



US010598292B2

(12) **United States Patent**  
**Melcher**

(10) **Patent No.:** **US 10,598,292 B2**

(45) **Date of Patent:** **Mar. 24, 2020**

(54) **HYDRAULIC BYPASS SYSTEM**

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(\* ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 113 days.

(21) Appl. No.: **15/585,064**

(22) Filed: **May 2, 2017**

(65) **Prior Publication Data**

US 2017/0321729 A1 Nov. 9, 2017

(Continued)

**Related U.S. Application Data**

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(60) Provisional application No. 62/332,893, filed on May 6, 2016.

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*Primary Examiner* — Keith J Frisby

(51) **Int. Cl.**

<b>B60G 21/073</b>	(2006.01)
<b>F16K 15/04</b>	(2006.01)
<b>B62M 27/02</b>	(2006.01)

(57) **ABSTRACT**

A hydraulic system includes a hydraulic pump. A first hydraulic shock is coupled to a first port of the hydraulic pump. A second hydraulic shock is coupled to a second port of the hydraulic pump. A first hydraulic cylinder is coupled to the first port of the hydraulic pump. A second hydraulic cylinder is coupled to the second port of the hydraulic pump. A first valve is coupled between the first hydraulic cylinder and second hydraulic cylinder. The first valve can be actuated by a computer system or can be a ball and spring check valve. A second valve is coupled between the first hydraulic cylinder and second hydraulic cylinder. A flow direction of the second valve is opposite a flow direction of the first valve. A first piston is disposed in the first hydraulic cylinder, and a second piston is disposed in the second hydraulic cylinder.

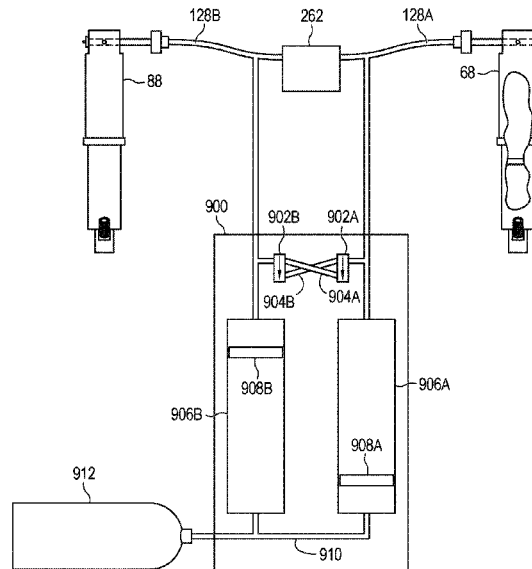
(52) **U.S. Cl.**

CPC ..... **F16K 15/044** (2013.01); **B60G 21/073** (2013.01); **B60G 2300/322** (2013.01); **B60G 2300/45** (2013.01); **B60G 2800/012** (2013.01); **B60Y 2200/252** (2013.01); **B60Y 2400/86** (2013.01); **B62M 2027/026** (2013.01)

(58) **Field of Classification Search**

CPC ..... B60G 21/073; B60G 2300/45; B60G 2300/322; B60G 2800/012; B62M 2027/026; B60Y 2200/252; B60Y 2400/86  
USPC ... 280/6.15, 124.103, 124.106, 5.509, 5.506, 280/124.16, 124.161, 124.157  
See application file for complete search history.

**15 Claims, 21 Drawing Sheets**



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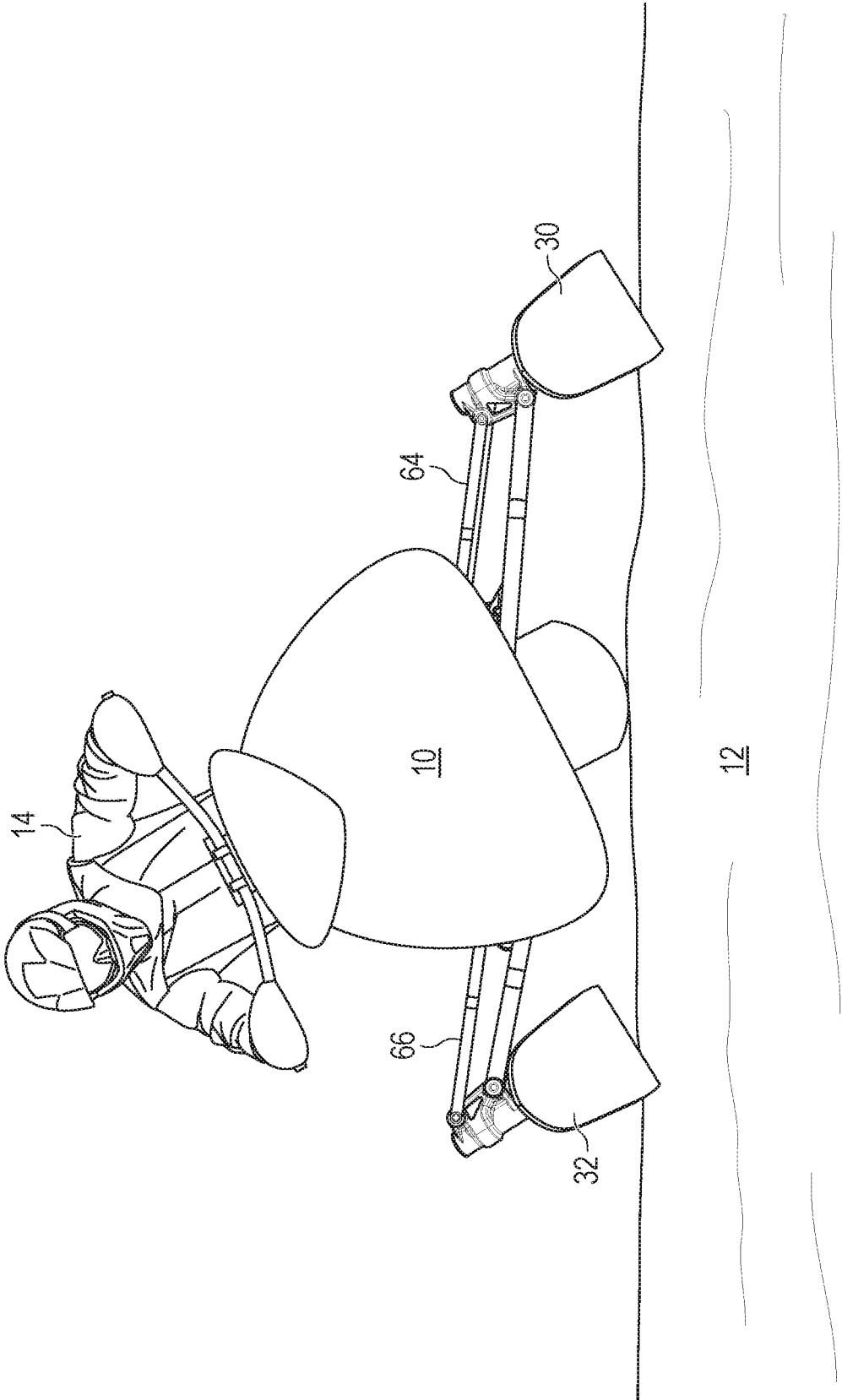


FIG. 1a

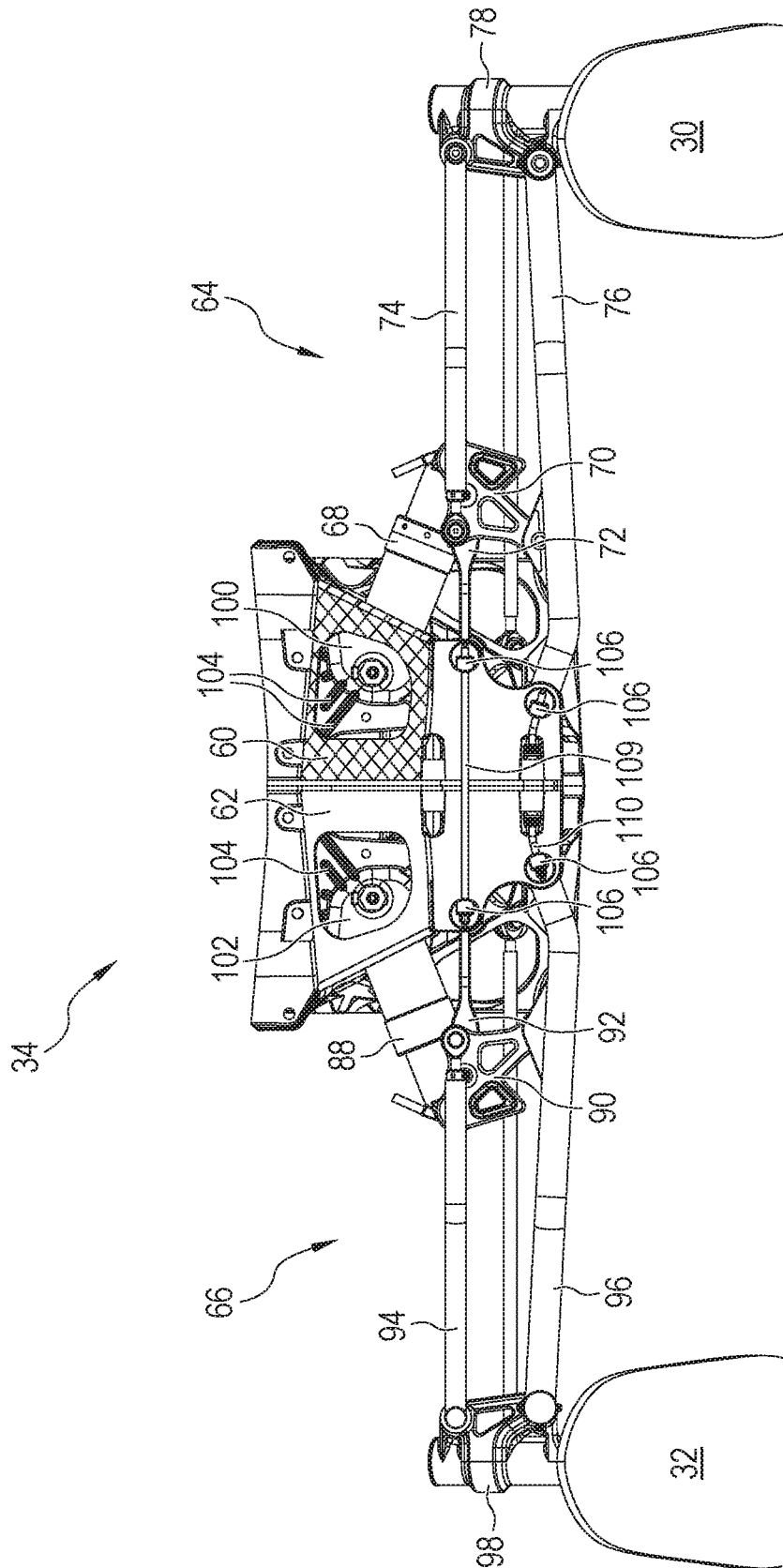


FIG. 1b

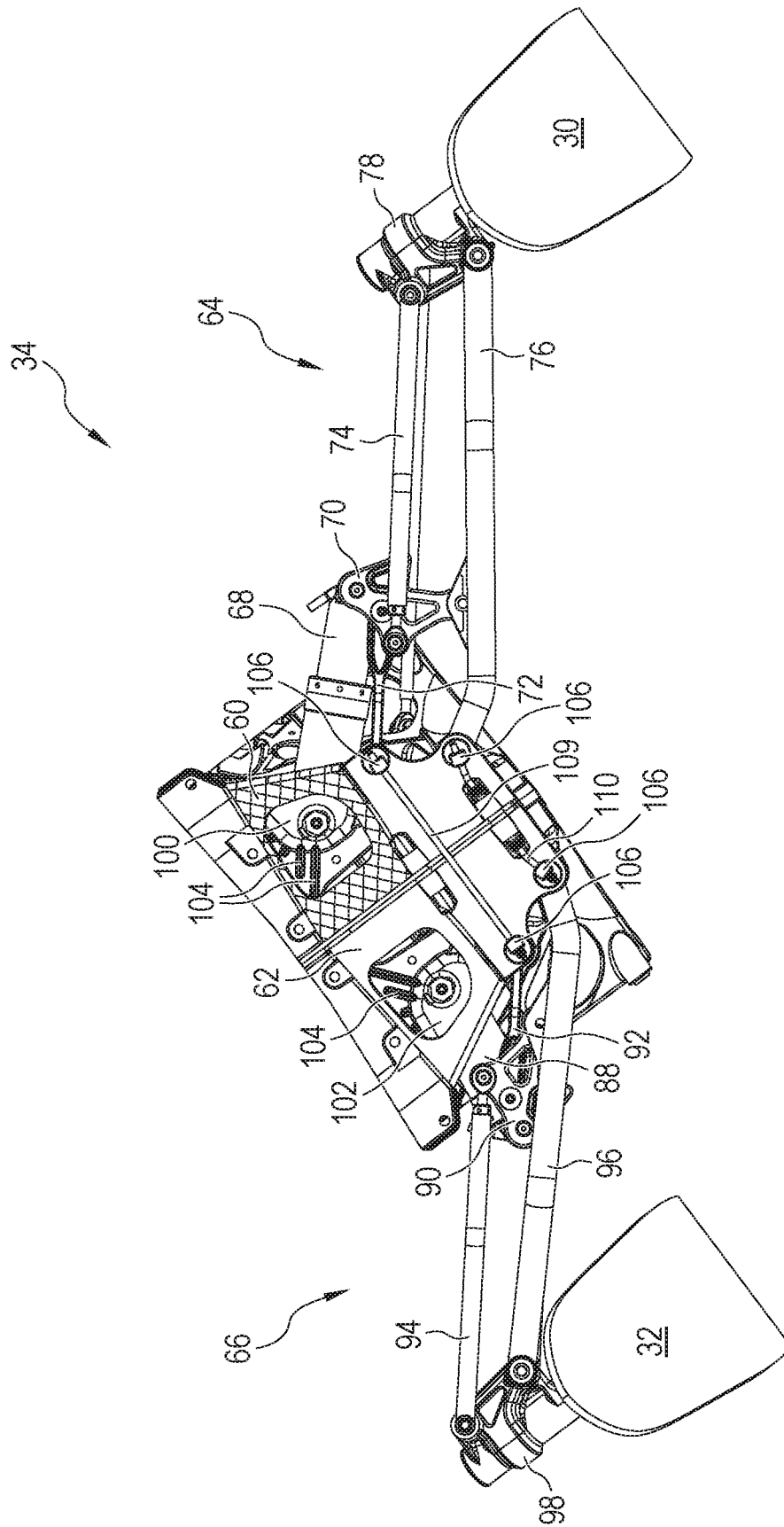
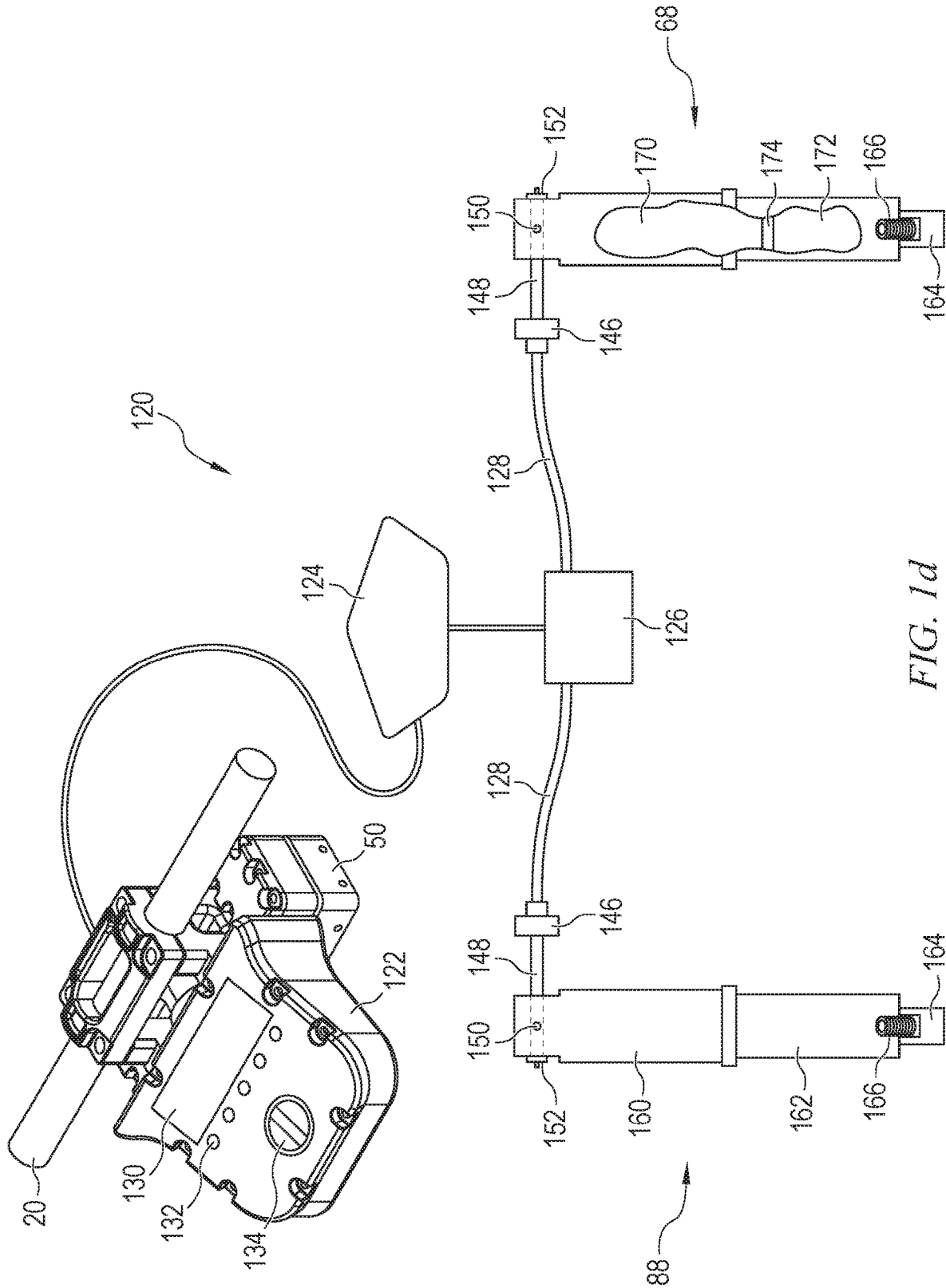


