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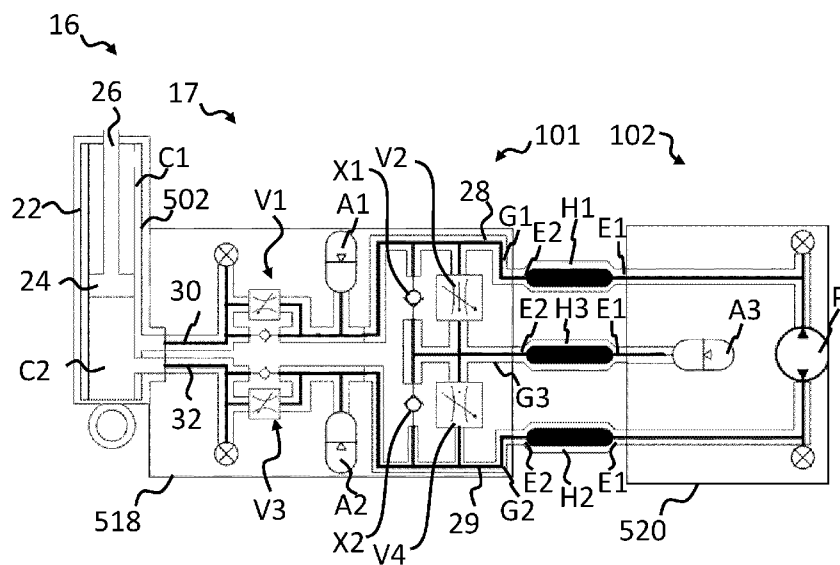


FIG. 3A

(57) Abstract: Aspects and embodiments of the invention relate to a hydraulic control apparatus (17), to an actuator system (16), and to a vehicle (1). The apparatus (17) is for a piston actuator (502) of an active suspension system (104) of a vehicle (1). The apparatus (17) comprises unsprung and sprung arrangements (518, 520), arranged to be positioned on unsprung and sprung masses (101, 102) of the vehicle (1), respectively. The unsprung arrangement (518) comprises a first to third hydraulic galleries (G1, G2, G3), the third hydraulic gallery (G3) interfaced with the first and second hydraulic galleries (G1, G2) by variable valves (V2, V4). The sprung arrangement (520) comprises a pump (P) comprising first and second ports (PP1, PP2) hydraulically couplable to the first and second hydraulic galleries (G1, G2) by respective first and second couplings (H1, H2) enabling movement of each of the unsprung and sprung arrangements (518, 520) to be decoupled from movement of the other.

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HYDRAULIC CONTROL APPARATUS FOR A VEHICLE

TECHNICAL FIELD

The present disclosure relates to a hydraulic control apparatus for a vehicle. Aspects of the invention relate to a hydraulic control apparatus, to an actuator system, and to a vehicle.

BACKGROUND

An active suspension system of a vehicle can be hydraulically-actuated. The active suspension system can comprise a hydraulically-controlled piston actuator. The piston actuator is controlled by a hydraulic control apparatus comprising hydraulic circuits. One of the hydraulic circuits is hydraulically coupled to a first fluid chamber of the piston actuator, while another of the hydraulic circuits is hydraulically coupled to a second fluid chamber of the piston actuator. The hydraulic pressure in each hydraulic circuit is actively controlled by a pump and/or valve arrangement, to control the force-displacement characteristics of the piston actuator, or even to actively extend or retract the piston actuator.

It is an aim of the present invention to address one or more disadvantages associated with the prior art.

SUMMARY OF THE INVENTION

Aspects and embodiments of the invention provide a hydraulic control apparatus, an actuator system, and a vehicle as claimed in the appended claims.

