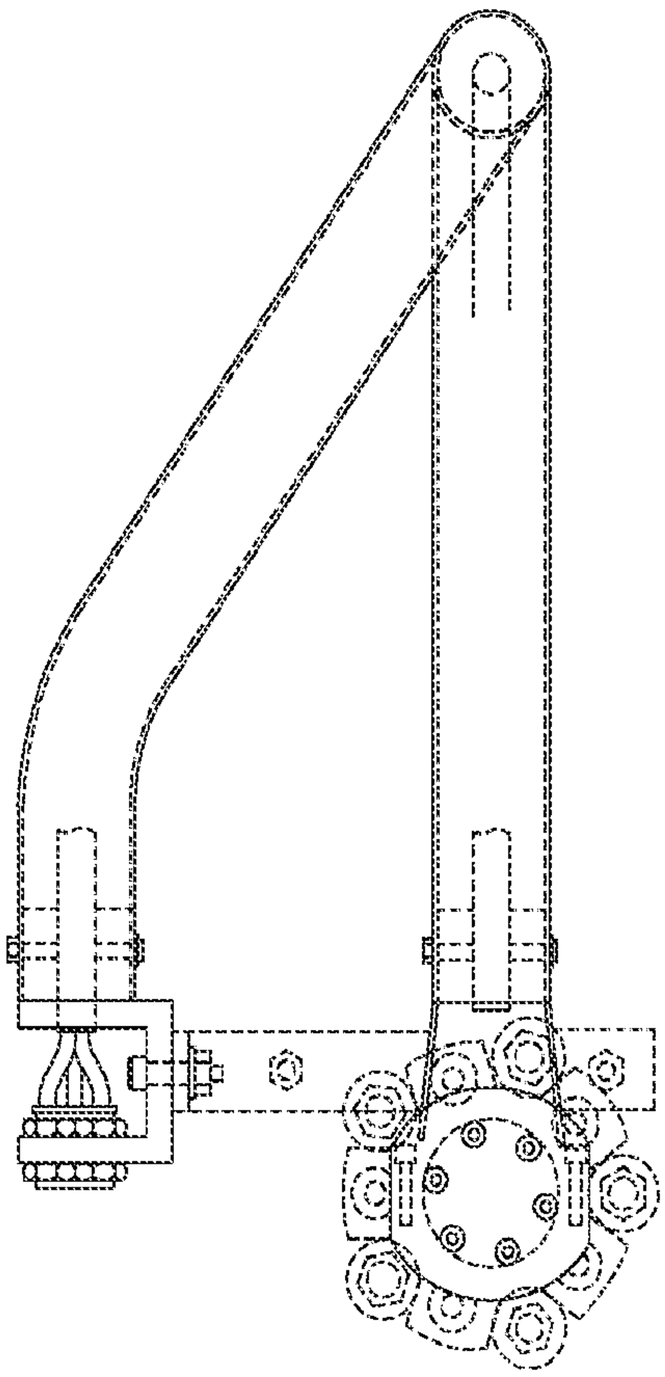

FIG. 36

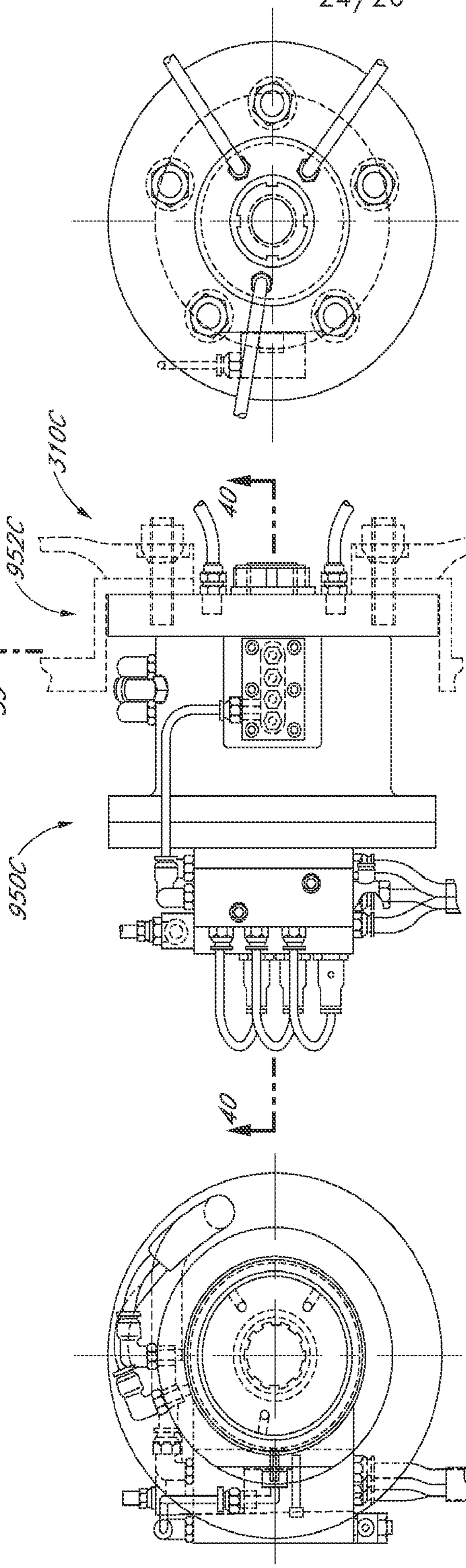

FIG. 38

FIG. 39