FIG. 1c



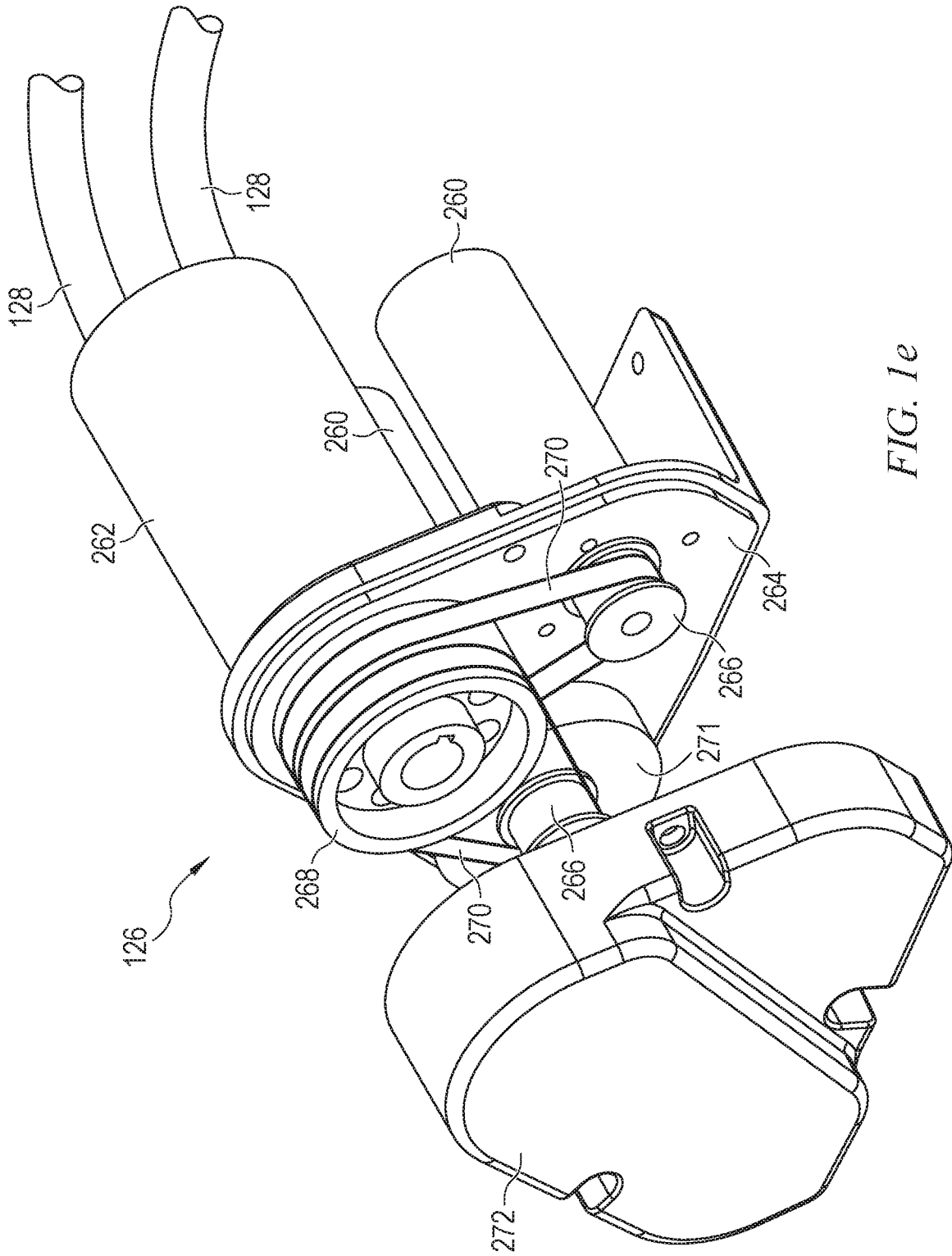


FIG. 1e

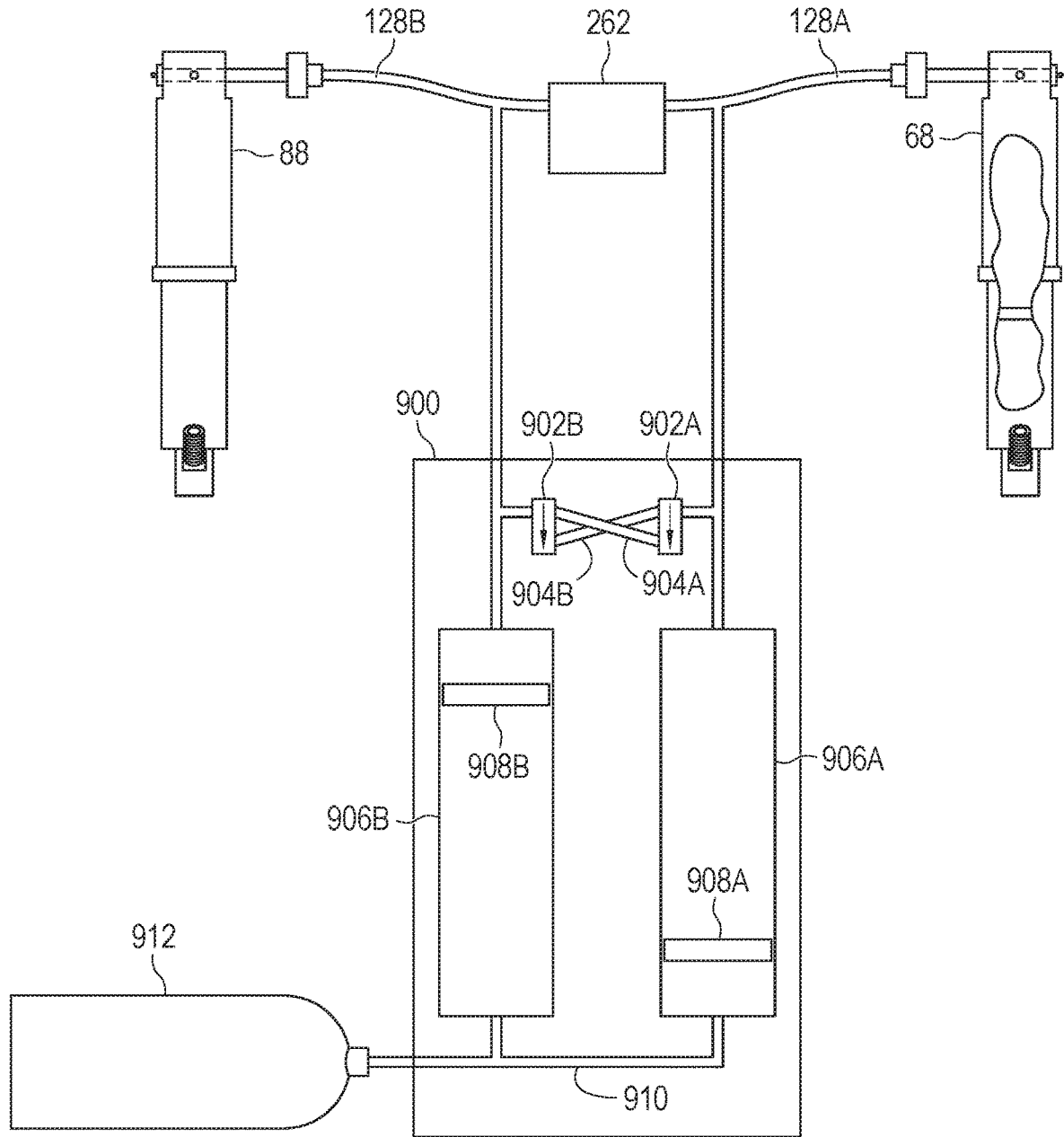


FIG. 2a

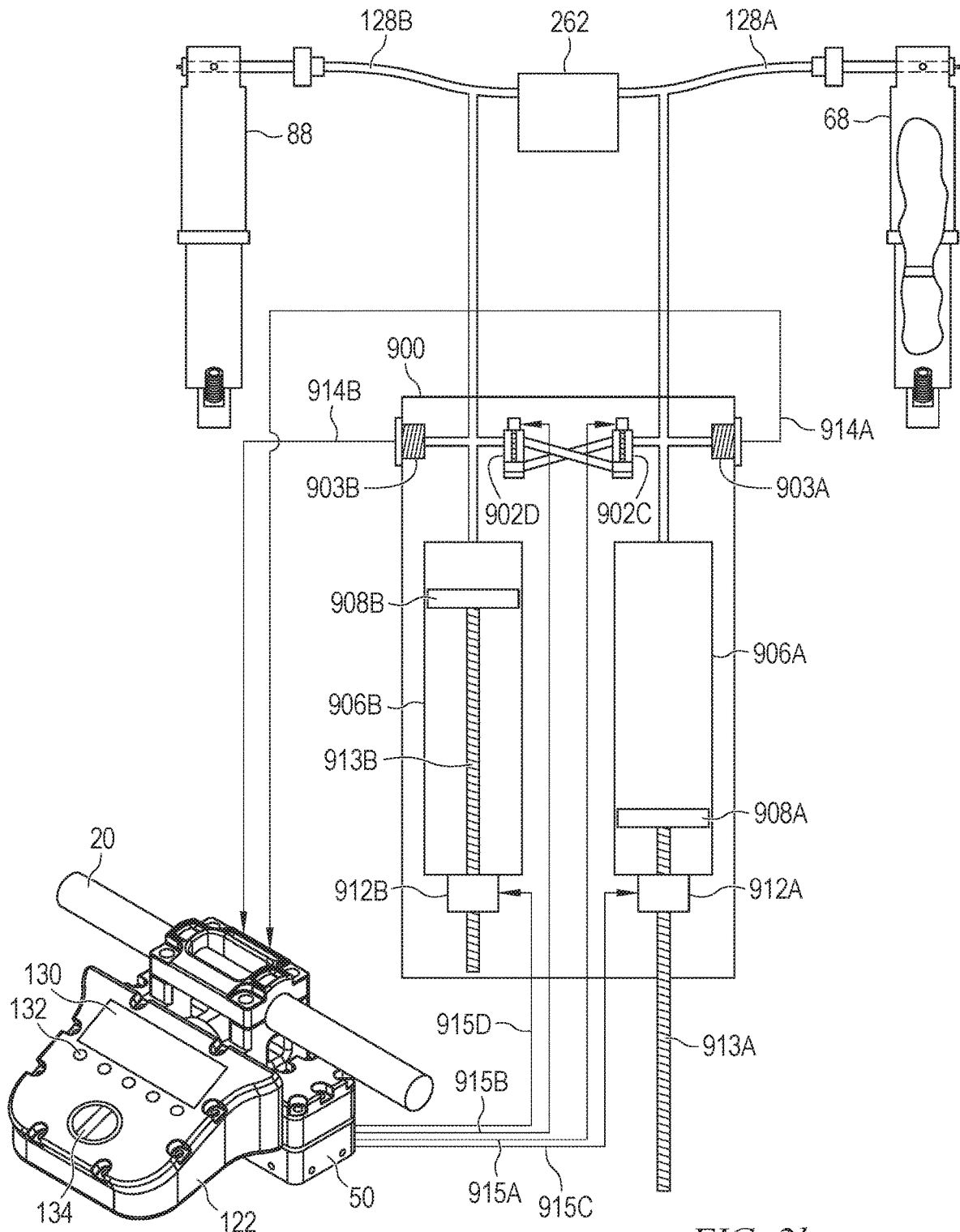


FIG. 2b

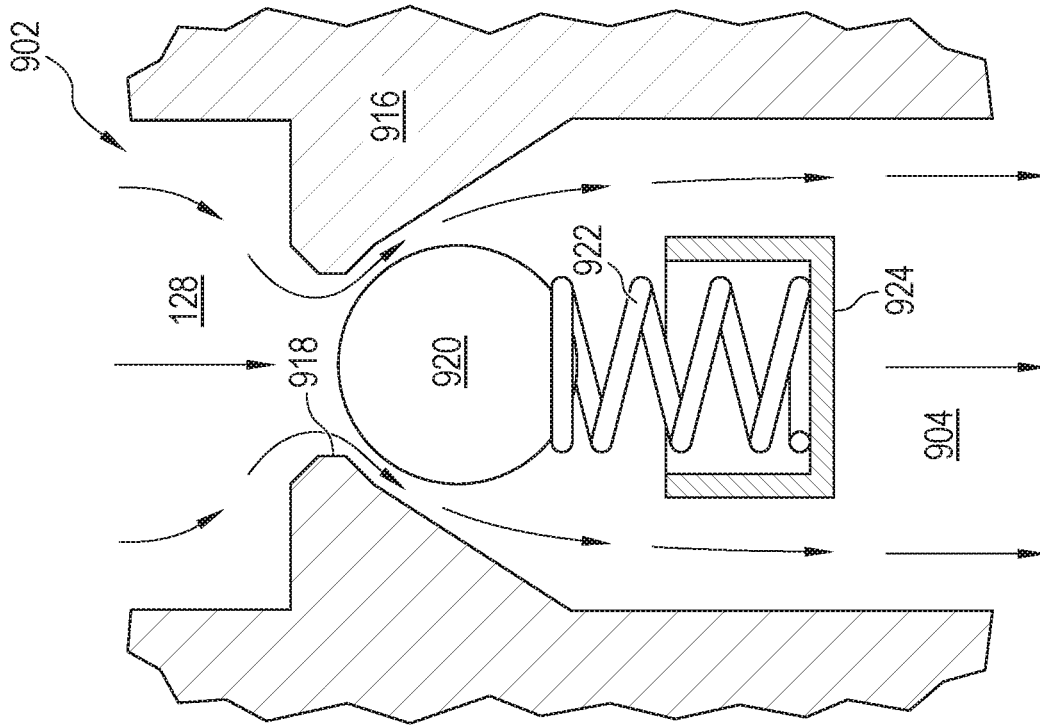


FIG. 3b