According to an aspect of the present invention there is provided a hydraulic control apparatus for a piston actuator of an active suspension system of a vehicle, the hydraulic control apparatus comprising:

an unsprung arrangement arranged to be positioned on an unsprung mass of the vehicle, the unsprung arrangement comprising:

a first hydraulic gallery hydraulically couplable to a first fluid chamber of the piston actuator;

a second hydraulic gallery hydraulically couplable to a second fluid chamber of the piston actuator;

a third hydraulic gallery interfaced with the first and second hydraulic galleries by variable valves;

the hydraulic control apparatus further comprising: a sprung arrangement arranged to be positioned on a sprung mass of the vehicle, the sprung arrangement comprising: a pump, the pump comprising a first port hydraulically couplable to the first hydraulic gallery by a first coupling, and a second port hydraulically couplable to the second hydraulic gallery by a second coupling, the first and second couplings enabling the pump to transfer hydraulic fluid between the first and second hydraulic galleries,

wherein the first and second couplings extend between the sprung and unsprung arrangements and enable movement of each of the unsprung and sprung arrangements to be decoupled from movement of the other.

There are several advantages to providing the third hydraulic gallery and variable valves as part of the unsprung arrangement rather than as part of the sprung arrangement. Firstly, the packaging volume of the sprung arrangement is minimised because many components are packaged in the unsprung arrangement proximal to the piston actuators, rather than being packaged in the sprung arrangement proximal to the pump.

Secondly, the first and second couplings can be lightweight, small-diameter lines or pipes because most of the fluid in the stroke of the piston actuator will be contained in the unsprung arrangement. Thirdly, overall cooling is improved because hydraulic fluid has further to flow between the variable valves and the pump, dissipating heat along the way. Fourth, the improved cooling means that thermal expansion causes smaller system volume changes, enabling the specification of smaller hydraulic accumulators. Fifth, the pressure loss between the piston actuator and the variable valves is low due to their relative proximity, therefore reducing parasitic damping. An overall effect based on these advantages is an improved hydraulic control apparatus, taking into account mass, cooling, and available packaging space.

The unsprung arrangement may be a first assembly. The sprung arrangement may be a second assembly.

The variable valves of the hydraulic control apparatus may be configured to lower hydraulic fluid pressure such that the third hydraulic gallery is a low-pressure hydraulic gallery relative to the first and second hydraulic galleries. Therefore, the third hydraulic gallery can be regarded as a low-pressure hydraulic gallery. The first and second hydraulic galleries can be regarded as high-pressure hydraulic galleries.

The sprung arrangement may comprise a hydraulic accumulator. The hydraulic accumulator may advantageously be configured to compensate for system volume changes of the hydraulic control apparatus. For example, the hydraulic accumulator may be sized to compensate for thermal expansion of hydraulic fluid.

Additionally, or alternatively, the hydraulic accumulator may be sized to compensate for system volume changes caused by a portion of a piston rod entering or leaving the fluid chambers of the piston actuator. This is because, as a piston actuator retracts, a portion of a piston rod will enter a fluid chamber of the piston actuator, decreasing system volume and therefore forcing some hydraulic fluid into the hydraulic accumulator.

An advantage of providing the hydraulic accumulator in the sprung arrangement is that the unsprung mass of the vehicle is minimised. The hydraulic accumulator may have a mass of several kilograms.

The hydraulic accumulator may be a third hydraulic accumulator, the unsprung arrangement further comprising a first hydraulic accumulator connected to (interfaced with) the first hydraulic gallery, and a second hydraulic accumulator connected to (interfaced with) the second hydraulic gallery.

A volume of the third hydraulic accumulator may be greater than a volume of each of the first and second hydraulic accumulators.

The first and second hydraulic accumulators may be high-pressure hydraulic accumulators, for example where the first and second hydraulic galleries are high-pressure hydraulic galleries. The third hydraulic accumulator may be a low-pressure hydraulic accumulator, for example when connected to a low-pressure hydraulic gallery such as the third hydraulic gallery or any other appropriate gallery.