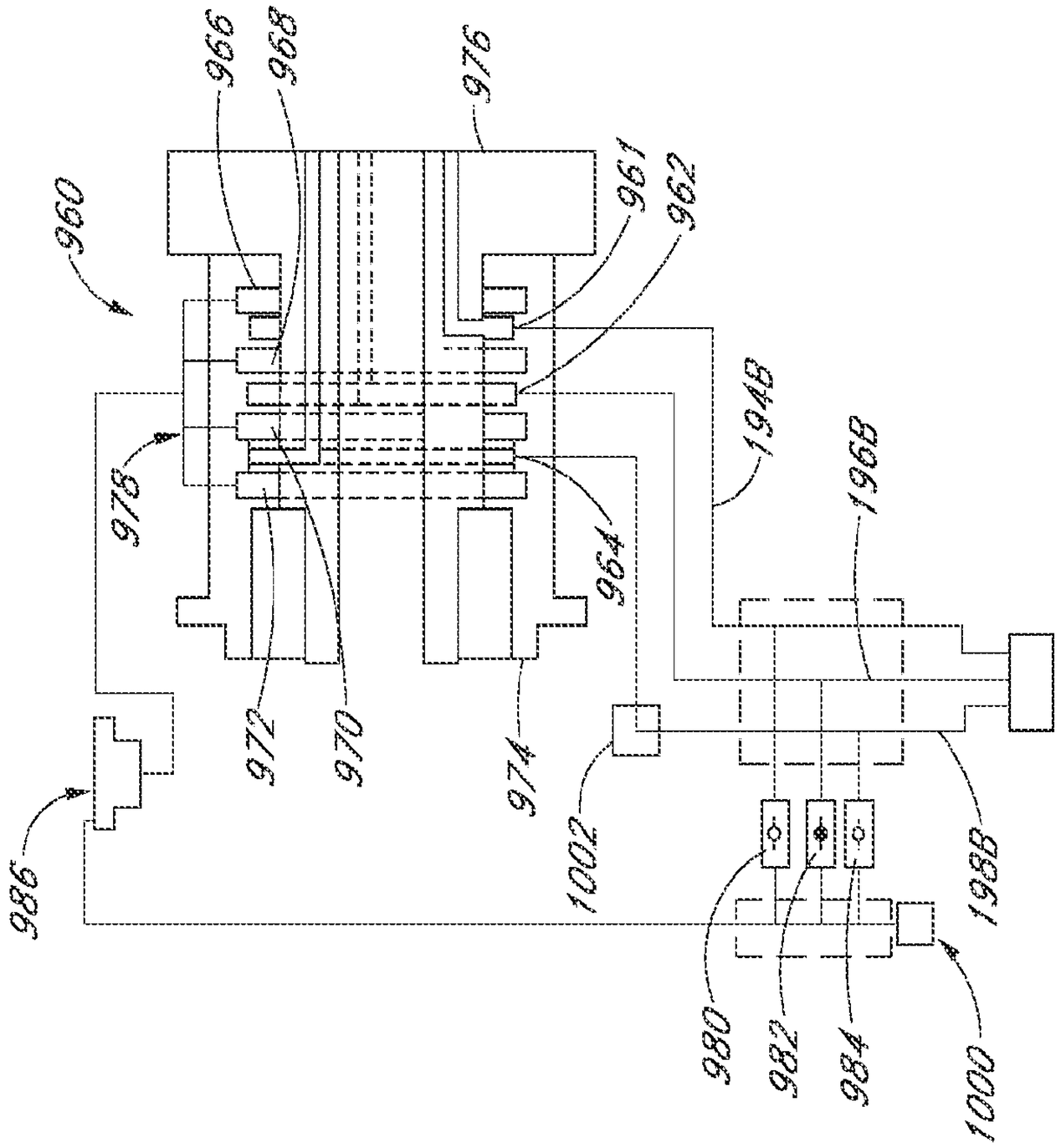
966
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FIG. 41