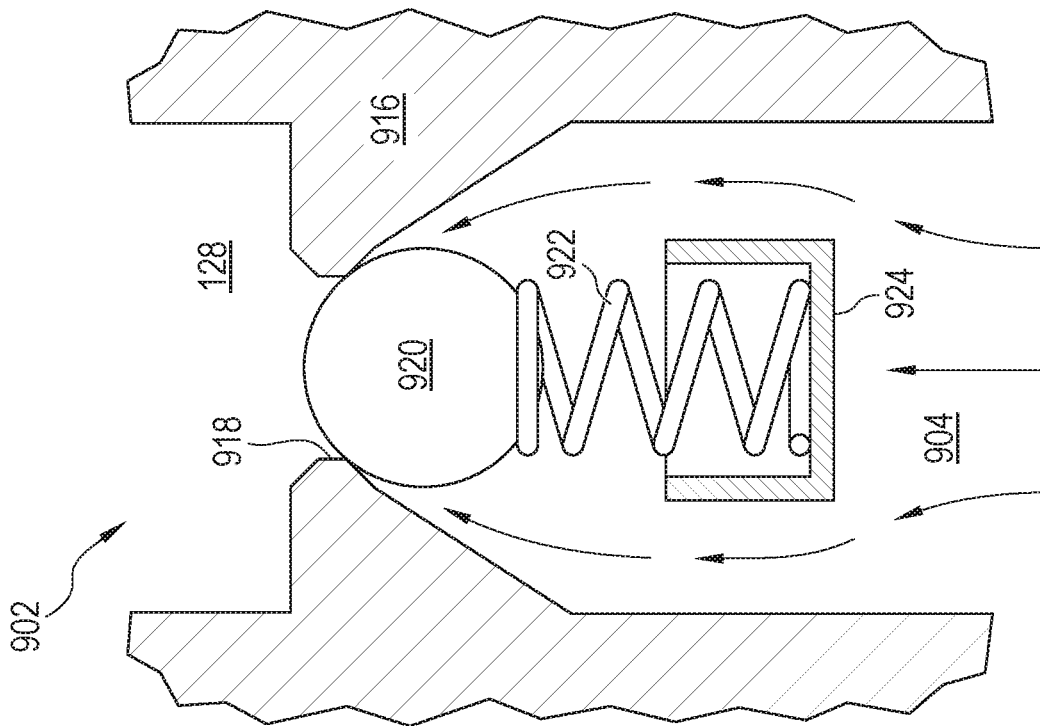


FIG. 3a

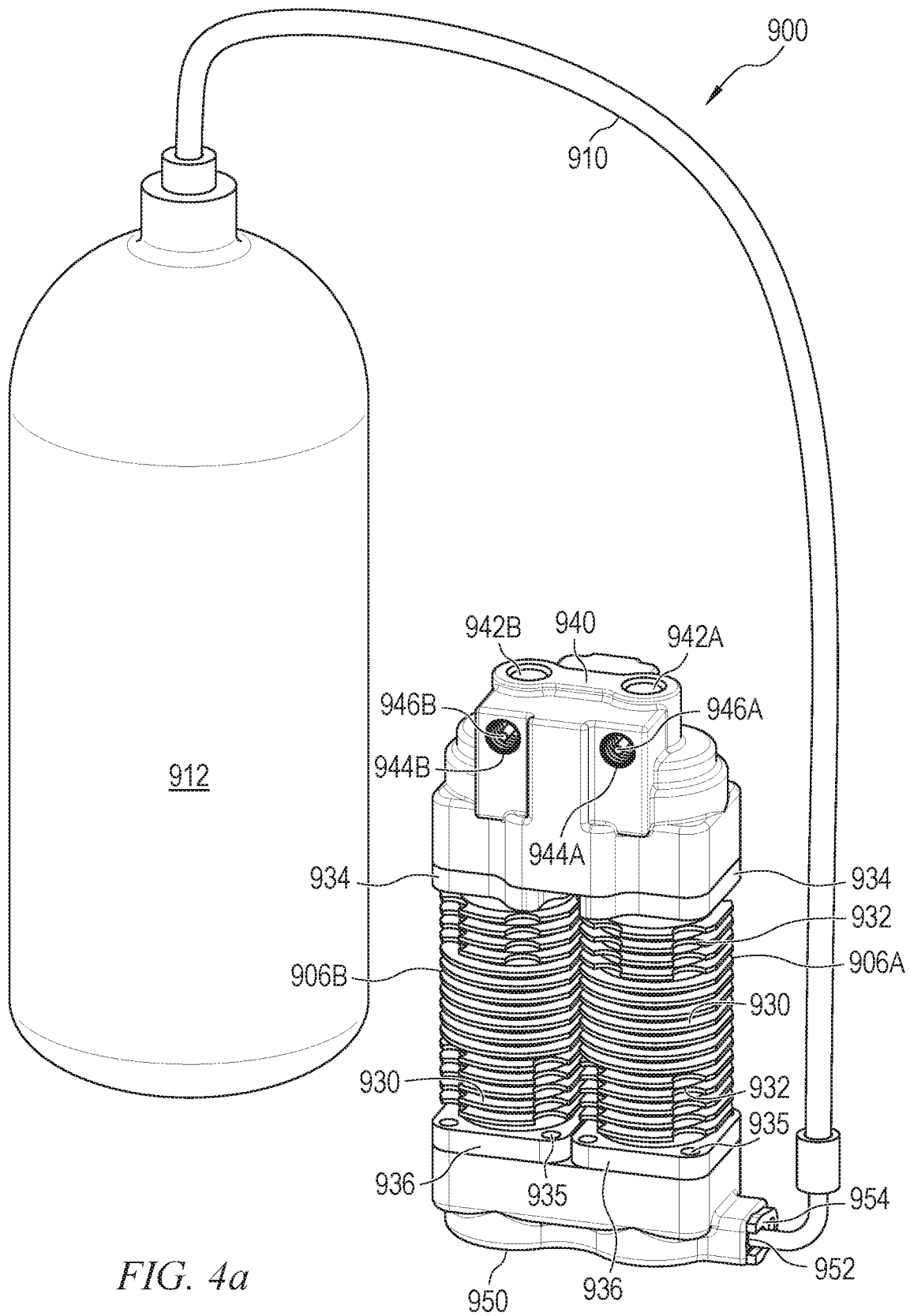


FIG. 4a

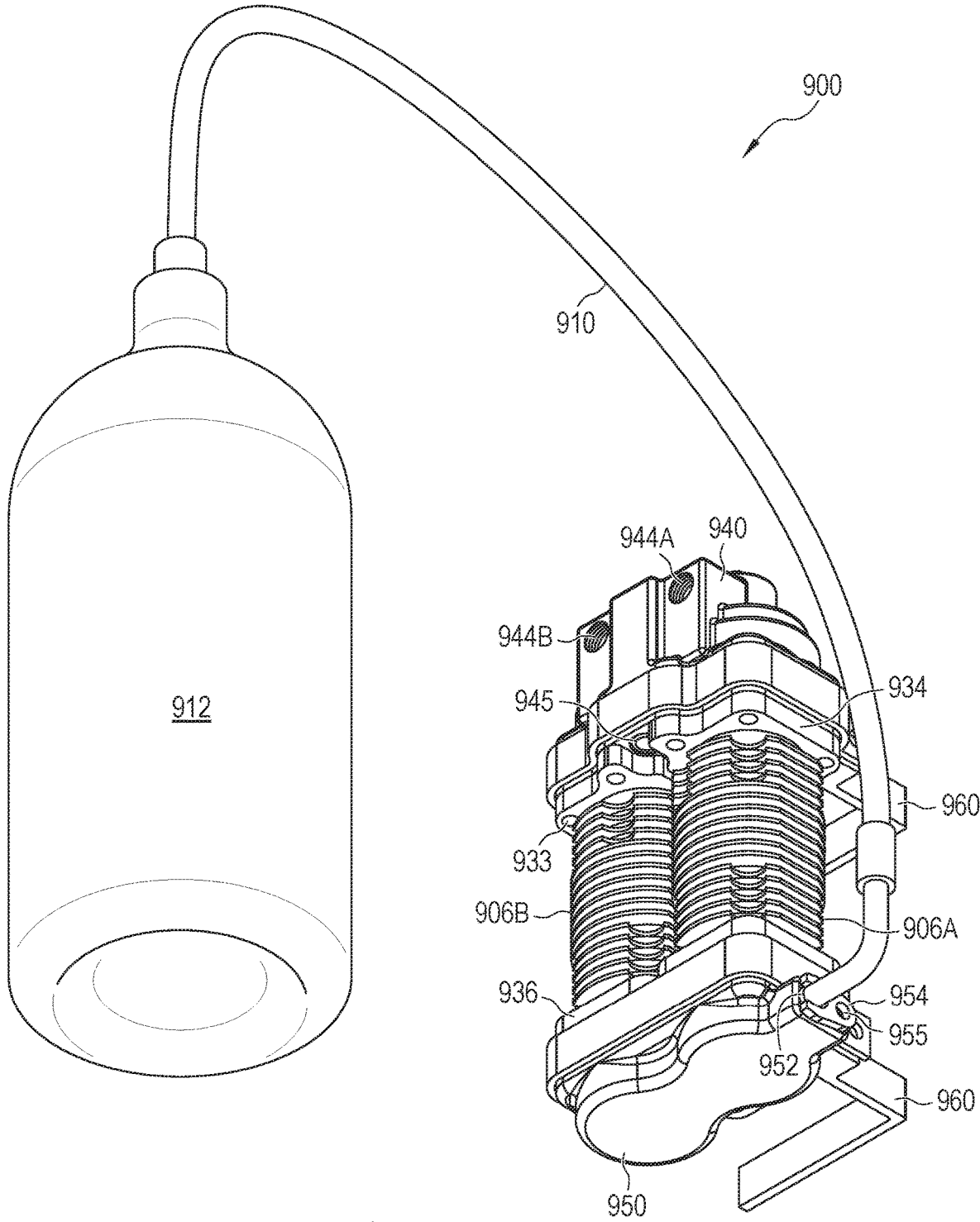


FIG. 4b

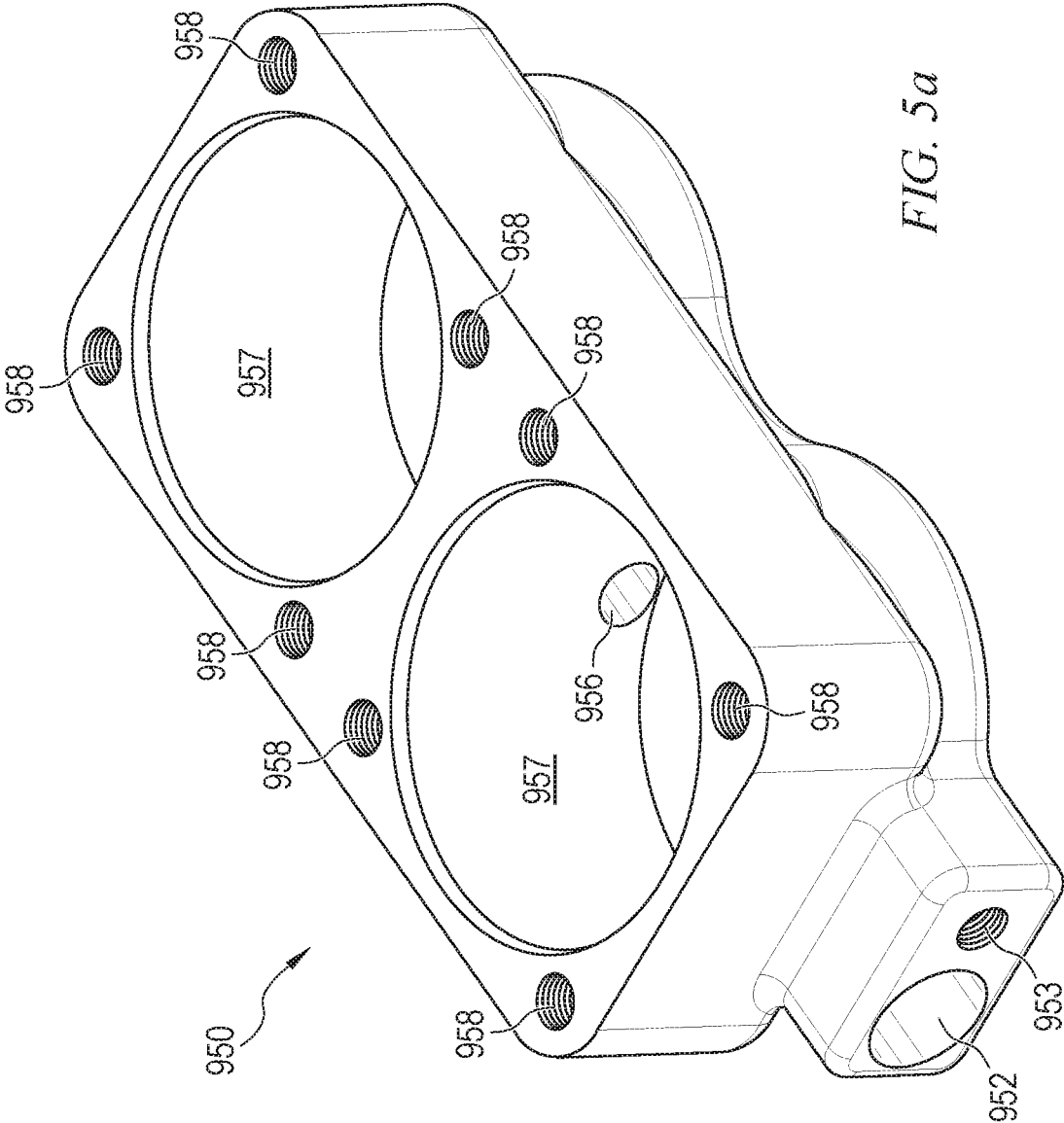


FIG. 5a