One or more of the variable valves may be positioned in a gap between the first and second hydraulic accumulators. The first and second hydraulic accumulators may each comprise a housing. Each housing may

be in the form of a cylinder, sphere, or other shape. Each housing may comprise opposite ends, which may be flat, domed, or hemispherical faces. Facing ends of the respective housings may be separated by the gap therebetween. Each variable valve may be housed in a valve housing, the valve housing being positioned in or mostly in the gap between the facing ends.

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An advantage is improved packaging of the unsprung arrangement because the variable valves do not protrude or mostly do not protrude beyond an envelope of the unsprung arrangement, defined by the first and second hydraulic accumulators.

10 The hydraulic accumulator may be arranged to be hydraulically shared between a plurality of piston actuators of the active suspension system, for different vehicle wheels. The hydraulic accumulator may be the third hydraulic accumulator. In examples, the sprung arrangement may comprise a middle hydraulic gallery that is hydraulically couplable to the first and second hydraulic galleries for each piston actuator, the hydraulic accumulator being connected to the middle hydraulic gallery.

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An advantage is reduced part count and system mass, because a pair of piston actuators can share a single hydraulic accumulator. Another advantage is enabling equalisation of hydraulic fluid temperatures for both piston actuators. Unequal temperatures may be encountered in situations where more work is done by one piston actuator than the other piston actuator, such as driving over road surfaces of asymmetric roughness.

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Alternatively, or additionally, the hydraulic accumulator may be hydraulically couplable to the third hydraulic gallery between the variable valves. The hydraulic accumulator and third hydraulic gallery may be located to low-pressure sides of the variable valves. Where the sprung arrangement may comprise the hydraulic accumulator and the unsprung arrangement may comprise the third hydraulic gallery, the hydraulic
25 accumulator may be hydraulically couplable to the third hydraulic gallery by a third coupling.

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The variable valves may be arranged to permit variable hydraulic fluid flow into the third hydraulic gallery. The variable valves may comprise a plurality of pressure control valves, each connected to a different one of the first and second hydraulic galleries, and arranged to permit one-way hydraulic fluid flow into the third hydraulic
30 gallery. The plurality of pressure control valves may be configured to lower the hydraulic fluid pressure as described earlier. Each pressure control valve may be operable to apply a force counteracting fluid flow in proportion to applied electrical current. The plurality of pressure control valves may each have a high-pressure side (inlet side) connected to a respective one of the first and second hydraulic galleries, and a low-pressure side (outlet side) connected to the third hydraulic gallery. The plurality of pressure control valves may define a
35 first interface between the third hydraulic gallery and the first and second hydraulic galleries.

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The unsprung arrangement may further comprise one-way valves. The one-way valves may comprise check valves. The third hydraulic gallery may be further interfaced with the first and second hydraulic galleries by the one-way valves arranged to permit one-way hydraulic fluid flow out of the third hydraulic gallery. The one-way
40 valves may permit one-way hydraulic fluid flow into a respective one of the first and second hydraulic galleries. The one-way valves may be in parallel hydraulic fluid branches to the variable valves. The one-way valves

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may define a second interface between the third hydraulic gallery and the first and second hydraulic galleries, additional to the interface provided by the variable valves.

One or more of the one-way valves may be positioned in the above-mentioned gap between the first and second hydraulic accumulators. For example, the one-way valves may be packaged in proximity to the variable valves which may also be in the gap. In other examples, the one-way valves but not the variable valves are positioned in the gap.

The pump may be a bidirectional pump operable to transfer hydraulic fluid between the first and second hydraulic galleries to control hydraulic pressure across the piston actuator.

An advantage is that the use of a bidirectional pump minimises part count by being able to reverse flow direction through the pump without needing additional flow control valves. A bidirectional pump can smoothly and continuously control the relative pressure in the first and second hydraulic galleries.