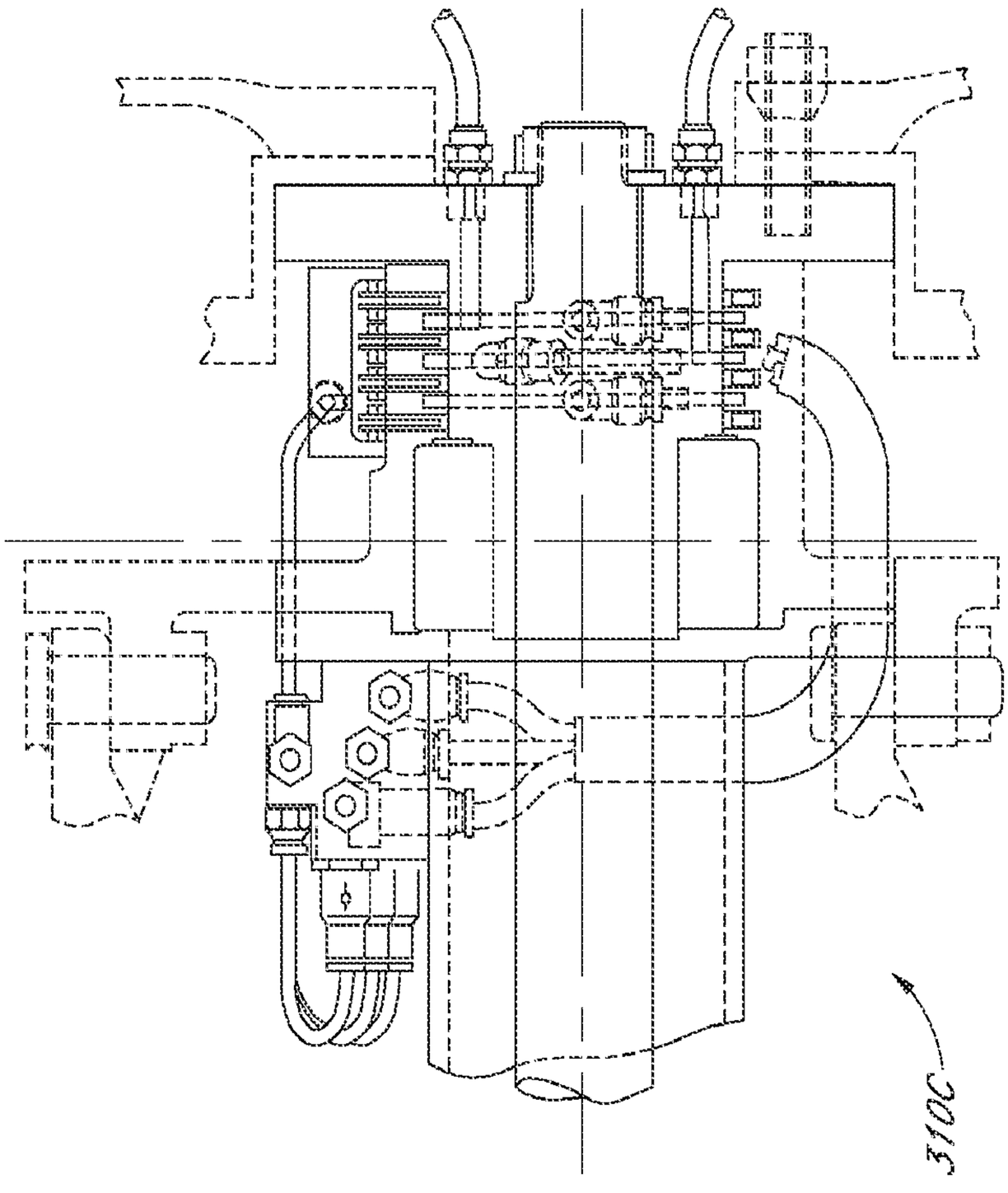