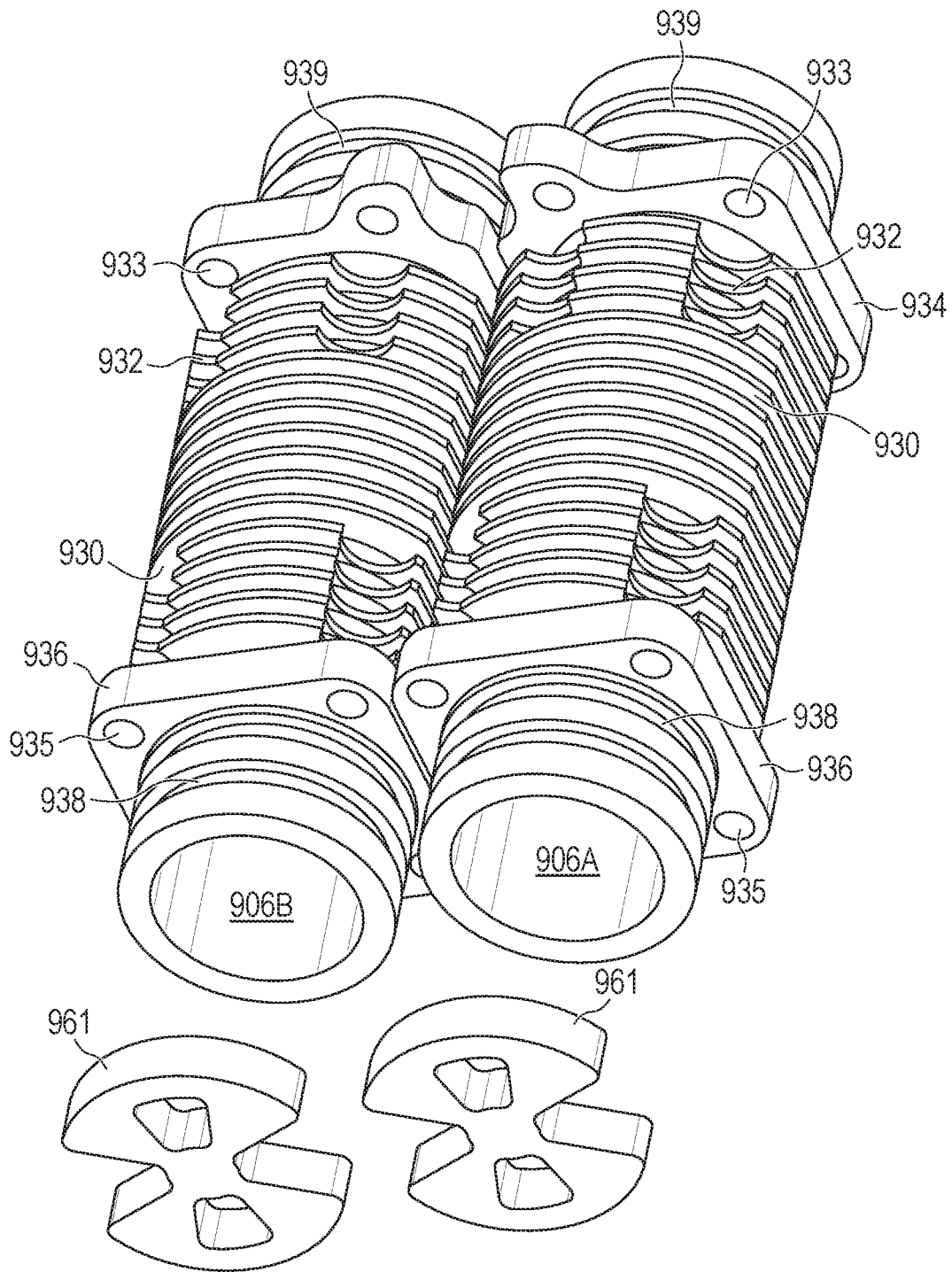


FIG. 5b

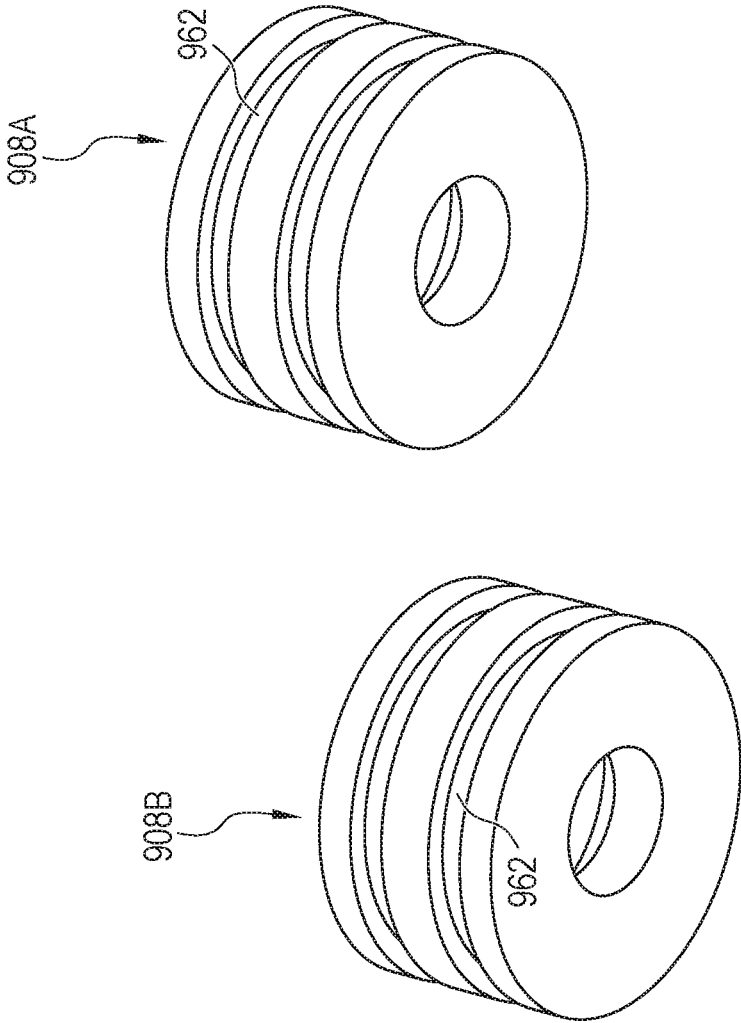


FIG. 5c

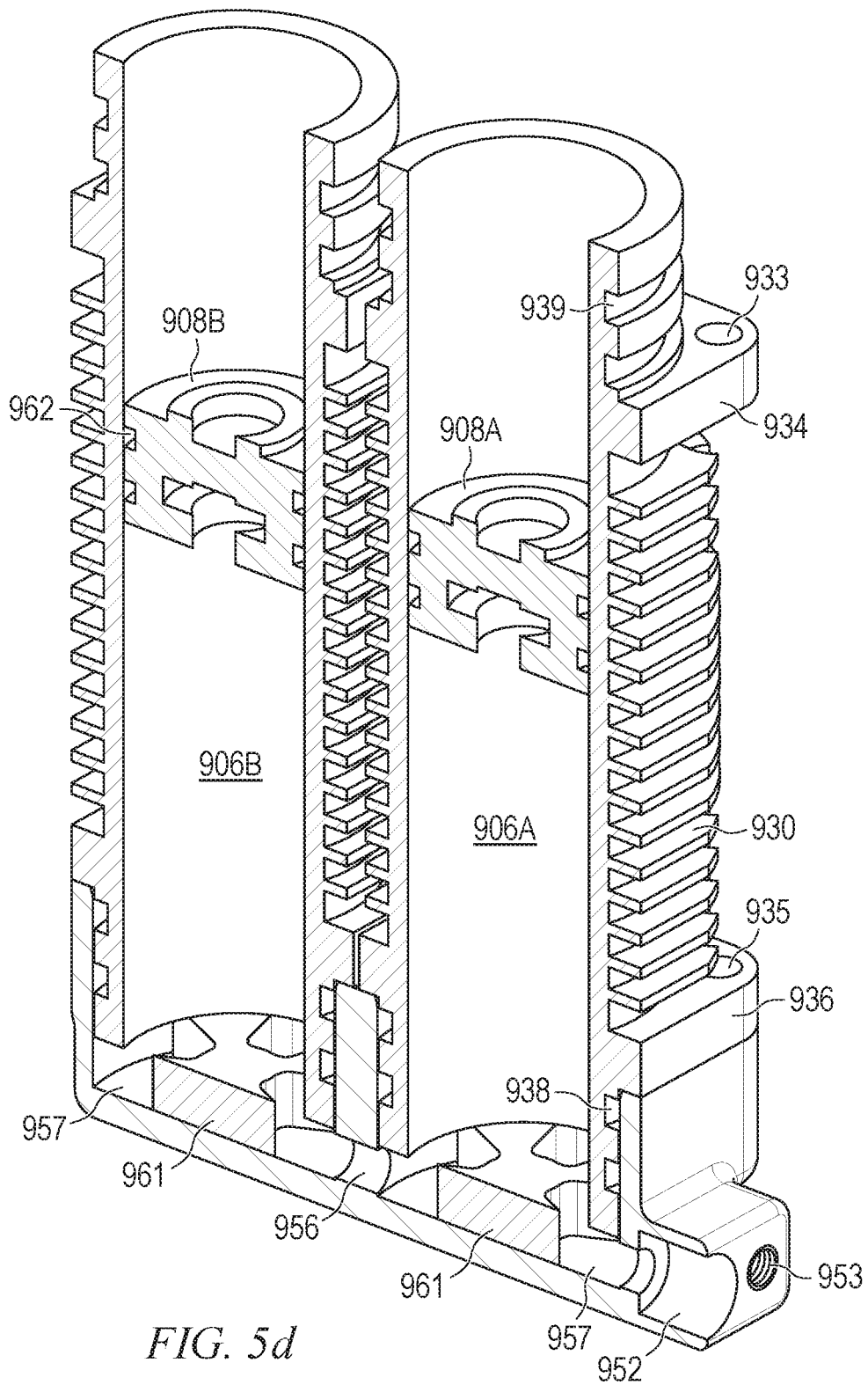


FIG. 5d

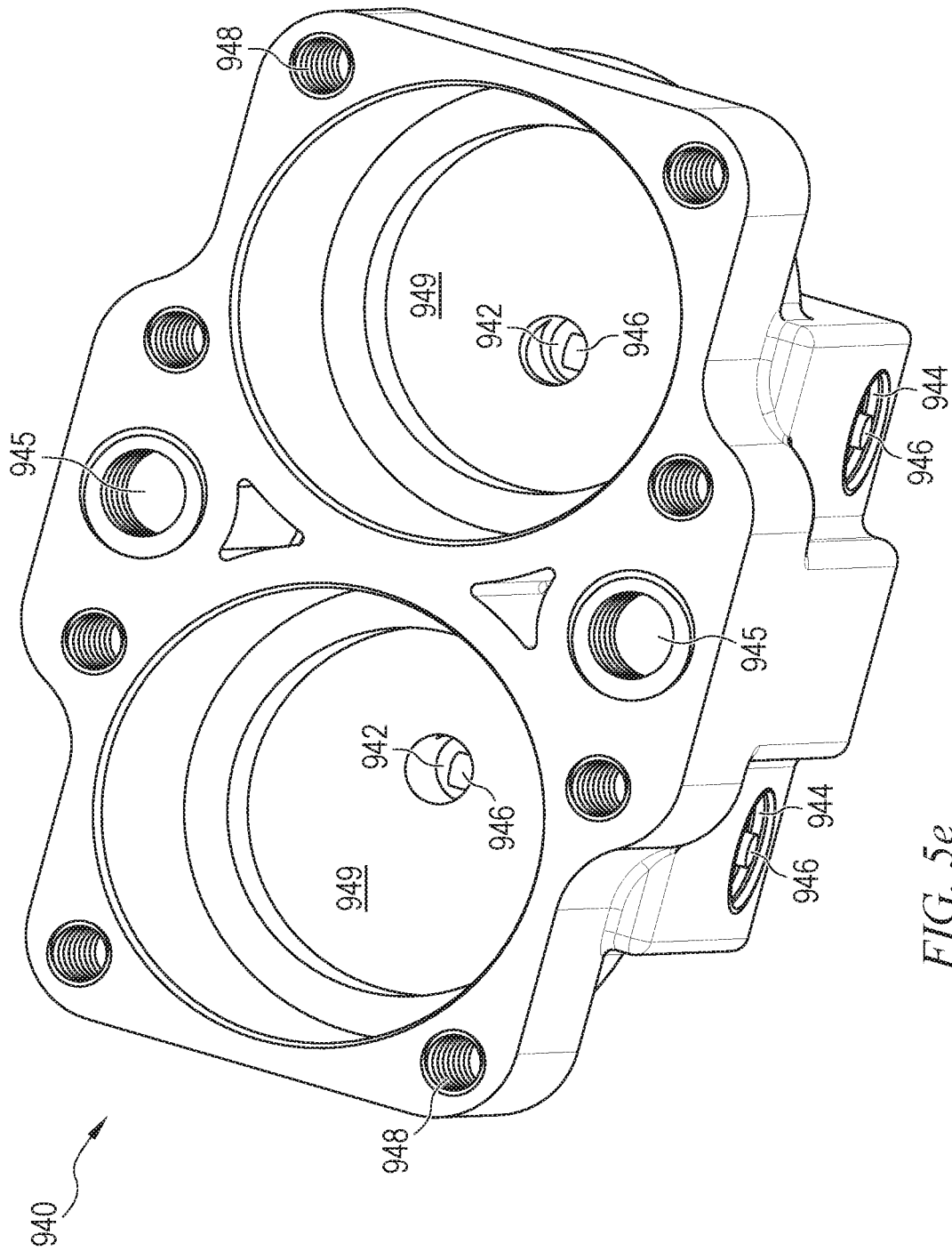


FIG. 5e