The first port of the pump may be arranged to pump hydraulic fluid into the first hydraulic gallery directly, meaning without the hydraulic fluid first passing through the second or third hydraulic galleries. The second port of the pump may be arranged to pump hydraulic fluid into the second hydraulic gallery directly, meaning without the hydraulic fluid first passing through the first or third hydraulic galleries.

The first and second couplings may comprise flexible hydraulic lines arranged in flow paths between the variable valves and the pump. The use of flexible hydraulic lines, such as hoses, enables the movement of each of the unsprung and sprung arrangements to be decoupled from movement of the other. First ends of the flexible hydraulic lines may be arranged to be connected to the sprung arrangement, proximal to the pump, and second opposite ends of the flexible hydraulic lines may be arranged to be connected to the unsprung arrangement, proximal to the variable valves. The first ends of the flexible hydraulic lines may be directly or indirectly connected to the respective first and second ports of the pump.

In the examples where the hydraulic accumulator may be hydraulically couplable to the third hydraulic gallery by a third coupling, the third coupling may comprise a third flexible hydraulic line. A first end of the third flexible hydraulic line may be arranged to be connected to the hydraulic accumulator at the sprung arrangement, and a second end of the third flexible hydraulic line may be arranged to be connected to the third hydraulic gallery at the unsprung arrangement.

The unsprung arrangement may further comprise a plurality of damper valves each connected to a different one of the first and second hydraulic galleries and arranged to control hydraulic fluid flow towards the variable valves. Each damper valve may comprise a variable valve to variably control hydraulic fluid flow away from the piston actuator and towards the variable valves. Each damper valve may further comprise a one-way valve arranged to permit one-way hydraulic fluid flow towards the respective fluid chamber of the piston actuator.

The one-way valve may comprise a check valve in parallel to each variable valve of the damper valve.

According to another aspect of the invention, there is provided a hydraulic control apparatus for a piston actuator of an active suspension system of a vehicle, the hydraulic control apparatus comprising:

an unsprung arrangement arranged to be positioned on an unsprung mass of the vehicle, the unsprung arrangement comprising:

5 a first hydraulic gallery hydraulically couplable to a first fluid chamber of the piston actuator;

 a second hydraulic gallery hydraulically couplable to a second fluid chamber of the piston actuator, wherein movement of a piston of the piston actuator in a first direction to contract the second fluid chamber while expanding the first fluid chamber increases pressure in the second hydraulic gallery while decreasing pressure in the first hydraulic gallery, wherein movement of the piston in a second opposite direction increases
10 pressure in the first hydraulic gallery while decreasing pressure in the second hydraulic gallery;

 a third hydraulic gallery bridging the first and second hydraulic galleries to enable hydraulic fluid exchange between the first and second hydraulic galleries through the third hydraulic gallery via variable pressure-reducing valves in dependence on pressure differences between the first and second hydraulic galleries;

15 the hydraulic control apparatus further comprising: a sprung arrangement arranged to be positioned on a sprung mass of the vehicle, the sprung arrangement comprising: a pump, the pump comprising a first port hydraulically coupled to the first hydraulic gallery by a first coupling, and a second port hydraulically coupled to the second hydraulic gallery by a second coupling, the first and second couplings enabling the pump to transfer hydraulic fluid between the first and second hydraulic galleries,

20 wherein the first and second couplings extend between the sprung and unsprung arrangements and enable movement of each of the unsprung and sprung arrangements to be decoupled from movement of the other.

According to a further aspect of the present invention there is provided a hydraulic control apparatus for an active suspension system of a vehicle, the hydraulic control apparatus comprising:

25 an unsprung arrangement comprising:

 a first hydraulic gallery;

 a second hydraulic gallery;

 a third hydraulic gallery interfaced with the first and second hydraulic galleries by valves;

the hydraulic control apparatus further comprising:

30 a sprung arrangement comprising a pump, the pump comprising a first port hydraulically couplable to the first hydraulic gallery by a first coupling, and a second port hydraulically couplable to the second hydraulic gallery by a second coupling.