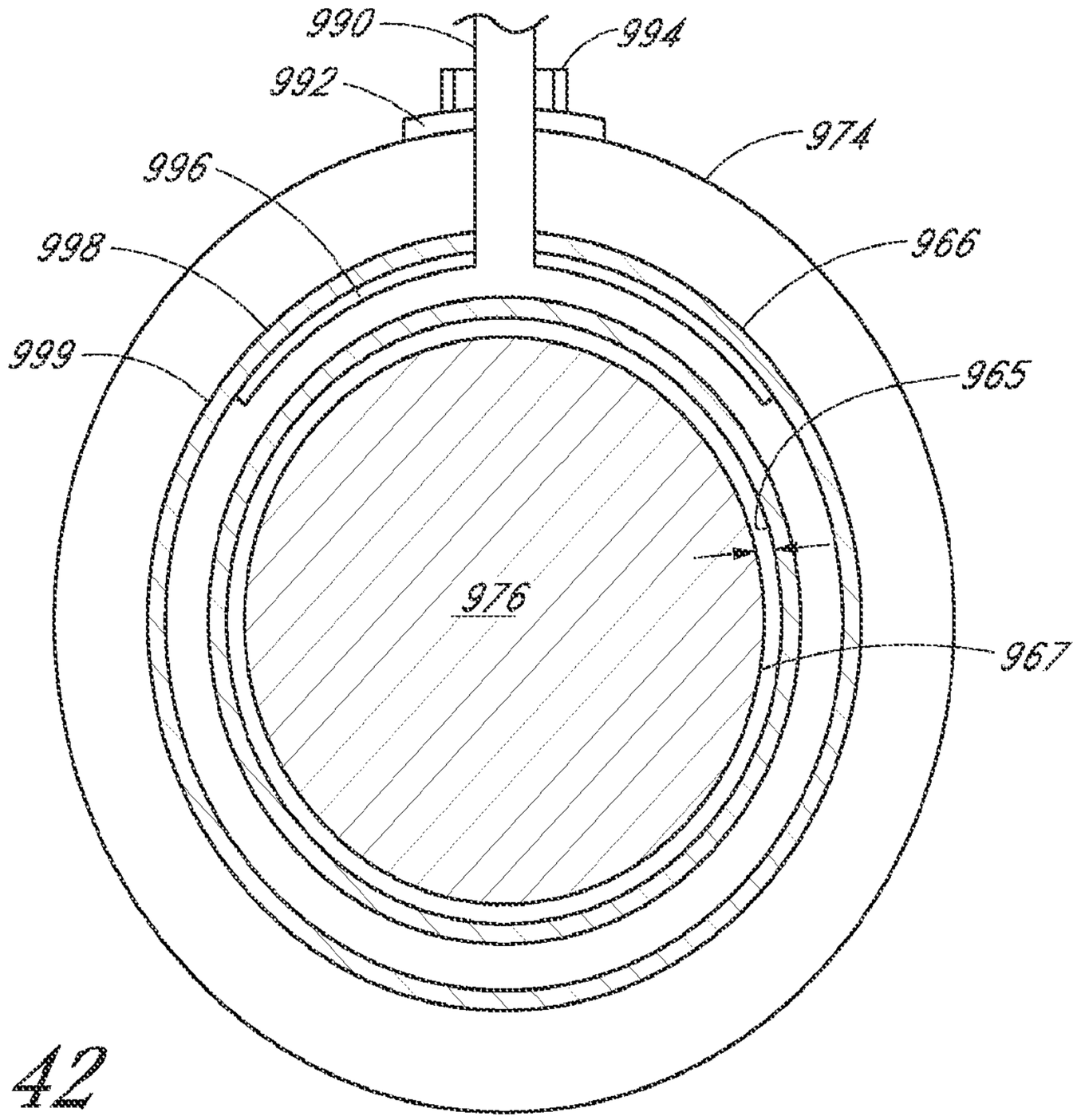