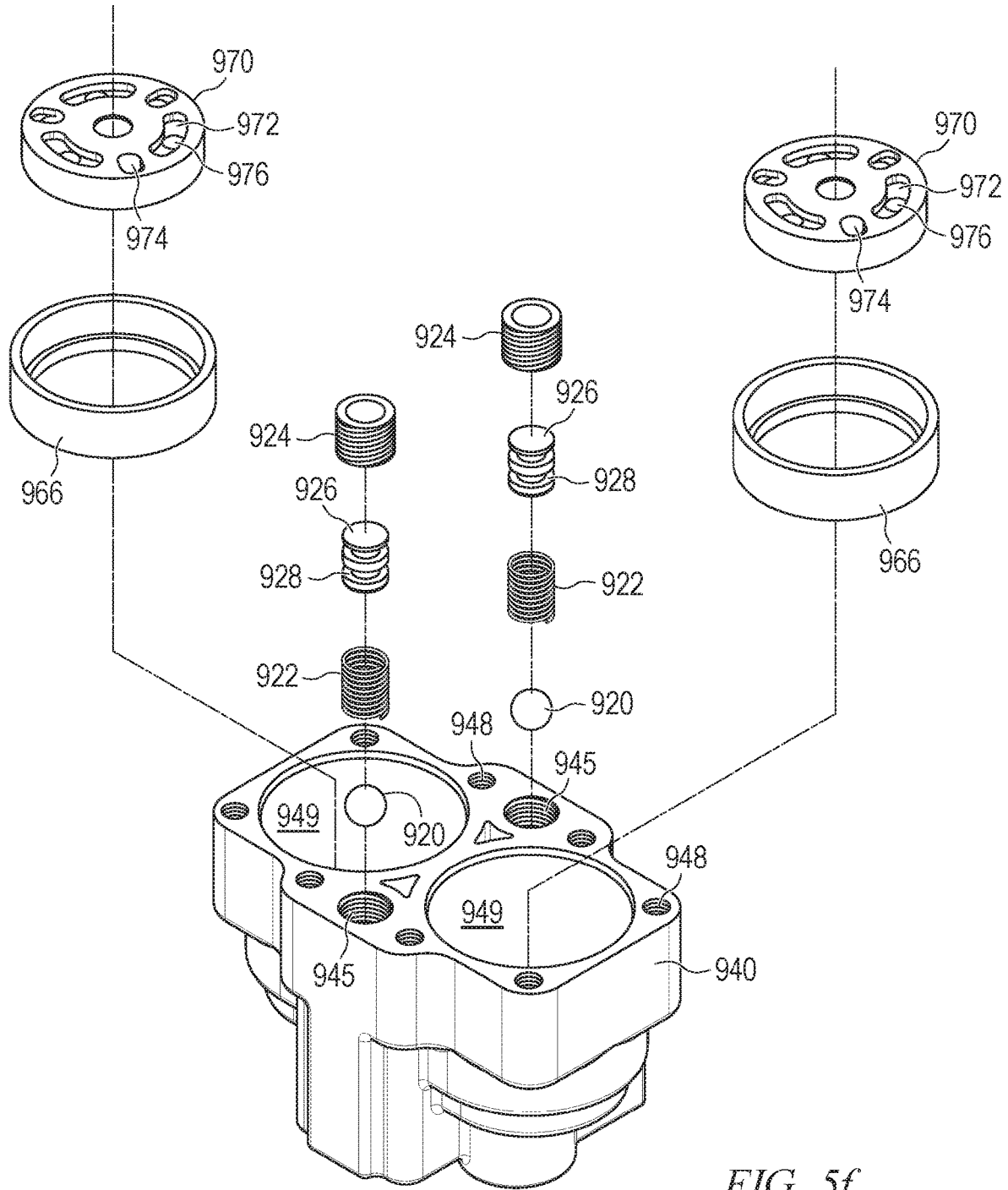


FIG. 5f

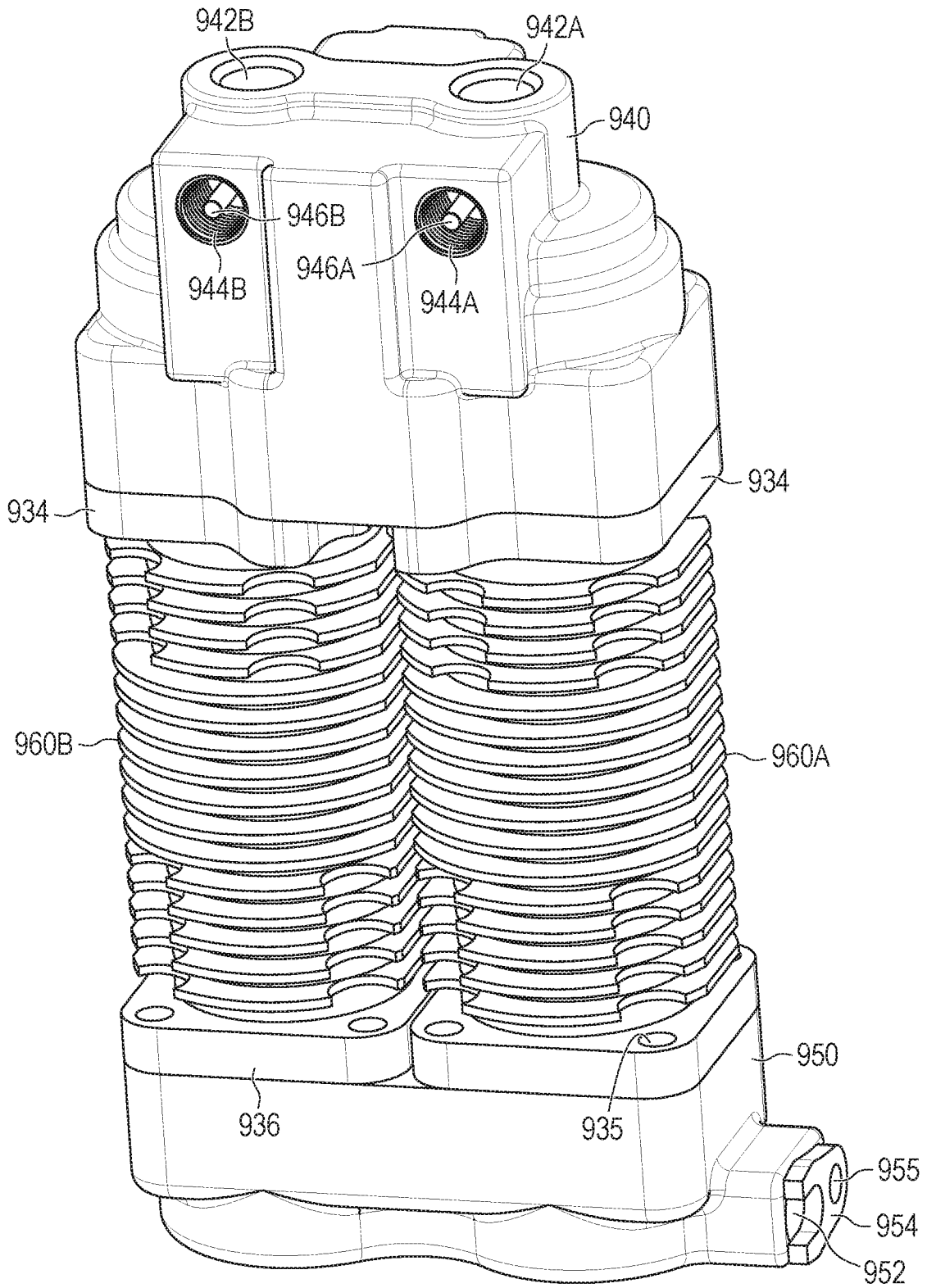


FIG. 5g

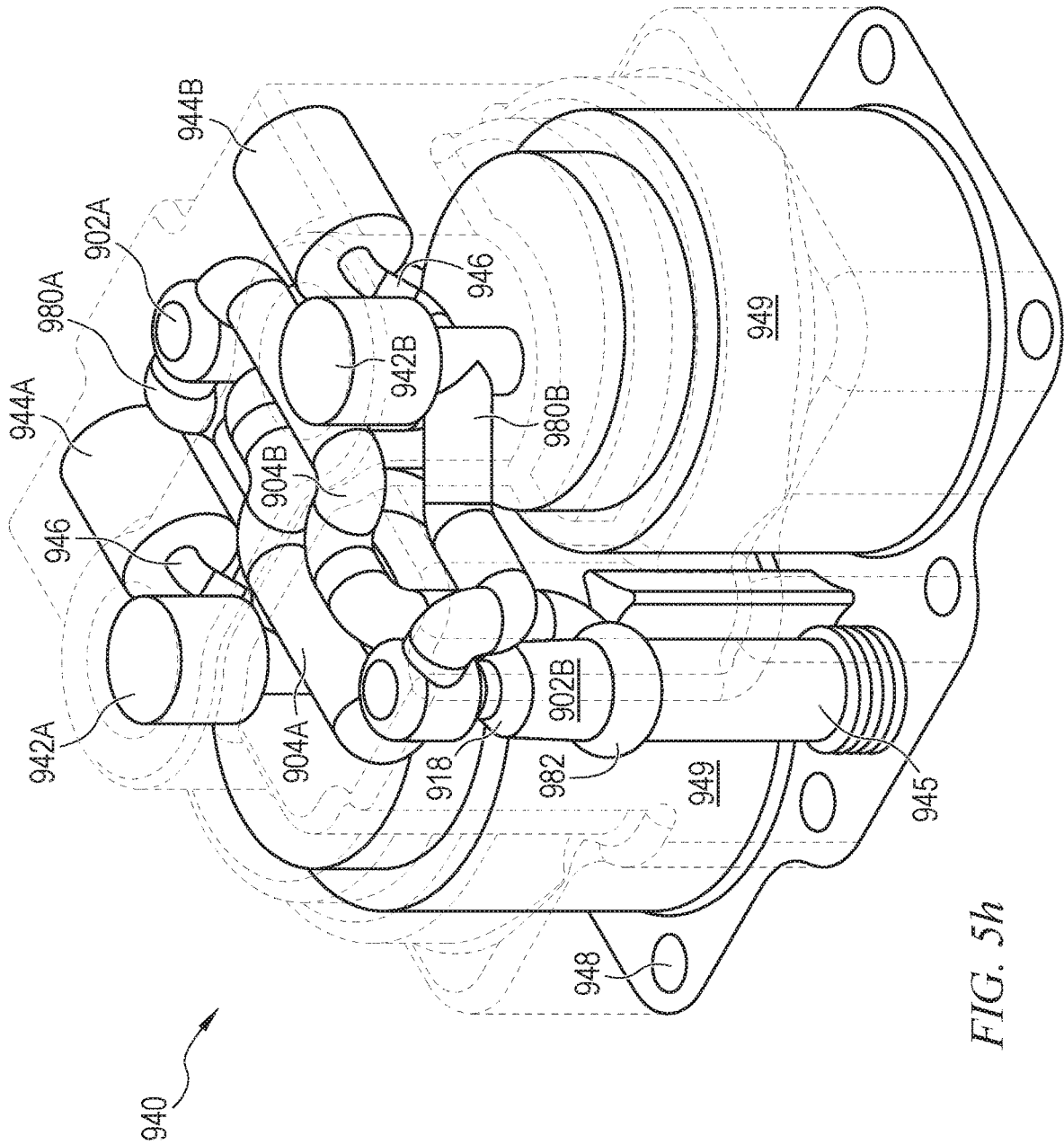
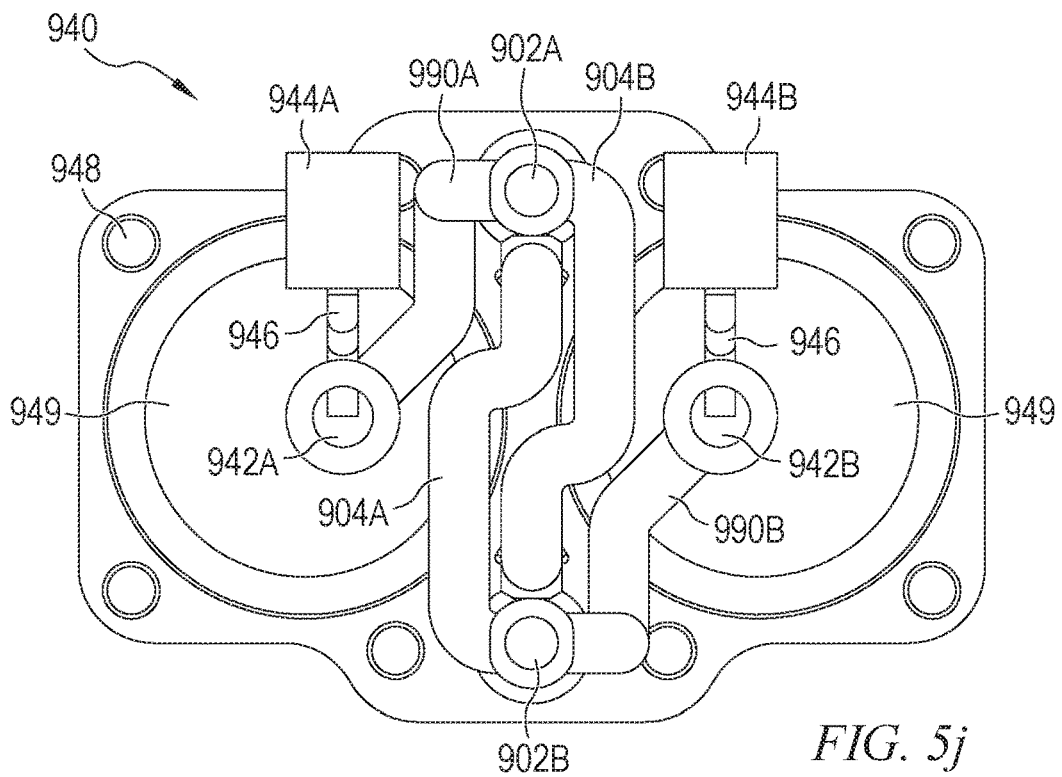
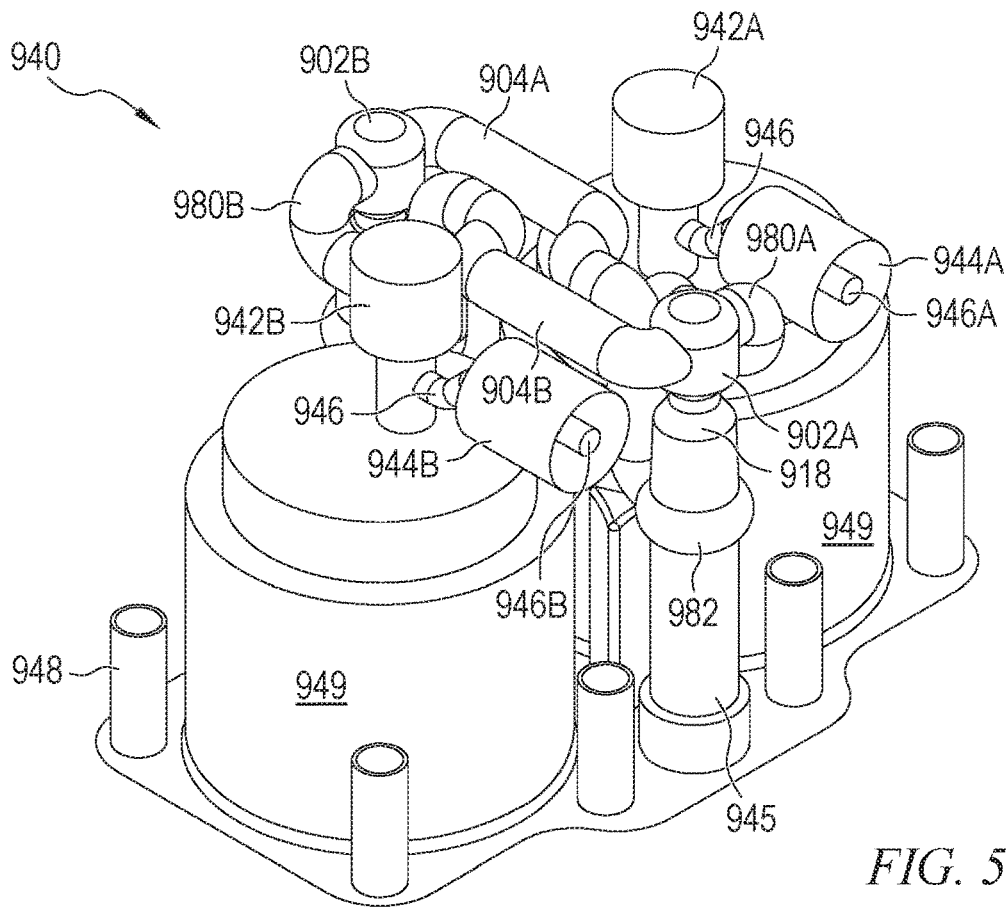