310C

FIG. 42


990
994
992
974
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967

FIG. 42

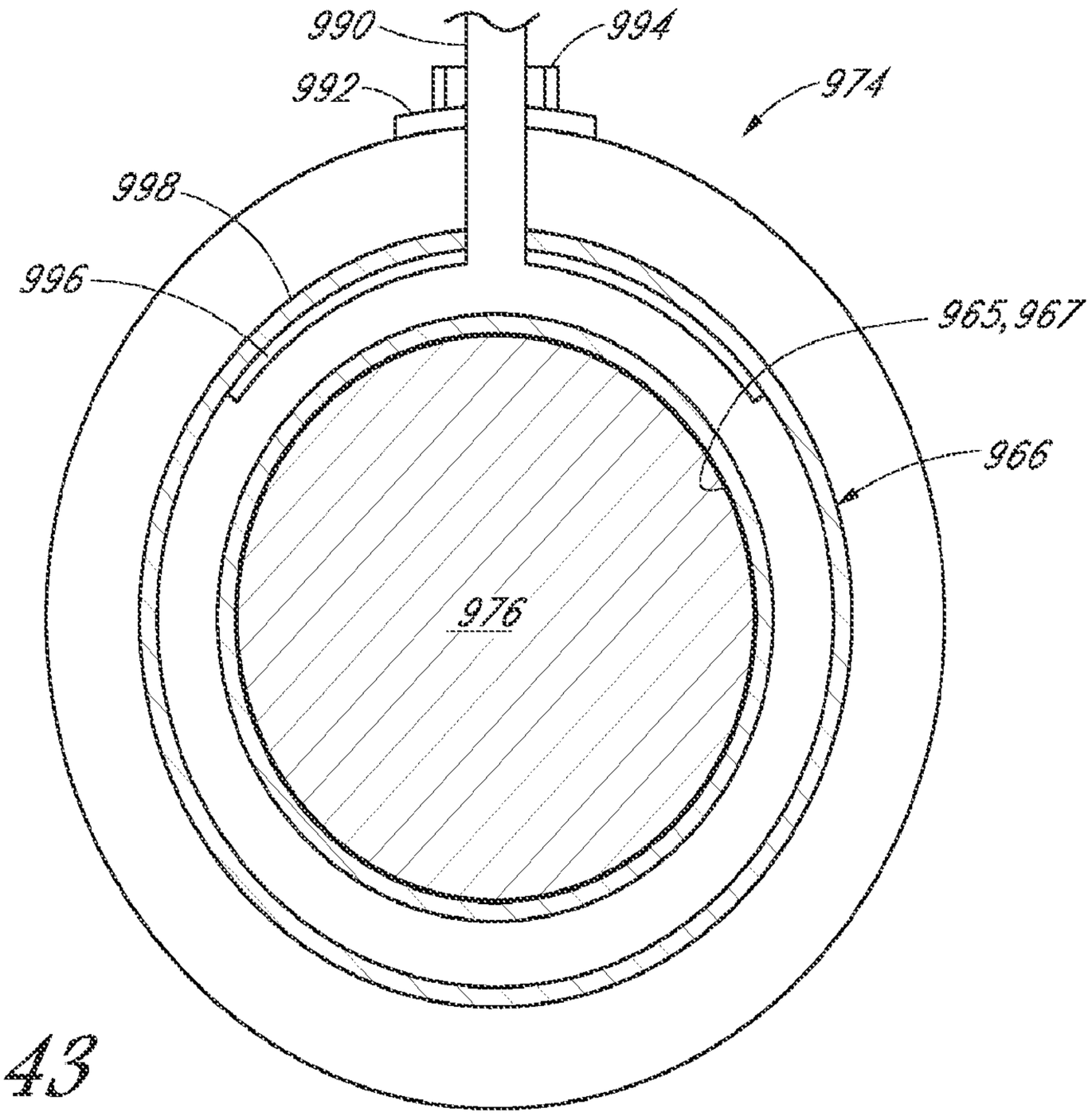
990
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