FIG. 5h



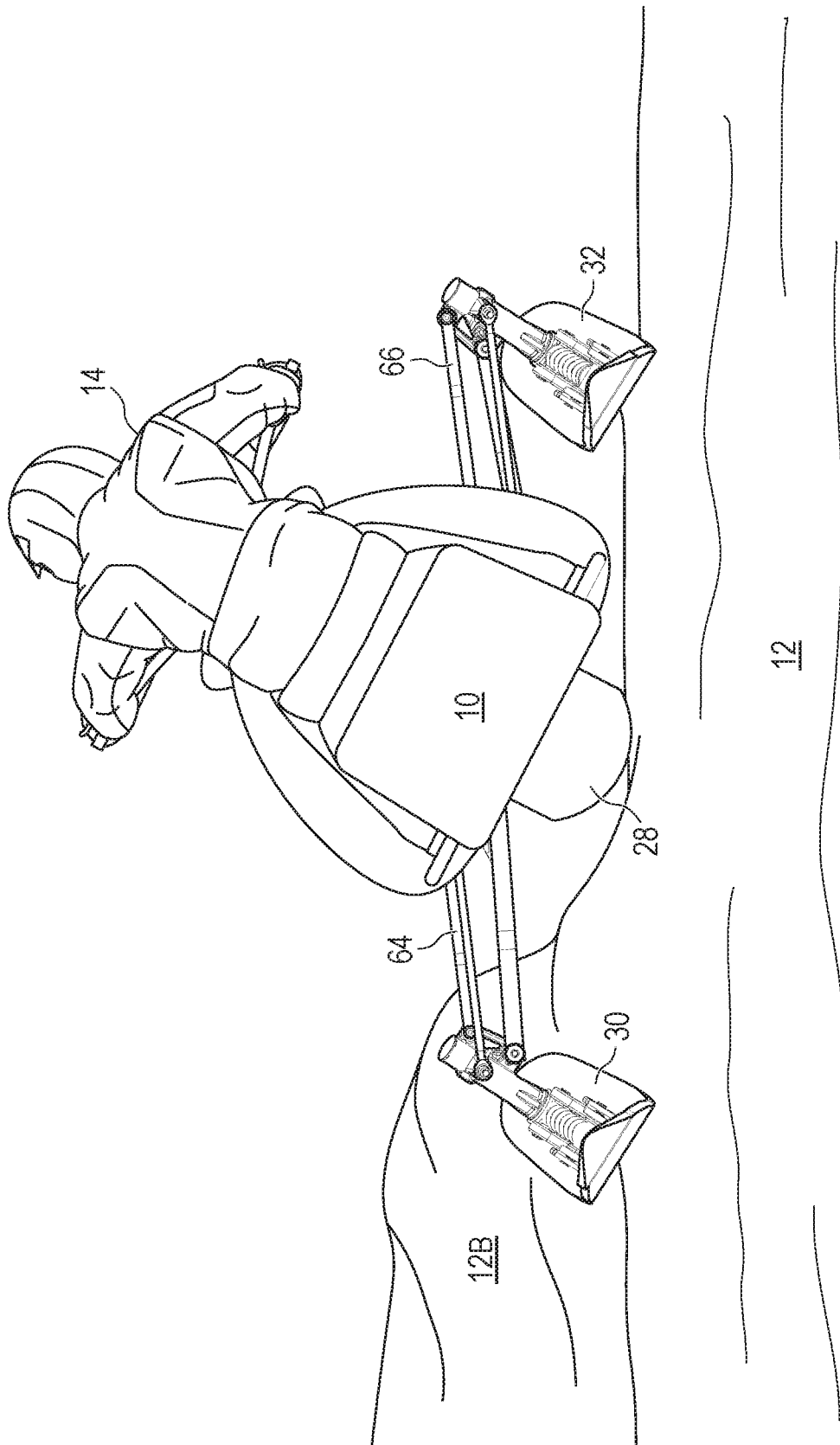


FIG. 6a

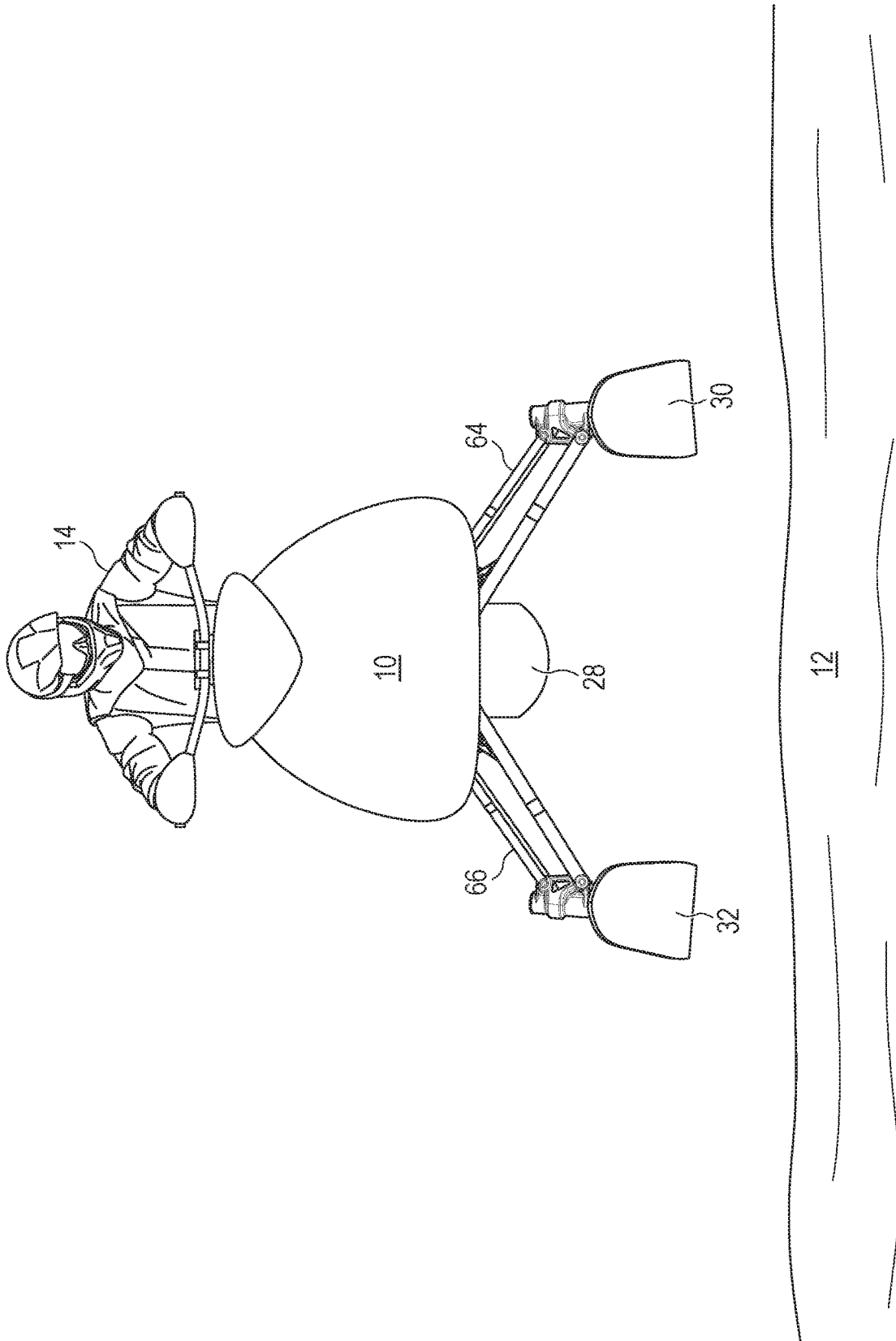


FIG. 6b

**HYDRAULIC BYPASS SYSTEM**

## CLAIM OF DOMESTIC PRIORITY

The present application claims the benefit of U.S. Provisional Application No. 62/332,893, filed May 6, 2016, which application is incorporated herein by reference.

## FIELD OF THE INVENTION

The present invention relates to hydraulic systems, and more particularly to a bypass system used with a hydraulic pump.

## BACKGROUND OF THE INVENTION

Vehicles with leaning capability have improved performance and safety. One embodiment of a leaning vehicle, illustrated as a snowmobile **10**, is illustrated in FIG. **1a**. While a snowmobile is specifically illustrated, similar leaning suspensions are used on other types of vehicles, e.g., cars, trucks, off-road vehicles, all-terrain vehicles, etc. Snowmobile **10** leans into turns so that skis **30** and **32** carve through snow similar to a skier's skis. Leaning of snowmobile **10** is facilitated by a front suspension **34**, shown separate from the snowmobile in FIG. **1b**, which attaches skis **30** and **32** to snowmobile **10** and actuates the skis. Hydraulic shocks **68** and **88** are used by suspension **34** to actuate suspension arms **64** and **66**. Suspension arms **64** and **66** each forms a parallelogram that is leaned over by force of hydraulic shocks **68** and **88** to lean snowmobile **10**. FIG. **1c** illustrates hydraulic shock **68** expanded, and hydraulic shock **88** collapsed, to lean suspension **34** toward the right of snowmobile **10**. Snowmobile **10** is leaned toward the left by expanding shock **88** and collapsing shock **68**.

FIG. **1d** illustrates hydraulic system **120** that leans suspension **34** by actuating hydraulic shocks **68** and **88**. Pump assembly **126** includes electric motors and a hydraulic pump that modify hydraulic pressure in the system to actuate hydraulic shocks **68** and **88**. Hydraulic fluid is pumped out of shock **68** and into shock **88** to collapse shock **68** and expand shock **88**. FIG. **1e** illustrates details of pump assembly **126** from FIG. **1d** in one embodiment. Electric motors **260** are controlled by a computer system. Electric motors **260** operate hydraulic pump **262** through pulleys **266** and **268**, connected by belts **270**. When pulley **268** is turned, hydraulic pump **262** pulls hydraulic fluid from one hose **128** and forces the hydraulic fluid out a second hose **128**. Changing the direction that pulley **268** is turned changes which hose **128** is losing fluid and which is receiving additional fluid. In some embodiments, an electric motor and hydraulic pump are coupled without using belts, e.g., by direct coupling to a common shaft or by other suitable means.

As illustrated, hydraulic system **120** is a closed system. All hydraulic fluid transferred between shock **68** and shock **88** is forced through hydraulic pump **262**. During some input events to suspension **34**, one hydraulic shock **68** or **88** may be under significantly elevated hydraulic pressure. An input event to the suspension system can be a change in terrain, e.g., a rock or bump hit by the snowmobile, which applies a significant force to the system. The elevated pressure forces hydraulic fluid through the pump and shocks at an increased rate that heats the hydraulic fluid, reduces efficiency, and increases wear and tear on hydraulic pump **262**.

Functioning of suspension **34** is more thoroughly explained in U.S. patent application Ser. No. 14/191,292

filed Feb. 26, 2014, now U.S. Pat. No. 9,545,976 issued Jan. 17, 2017, the disclosure of which is incorporated herein by reference.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1a-1e** illustrate a vehicle having a leaning suspension with hydraulic actuation;

FIGS. **2a-2b** illustrate block diagrams of a bypass system coupled to the hydraulic system of the leaning suspension;

FIGS. **3a-3b** illustrate operation of one check valve embodiment usable in the bypass system;

FIGS. **4a-4b** illustrate perspective views of one physical implementation of the bypass system;

FIGS. **5a-5j** illustrate various cross-sectional and exploded views of the bypass system implementation; and

FIGS. **6a-6b** illustrate situations benefiting from the functionality of the bypass system.

## DETAILED DESCRIPTION OF THE DRAWINGS

The present invention is described in one or more embodiments in the following description with reference to the figures, in which like numerals represent the same or similar elements. While the invention is described in terms of the best mode for achieving the invention's objectives, it will be appreciated by those skilled in the art that it is intended to cover alternatives, modifications, and equivalents as may be included within the spirit and scope of the invention as defined by the appended claims and their equivalents as supported by the following disclosure and drawings. While a snowmobile is illustrated, the bypass system is compatible with other leaning vehicles that utilize a hydraulic actuating system. The bypass system may also be used in hydraulic systems that are used in other situations besides actuating a leaning suspension of a vehicle.

FIG. **2a** illustrates hydraulic system **120** from FIG. **1d** with a passive bypass system **900** attached between shocks **68** and **88** in parallel with hydraulic pump **262**. Bypass system **900** includes check valves **902**, which allow hydraulic fluid to be bypassed between the two sides of hydraulic system **120**. Check valve **902A** allows hydraulic fluid to flow from shock **68** to shock **88** through hoses **128** when the hydraulic pressure of shock **68** is sufficiently high relative to the hydraulic pressure in shock **88** to open check valve **902A**. Check valve **902B** allows hydraulic fluid to flow from shock **88** to shock **68** through hoses **128** when the hydraulic pressure of shock **88** is sufficiently high relative to the hydraulic pressure in shock **68** to open check valve **902B**. When the hydraulic pressures in shocks **68** and **88** are within a normal or desired range of each other, neither of check valves **902** are open, and no hydraulic fluid bypasses hydraulic pump **262** through bypass system **900**. In passive systems, the maximum pressure seen at the ports of hydraulic pump **262** is set by the spring pressure in check valves **902**.

Check valves **902** are connected in parallel with each other, and with hydraulic pump **262**, between shock **68** and shock **88**. Check valves **902A** and **902B** are oriented in opposite directions so that each check valve allows flow in an opposite direction from the other. Operation of check valves **902** is described below with reference to FIGS. **3a-3b**.

Bypass system **900** allows hydraulic fluid to bypass hydraulic pump **262** when an external event input to hydraulic system **120** raises the hydraulic pressure in one of the shocks **68** or **88** to an undesirable level. Bypass system **900** limits the pressure applied to hydraulic pump **262** to

approximately a maximum pressure set by configuring check valves **902** to turn on at or about the maximum desired hydraulic pressure.