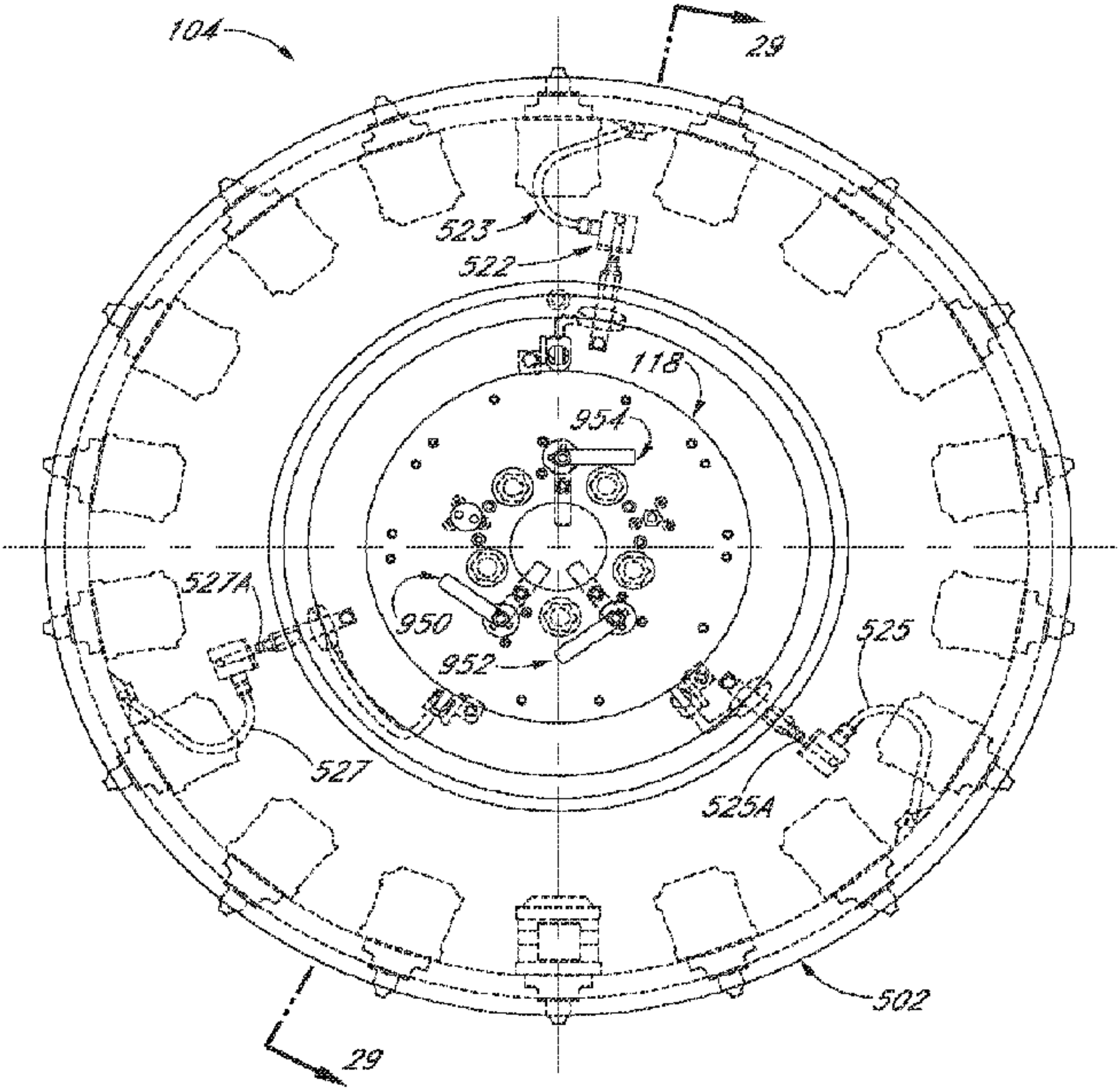
FIG. 43


104
29
523
522
118
954
950
952
527A
527
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525A
502
29