Pathways **904A** and **904B** are used within bypass system **900** to couple check valves **902** to each other. Pathway **904A** couples the bottom, or downstream, side of check valve **902A** to the top, or upstream, side of check valve **902B**. Pathway **904B** couples the bottom side of check valve **902B** to the top side of check valve **902A**. When check valve **902A** turns on, hydraulic fluid flows through check valve **902A** and pathway **904A** to the top side of check valve **902B** and to the shock **88** side of hydraulic system **120**. The elevated pressure at the upstream side of check valve **902A** is transferred through pathway **904B** to help keep check valve **902B** closed. When check valve **902B** turns on, hydraulic fluid flows through check valve **902B** and pathway **904B** to the top side of check valve **902A** and to the shock **68** side of hydraulic system **120**.

Bypass system **900** includes hydraulic reservoirs or cylinders **906** that allow for hydraulic fluid to be removed from or added back into hydraulic system **120**. Hydraulic cylinder **906A** is coupled to the shock **68** side of hydraulic system **120**, and hydraulic cylinder **906B** is coupled to the shock **88** side of the hydraulic system. Hydraulic cylinder **906A** includes a piston **908A** and hydraulic cylinder **906B** includes a piston **908B**. Pistons **908** slide up and down freely within their respective hydraulic cylinders as the relative pressures above and below the pistons change. Pistons **908** operate within hydraulic cylinders **906** similarly to floating pistons **174** in shocks **68** and **88**.

Hydraulic cylinders **906** allow hydraulic fluid to be removed from and added back into hydraulic system **120**. Modifying the amount of hydraulic fluid in hydraulic system **120** allows control of the spring rate of shocks **68** and **88**. As shocks **68** and **88** are extended by external forces, the spring rate is reduced by a reduction in the pressure within the shocks. As the suspension extends, spring rate and mechanical leverage is reduced. Bypass system **900** adds hydraulic fluid from hydraulic cylinders **906** to shocks **68** and/or **88** to substantially maintain piston position within the shocks and spring rate of the shocks.

As shocks **68** and **88** are compressed by external forces, the spring rate is increased by the increase of hydraulic pressure in the shocks. Removing hydraulic fluid from hydraulic system **120** keeps the spring rate of shocks **68** and **88** at comfortable levels. The accumulation of hydraulic fluid in cylinders **906** as the fluid is forced out of shocks **68** and/or **88** reduces or maintains the spring rate of the shocks. The force of fluid into and out of cylinders **906**, and the accompanying thermal transfer from the fluid to the cylinders, provides control of the suspension through the first half of suspension travel.

Hydraulic cylinders **906** are each coupled through hose or pathway **910** to air canister **912**. Air canister **912** contains compressed air to apply pressure to pistons **908** opposite shocks **68** and **88**. Hydraulic cylinders **906** provide room for hydraulic fluid to be removed from and then added back into hydraulic system **120**. Compressed air from canister **912** helps balance hydraulic pressure in hydraulic system **120** and bypass system **900**, which regulates when, and how much, hydraulic fluid flows between hydraulic system **120** and bypass system **900**.

As suspension **34** experiences events that apply force to hydraulic shocks **68** and **88**, the hydraulic pressure within the shocks is transferred to bypass system **900** through hoses **128**. If one side of suspension **34** sees increased pressure, the pressure increases through the associated hose **128** to the

associated side of bypass system **900** forcing additional hydraulic fluid into that side of the bypass system. Increasing the pressure over the cracking pressure of the associated check valve **902** will cause hydraulic fluid to be transferred to the other side of hydraulic system **120** in addition to being transferred to bypass system **900**. If one side of suspension **34** sees reduced pressure, the pressure reduces through the associated hose **128** to the associated side of bypass system **900** and draws hydraulic fluid from that side of the bypass assembly.

Air canister **912** applies counter-pressure to pistons **908**. The pressure applied by air canister **912** forces additional hydraulic fluid into hydraulic system **120** when hydraulic pressure in one or both sides of hydraulic system **120** is decreased. In some cases, snowmobile **10** may go airborne, in which case both sides of suspension **34** fall. Both sides of hydraulic system **120** see significantly reduced pressure. The pressure in both hoses **128** is reduced, which propagates to hydraulic cylinders **906** above their respective pistons **908**. Air canister **912** applies counter-pressure to force spare hydraulic fluid from hydraulic cylinders **906** into hydraulic shocks **68** and **88** through hoses **128**. The additional fluid increases the spring rate of shocks **68** and **88** when snowmobile **10** initially contacts the ground. Without forcing additional fluid into hydraulic shocks **68** and **88** with air canister **912**, suspension **34** would have a significantly reduced spring rate on initial contact. The suspension would not apply significant force back to the ground until returning to approximately the same position the suspension was in before leaving the ground.

Air canister **912** is initially provided with a pressure equivalent to the pressure in shocks **68** and **88** while the vehicle is stationary, so that the entire system is in equilibrium when at rest. When snowmobile **10** gets air, the pressure in air canister **912** is significantly higher than the hydraulic pressure in shocks **68** and **88**, and the air canister forces additional hydraulic fluid into hydraulic system **120** to keep the spring rate of suspension **34** from falling below desired levels. In one embodiment, the volume of air canister **912** is set such that when suspension **34** extends, spring rate is maintained at useful levels. Suspension **34** is fully extended while snowmobile **10** is in the air, and then the suspension collapses when landing. Hydraulic fluid is forced back into bypass system **900** to absorb the energy of the suspension landing event. Pressure between air canister **912** and hydraulic system **120** equalizes as suspension **34** returns to the normal position. Bypass system **900** provides rebound and compression damping for suspension **34**.

Using a larger air canister **912** to increase or maximize air volume in bypass system **900** helps reduce pressure or spring rate drop at shocks **68** and **88** during the first half of suspension travel. Air canister **912** provides a passive system for adding or removing hydraulic fluid from hydraulic system **120**. FIG. **2b** illustrates an embodiment with air canister **912** replaced by electric motors **912** actuating pistons **908** through lead screws **913**. Lead screws **913** extend through hollow shafts of motors **912**. Lead screws **913** can be notched to prevent significant rotation of the lead screws within motors **912**. Lead screws **913** can alternatively extend through pistons **908** rather than motors **912**. Check valves **902A** and **902B** can also be replaced by lead screw systems **902C** and **902D**. In some active embodiments, check valves **902** remain as a safety measure in case of failure of the active valves.

The computer system within control panel **122**, or located elsewhere, reads hydraulic pressure of the system through transducers **903**. Transducers **903** are hydraulically coupled

to hoses 128A and 128B to generate electrical signals 914 that provide information as to the present hydraulic pressure seen on each side of the system.

Control panel 122 uses the hydraulic pressure information 914 from transducers 903 to determine when to add or remove hydraulic fluid from hydraulic system 120, and when to bypass fluid between shocks 68 and 88. Control panel 122 outputs control signals 915C and 915D to turn lead screws 913 and actuate pistons 908, thus drawing fluid into or expelling fluid from cylinders 906. Control panel 122 outputs control signals 915A and 915B to open or close bypass lead screw systems 902C and 902D, thus bypassing hydraulic fluid between the two sides of the system when desirable.

Control panel 122 can use other data inputs besides only transducers 903 to determine how to operate valves 902 and motors 912. Control panel 122 can operate bypass system 900 based on vehicle speed, lean angle, four wheel steering, position, and attitude of the vehicle using accelerometers and gyros, as well as any other sensors distributed around the vehicle or on hydraulic system 120. Electrical current draw or the rotational speed of pump 262 can be detected to indicate system pressure. Pistons 908 are actively actuated to control the volume of hydraulic fluid within hydraulic system 120, the pressure within hydraulic shocks 68 and 88, the spring rate of suspension 34, or whatever other characteristic is of concern. A computer system observes hydraulic pressure fluctuations using transducers 903, as well as outputs of other various sensors placed around the vehicle, and makes decisions about how much fluid to bypass. Active bypass potentially increases efficiency by allowing more accurate control of the amount and timing of fluid bypassed.

In some embodiments, valves 902 and motors 912 are controlled by the computer system in control panel 122 based on a light imaging, detection, and ranging (LIDAR) system disposed on snowmobile 10. The LIDAR system can scan terrain 12 in front of snowmobile 10 and automatically reconfigure hydraulic system 120 and bypass system 900 to compensate for upcoming hazards or changes of terrain 12 in advance. The LIDAR system can also detect oncoming vehicles and extend suspension 34 to avoid or reduce injury from the vehicles. Extending suspension 34 toward hazards can help the suspension be used to protect rider 14. Suspension 34 has an active role in protecting passengers and improving ride quality.

FIGS. 3a-3b illustrate operation of check valves 902A and 902B. Check valves 902 are illustrated in an implementation using ball check valves, but other types of check valves are used in other embodiments. A check valve 902 is coupled to a hose 128 at the upstream side of the check valve, and coupled to a hydraulic pathway 904 at the downstream side. Check valve 902 includes a container 916 that holds the parts of the check valve together and guides hydraulic fluid through the system. Container 916 includes a seat 918 that forms a circle around the inside of the container. When check valve 902 is closed, ball 920 contacts seat 918 in a full circle to create a seal. Spring 922 presses against ball 920 and base 924. Spring 922 applies a force to ball 920 to help keep the seal between the ball and seat 918 when the upstream and downstream pressure are within close proximity.

FIG. 3a illustrates check valve 902 with hydraulic pressure in hydraulic pathway 904 greater than the hydraulic pressure in hose 128. The hydraulic fluid in pathway 904 applies addition force, along with spring 922, against ball

920. Ball 920 maintains a seal with seat 918 and substantially prevents flow of hydraulic fluid from pathway 904 to hose 128.

FIG. 3b illustrates check valve 902 with the hydraulic pressure in hose 128 substantially higher than the hydraulic pressure in pathway 904. Ball valve 902 opens when the pressure of hydraulic fluid in hose 128 is sufficiently above the pressure of pathway 904 to counteract the force of spring 922 and create a separation between ball 920 and seat 918. The pressure required in hose 128, relative to the pressure in pathway 904, to open check valve 902 is called the cracking pressure of the check valve. The cracking pressure of ball check valve 902 is configured to set the desired maximum pressure for a side of hydraulic system 120.

FIGS. 4a and 4b illustrate one physical implementation of bypass system 900 in two different perspective views. Bypass system 900 includes cylinders 906 oriented in parallel and physically mounted or coupled between a manifold or valve block 940 and air distribution block or cap 950. In one embodiment, cylinders 906, manifold 940, and cap 950, are separately manufactured using 3d-printing, molding, or other suitable manufacturing technique and then assembled together. Cylinders 906, manifold 940, and cap 950 can be manufactured from titanium, titanium alloys, steel, aluminum, plastic, or another suitable material.

Cylinders 906 include air cooling fins 930 disposed around the cylinders. Air cooling fins 930 are generally formed as an integral part of the cylinders, but can be attached after the cylinders are manufactured. Fins 930 are formed of a similar material to the cylinders themselves, with good heat transferring qualities, to facilitate heat transfer from hydraulic fluid within the cylinders to the fins. Heat is transferred from the fins to ambient air around cylinders 906. Cooling the hydraulic fluid through fins 930 improves performance of hydraulic pump 262.

Fins 930 near the tops and bottoms of cylinders 906 include cutouts 932 to allow room for inserting screws or bolts to attach the cylinders to cap 950 and manifold 940. Cylinders 906 include screw holes 933 through base plate 934, and screw holes 935 through base plate 936, for attaching the cylinders to manifold 940 and cap 950, respectively. In one embodiment, cylinders 906, fins 930, and base plates 934 and 936 are all separately formed of a uniform piece of material by 3D-printing a metal such as copper, steel, titanium, plastic, or another appropriate metal, metal alloy, polymer, etc. Bolts are inserted through openings 935 of base plate 936 and turned to mate with threaded openings of cap 950. Bolts are inserted through openings 933 of base plate 934 and turned to mate with threaded openings of manifold 940.

Manifold 940 includes openings 942 on top of the manifold opposite cylinders 906 for attachment of hoses 128 from hydraulic system 120. Hoses 128 can be attached by a threading of the hoses corresponding to threading inside of openings 942. In another embodiment, the ends of hoses 128 include flanges, and a metal bracket is bolted onto the top of manifold 940 to hold in the hoses by their respective flanges. Other appropriate attachment mechanisms are used in other embodiments. Internal pathways of manifold 940 hydraulically couple hoses 128 at openings 942 to respective cylinders 906. Manifold 940 also includes check valves 902, as well as pathways 904, as illustrated below. Check valves 902 are inserted into openings 945 of manifold 940 and held in place by threading between the manifold and bases 924.

Openings 944 are coupled to the pathway between openings 942 and cylinders 906. Openings 944 allow for observation of the hydraulic pressure at each cylinder. Pressure

transducers 903 are threaded into openings 944 and used to convert the pressure on each side of the system to an electrical signal. The pressure at hoses 128 is transferred to transducers 903 through pathways 946. Openings 944 and transducers 903 are optional in the passive system, because the system operates automatically based on the counter-pressure provided by air canister 912. In the passive system, pressure readings from transducers 903 can be used for troubleshooting or monitoring, but are not necessary for the functionality of the system. In active systems, where pistons 908 and/or valves 902 are actuated by a computer system, transducers 903 in openings 944 provide input to the algorithm that operates the pistons and valves.

Cap 950 couples the bottom sides of each cylinder 906 to air canister 912 via opening 952. The end of hose 910 includes a flange that is held into place by bracket 954. A bolt is inserted through opening 955 of bracket 954 to attach the bracket to cap 950. Cap 950 distributes air pressure from canister 912 to the bottom sides of both cylinders 906. The air pressure presses on the bottom sides of pistons 908 to provide a counter to the hydraulic pressure from hydraulic system 120. Brackets 960 allow attachment of bypass system 900 to snowmobile 10, another vehicle with a leaning suspension, or another substrate where use of the bypass functionality is desired.

FIGS. 5a-5j illustrate details of the components of bypass system 900. FIG. 5a shows cap 950 separate from bypass system 900. Opening 952 allows airflow between canister 912 and cylinders 906. Opening 953 is threaded to allow attachment of bracket 954 by a bolt. Opening 956 extends between the two cylinder openings 957 of cap 950. Cylinder 906A is inserted into or attached over one cylinder opening 957, and cylinder 906B is inserted into or attached over the second cylinder opening. Opening 956 allows the air pressure under each piston 908 to equalize. Opening 952 allows the pressure in air canister 912 to equalize with cylinders 906. Openings 958 are threaded to allow attachment of cylinders 906 via bolts inserted through openings 935.

FIG. 5b illustrates spacers 961, which are inserted into cylinder openings 957 of cap 950 below cylinders 906. Spacers 961 provide proper spacing between cap 950 and cylinders 906. A seal is created between cap 950 and cylinders 906 by O-rings inserted into grooves 938. The O-rings are press-fit between cap 950 and cylinders 906. O-rings in grooves 939 provide a similar seal between manifold 940 and cylinders 906. Spacers 961 are also shaped to ensure proper air flow between cylinder openings 957 and canister 912, as seen in FIG. 5d. In some embodiments, spacers 961 are formed from urethane, or other similar material, and provide cushioning for pistons 908 hitting cap 950.

FIG. 5c illustrates pistons 908, which are inserted into cylinders 906. Grooves 962 are configured to hold O-rings around pistons 908. The O-rings create a seal within cylinders 906 at pistons 908 that helps keep hydraulic fluid above the pistons separate from air below the pistons.

FIG. 5d illustrates a cross section of cap 950, spacers 961, cylinders 906, and pistons 908 assembled. Spacers 961 are inserted into cap 950, and then cylinders 906 are inserted over the spacers and bolted down. Spacers 961 are shaped to provide ample air flow between air canister 912 to both cylinders 906 through openings 952 and 956. Pistons 908 float within respective cylinders 906.

In one embodiment, pistons 908 rest on spacers 961 when snowmobile 10 is at rest. In another embodiment, pressure in air canister 912 is increased such that pistons 908 float within cylinders 906 when snowmobile 10 is at rest. Cyl-

inders 906 of bypass system 908 then operate as part of the primary suspension of snowmobile 10 along with shocks 68 and 88. Bypass system 900 is turned into a supplement for suspension 34. Any movement of suspension 34 will cause movement of pistons 908, the effect of which can be used to tune the suspension for different scenarios. Having air volume in bypass system 900 exceed the air volume in shocks 68 and 88 aids in using bypass system 900 as part of the primary suspension in desired situations.

FIG. 5e illustrates manifold 940 from the side that cylinders 906 attach onto. The top end of each cylinder 906, opposite cap 950, is inserted into a corresponding cylinder opening 949. Each cylinder is hydraulically coupled to a hose 128 through an opening 942. Pathways 946 transmit hydraulic pressure from openings 942 to corresponding openings 944 so that transducers 903 are able to sense the magnitude of hydraulic pressure on both sides of the bypass system. Check valves or actuators 902 are inserted into openings 945 to control flow of hydraulic fluid between the two cylinders 906 inserted into cylinder openings 949.

FIG. 5f illustrates an exploded view of the manifold assembly with check valves and hydraulic valves being inserted into manifold 940. Check valves 902 each include ball 920, spring 922, plunger 926, and base 924. Plunger 926 includes grooves 928 that accept O-rings to seal opening 945 when check valves 902 are installed. Bases 924 include threads to mechanically interface with threads in openings 945 and hold check valves 902 into the openings. Springs 922 extend between plungers 926 and balls 920 to press the balls against seats 918 within openings 945. Alternatively, in an active system, the motor, lead screw, and plunger assemblies 902C-902D are inserted into openings 945, having control terminals for the motor exposed to control the valves. A linear actuator or other actuation mechanism can be used in other embodiments.

Liners 966 are inserted into cylinder openings 949 to create a buffer between manifold 940 and shim stack dampening valves 970, reducing wear and tear. Liners 966 are formed from polytetrafluoroethylene (PTFE) or another polymer in some embodiments. Dampening valves 970 are illustrated as only the core of the valves. In use, a stack of shims will be bolted onto each side of the illustrated core. Each side of the core, i.e., the top and bottom faces as illustrated, includes tangentially oriented openings 972 and radially oriented openings 974. Each tangentially oriented opening 972 on one face of the core is coupled to a radially oriented opening 974 on the opposite face of the core through an opening 976.

The shims on one side of dampening valve 970 fully cover tangentially oriented openings 972 on that side of the valve, but the radially oriented openings 974 on that side extend outside a footprint of the shims. Hydraulic fluid flowing into or out of cylinders 906 flows through dampening valves 970, which regulate the flow rate of hydraulic fluid. When hydraulic pressure on a first side of dampening valve 970 is higher than a second side, the hydraulic pressure forces hydraulic fluid into the radially oriented openings 974 on the first side around the shims on that first side. The hydraulic fluid presses on and bends shims on the second side of the valve through tangentially oriented openings 972 on the second side that are covered by the shims.

The characteristics of the shim stack on each side of dampening valve 970 determines how bypass system 900 behaves when presented with hydraulic pressure changes. Dampening valves 970 control the flow rate of hydraulic fluid into and out of cylinders 906. The rate of hydraulic fluid flowing to cylinders 906 from hydraulic system 120

during high-pressure events, or to hydraulic system 120 from cylinders 906 during low-pressure events, is limited by being forced through dampening valves 970. FIG. 5g illustrates manifold 940 put together with cylinders 906 and cap 950.

FIG. 5h illustrates a perspective view of manifold 940 with the material the manifold is formed of being illustrated in a transparent manner. The hydraulic pathways and other internal structures that the manifold 940 material forms are visible. Check valves 902 are installed into openings 945 with balls 920 against seats 918. A hydraulic pathway 980B extends from opening 942B to the upstream side of check valve 902B. Pathway 980A similarly extends from opening 942A to the upstream side of check valve 902A. Pathways 980 apply the hydraulic pressure of each side of bypass system 900 to the upstream side of a respective check valve 902. Pathway 904A extends from the upstream side of check valve 902B to the downstream side of check valve 902A. Pathway 904B extends from the upstream side of check valve 902A to the downstream side of check valve 902B.

When the hydraulic pressure at opening 942B is sufficiently greater than the hydraulic pressure at opening 942A, the pressure applied at the upstream side of check valve 902B will crack the check valve open. Hydraulic fluid flows through check valve 902B to pathway 904B at the downstream side of the check valve, and further through pathway 904B to the upstream side of check valve 902A. Finally, the hydraulic fluid flows through pathway 980A to the opening 942A side of bypass system 900. Hydraulic fluid flows from opening 942B through pathway 980B, check valve 902B, pathway 904B, and pathway 980A to opening 942A until the pressures on the sides of bypass system 900 equalize to the point that check valve 902B closes. Check valve 902A operates similarly when opening 942A includes a greater pressure than opening 942B, with hydraulic fluid flowing through pathway 980A, check valve 902A, pathway 904A, and pathway 980B in series to opening 942B.

Opening 945 includes an expanded portion 982 around check valves 902 where springs 922 are located. Hydraulic fluid flows between pathway 904B and check valve 902B within a height of spring 922. The expanded portion 982 allows hydraulic fluid to spread out and flow through the entire radius of the spring, increasing flow rate. While expanded portion 982 is not necessary, hydraulic fluid would then substantially flow through spring 922 only where opening 945 and pathway 904B meet, potentially limiting flow rate.

FIG. 5i illustrates an alternative perspective view to FIG. 5h, and FIG. 5j illustrates a top view. FIGS. 5h-5j show three different angles of the internal pathways of manifold 940.

FIGS. 6a-6b illustrate situations where bypass system 900 provides significant benefit to a rider 14 of snowmobile 10 or other vehicle with leaning capability. In FIG. 6a, left ski 30 of snowmobile 10 is impacting a bump 12b in terrain 12. As ski 30 impacts bump 12b, a mechanical force is applied through ski 30 and suspension arm 64 to shock 68. Referring to FIG. 2b for the general structure of hydraulic system 120, the compressive force on shock 68 increases hydraulic pressure in hose 128A to hydraulic pump 262 and cylinder 906A of bypass system 900. The compressive force on shock 68 is absorbed by cylinder 906A accepting additional hydraulic fluid rather than solely by increased pressure to hydraulic pump 262, as would be the case without bypass system 900. Piston 908A moves lower, or more toward air canister 912, to accommodate additional hydraulic fluid

volume. Air is forced into air canister 912 by piston 908A, which raises the air pressure in the air canister and under piston 908B.

If hydraulic pressure in hose 128A reaches the cracking pressure of check valve 902A, the compressive force on shock 68 is absorbed both by hydraulic fluid flowing into cylinder 906A, and also by hydraulic fluid flowing through the check valve to the shock 88 side of hydraulic system 120. Bypass system 900 reduces the maximum pressure on hydraulic pump 262, which reduces wear and improves operation of the pump.

FIG. 6b illustrates rider 14 taking snowmobile 10 over a jump. Gravity causes both suspension arms 64 and 66 to fall. An expansive force is applied to both shocks 68 and 88. The air pressure in shocks 68 and 88 under pistons 174 is significantly reduced. Without bypass system 900, the low pressure in both shocks 68 and 88 means that the shocks will not apply significant force back to terrain 12 when snowmobile 10 lands. Only once the shocks compress close to their resting positions do shocks 68 and 88 begin to significantly perform their intended task of cushioning the landing of snowmobile 10.

On the other hand, with bypass system 900, air canister 912 forces hydraulic fluid stored in cylinders 906 into shocks 68 and 88. The extra hydraulic fluid in shocks 68 and 88 increases the spring rate of the shocks during the jump while the shocks remain extended. Shocks 68 and 88 begin absorbing the shock of landing the jump quickly upon contacting terrain 12 because bypass system 900 approximately equalized the air pressure in the shocks with the air pressure in air canister 912. Once snowmobile 10 lands back on terrain 12, hydraulic fluid is returned from shocks 68 and 88 to cylinders 906 until the air pressure in air canister 912 returns to approximately the resting air pressure. Dampening valves 970 are used to regulate the rate at which hydraulic fluid flows between respective shocks 68 and 88 and cylinders 906.

Bypass system 900 allows hydraulic fluid to bypass hydraulic pump 262 by flowing through the bypass system instead of further increasing the hydraulic pressure seen at the hydraulic pump when the pressure of one side of hydraulic system 120 is above the hydraulic pressure in the other side by a desired maximum pressure. Limiting the pressure also increases performance of hydraulic pump 262 and helps control the temperature of the hydraulic fluid, reducing the likelihood of thermal breakdown of the fluid under elevated pressures.

Bypass system 900 provide the following capabilities. Adjustable high pressure bypass limit allows bypass system 900 to continually circulate hydraulic fluid of hydraulic system 120 to reduce oil temperature and set the maximum pressure seen at hydraulic pump 262. The pressure limit can be adjusted by replacing springs 922 with stiffer or weaker springs. In active systems, the pressure limit can be adjusted by modifying the algorithm used to control the bypass of fluid. Bypass system 900 controls the spring rate of suspension 34 by injecting additional fluid into, or removing fluid from, hydraulic shocks 68 and 88. Bypass system 900 provides rebound and compression damping. Bypass system 900 allows monitoring pressure across pump ports, across hydraulic shocks 68 and 88, or both.

As a passive system, bypass system 900 is activated when pressure drops below a set accumulator pressure (in air canister 912), thus maintaining the set pressure as suspension 34 extends. Oil flows from cylinders 906 into primary suspension hydraulic system 120 when the pressure in shocks 68 and 88 drops below the pressure in air canister

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912. The pressure in hydraulic system 120 is thereby raised or maintained. Suspension 34 collapsing from full extension forces oil back into cylinders 906 through bypass valving to absorb suspension event energy.

As an active system, bypass system 900 is capable of adjusting spring rate and dampening throughout suspension travel by introducing or removing oil from hydraulic system 120 via electrically driven bypass reservoir pistons. Spring rate can be customized to different situations that a vehicle finds itself. The bypass ball check valves can be replaced with an electrically driven plunger capable of controlling bypass fluid flow via measurements from various sensors placed around the vehicle.

While one or more embodiments of the present invention have been illustrated in detail, the skilled artisan will appreciate that modifications and adaptations to those embodiments may be made without departing from the scope of the present invention as set forth in the following claims.

What is claimed is:

1. A hydraulic system, comprising:
  - a hydraulic pump;
  - a first hydraulic shock coupled to a first port of the hydraulic pump;
  - a first floating piston disposed in the first hydraulic shock;
  - a second hydraulic shock coupled to a second port of the hydraulic pump;
  - a second floating piston disposed in the second hydraulic shock;
  - a first hydraulic cylinder coupled to the first port of the hydraulic pump;
  - a third floating piston disposed in the first hydraulic cylinder;
  - a second hydraulic cylinder coupled to the second port of the hydraulic pump;
  - a fourth floating piston disposed in the second hydraulic cylinder; and
  - a first valve coupled between the first hydraulic cylinder and second hydraulic cylinder in parallel with the hydraulic pump.
2. The hydraulic system of claim 1, wherein the first valve is a ball and spring check valve.
3. The hydraulic system of claim 1, further including a second valve coupled between the first hydraulic cylinder and second hydraulic cylinder in parallel with the first valve, wherein the first valve and second valve are both unidirectional with a flow direction of the second valve opposite a flow direction of the first valve.
4. The hydraulic system of claim 1, further including an air canister coupled to the first hydraulic cylinder and second hydraulic cylinder opposite the hydraulic pump.
5. A hydraulic system, comprising:
  - a hydraulic pump;
  - a first hydraulic cylinder coupled to a first port of the hydraulic pump;
  - a second hydraulic cylinder coupled to a second port of the hydraulic pump, wherein the hydraulic pump is configured to transfer hydraulic fluid from the first hydraulic cylinder to the second hydraulic cylinder when the hydraulic pump is operated in a first direction, and wherein the hydraulic pump is configured to transfer hydraulic fluid from the second hydraulic cylinder to the first hydraulic cylinder when the hydraulic pump is operated in a second direction opposite the first; and
  - a first valve comprising an inlet coupled to the first port and an outlet coupled to the second port, wherein the

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- valve is configured to allow hydraulic fluid to flow from the inlet to the outlet only when a first hydraulic pressure at the inlet relative to a second hydraulic pressure at the outlet exceeds a threshold.
- 6. The hydraulic system of claim 5, wherein the first valve is a ball and spring check valve.
- 7. The hydraulic system of claim 5, further including an air tank coupled to the first hydraulic cylinder and second hydraulic cylinder by an air pathway.
- 8. The hydraulic system of claim 5, further including a second valve coupled between the first hydraulic cylinder and second hydraulic cylinder, wherein a flow direction of the second valve is opposite a flow direction of the first valve.
- 9. A hydraulic system, comprising:
  - a hydraulic pump including a first port and a second port;
  - a first hydraulic cylinder directly hydraulically coupled to the first port;
  - a second hydraulic cylinder directly hydraulically coupled to the second port; and
  - a first check valve comprising an inlet directly hydraulically coupled to the first port and an outlet directly hydraulically coupled to the second port; and
  - a second check valve comprising an inlet directly hydraulically coupled to the second port and an outlet directly hydraulically coupled to the first port.
- 10. The hydraulic system of claim 9, wherein the first check valve is a ball and spring check valve.
- 11. The hydraulic system of claim 9, further including an air canister coupled to the first hydraulic cylinder and second hydraulic cylinder opposite the hydraulic pump.
- 12. A method of bypassing fluid in a hydraulic system, comprising:
  - providing a hydraulic pump including a first port and a second port;
  - providing a first hydraulic cylinder directly hydraulically coupled to the first port;
  - providing a second hydraulic cylinder directly hydraulically coupled to the second port;
  - coupling a first check valve between the first port and second port with an inlet of the first check valve directly hydraulically coupled to the first port and an outlet of the first check valve directly hydraulically coupled to the second port; and
  - coupling a second check valve between the first port and second port with an inlet of the second check valve directly hydraulically coupled to the second port and an outlet of the second check valve directly hydraulically coupled to the first port.
- 13. The method of claim 12, further including:
  - providing a snowmobile including a suspension comprising a first shock and a second shock;
  - coupling the first port of the hydraulic pump to the first shock; and
  - coupling the second port of the hydraulic pump to the second shock.
- 14. The method of claim 13, further including using the hydraulic pump to actuate the first shock and second shock, thereby leaning the snowmobile.
- 15. The method of claim 12, further including attaching an air canister to the first hydraulic cylinder and second hydraulic cylinder opposite the hydraulic pump.

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