According to a further aspect of the invention, there is provided an actuator system comprising the hydraulic
35 control apparatus and the piston actuator. The unsprung arrangement may be secured to the piston actuator.

According to a further aspect of the invention, there is provided a vehicle comprising the actuator system.

40 Within the scope of this application it is expressly intended that the various aspects, embodiments, examples and alternatives set out in the preceding paragraphs, in the claims and/or in the following description and drawings, and in particular the individual features thereof, may be taken independently or in any combination

that falls within the scope of the appended claims. That is, all embodiments and/or features of any embodiment can be combined in any way and/or combination that falls within the scope of the appended claims, unless such features are incompatible. The applicant reserves the right to change any originally filed claim or file any new claim accordingly, including the right to amend any originally filed claim to depend from and/or incorporate any feature of any other claim although not originally claimed in that manner.

BRIEF DESCRIPTION OF THE DRAWINGS

One or more embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

FIG. 1 illustrates an example of a vehicle;

FIG. 2 illustrates an example of an active suspension system of a vehicle;

FIG. 3A illustrates a first example of an actuator system of an active suspension system;

FIG. 3B illustrates a detail view of respective valves and pumps of the actuator system;

FIG. 3C illustrates a detail view of damper valves and check valves of the actuator system;

FIG. 4 schematically illustrates a second example of an actuator system of an active suspension system; and

FIG. 5 schematically illustrates an example of parts of an unsprung arrangement.

DETAILED DESCRIPTION

A vehicle 1 in accordance with an embodiment of the present invention is described herein with reference to the accompanying FIG. 1. In some, but not necessarily all examples, the vehicle 1 is a passenger vehicle, also referred to as a passenger car or as an automobile. In other examples, embodiments of the invention can be implemented for other applications, such as commercial vehicles.

FIG. 1 is a front perspective view and illustrates a longitudinal x-axis between the front and rear of the vehicle 1 representing a centreline, an orthogonal lateral y-axis between left and right lateral sides of the vehicle 1, and a vertical z-axis. A forward/fore direction typically faced by a driver's seat is in the negative x-direction; rearward/aft is +x. A rightward direction as seen from the driver's seat is in the positive y-direction; leftward is -y. These are a first lateral direction and a second lateral direction.

In summary, FIGS. 2 to 5 illustrate a hydraulic control apparatus 17 for a piston actuator 502 of an active suspension system 104 of a vehicle 1, the hydraulic control apparatus 17 comprising:

an unsprung arrangement 518 arranged to be positioned on an unsprung mass 101 of the vehicle 1, the unsprung arrangement 518 comprising:

a first hydraulic gallery G1 hydraulically couplable to a first fluid chamber C1 of the piston actuator 502;

a second hydraulic gallery G2 hydraulically couplable to a second fluid chamber C2 of the piston actuator 502;

a third hydraulic gallery G3 interfaced with the first and second hydraulic galleries G1, G2 by variable valves V2, V4;

the hydraulic control apparatus 17 further comprising: a sprung arrangement 520 arranged to be positioned on a sprung mass 102 of the vehicle 1, the sprung arrangement 520 comprising: a pump P, the pump P comprising a first port PP1 hydraulically couplable to the first hydraulic gallery G1 by a first coupling H1, and a second port PP2 hydraulically couplable to the second hydraulic gallery G2 by a second coupling H2, the first and second couplings H1, H2 enabling the pump P to transfer hydraulic fluid between the first and second hydraulic galleries G1, G2, wherein the first and second couplings H1, H2 extend between the sprung and unsprung arrangements 520, 518 and enable movement of each of the unsprung and sprung arrangements 518, 520 to be decoupled from movement of the other.

The term 'hydraulically couplable' refers to parts which are 'hydraulically coupled' when the hydraulic control apparatus 17 is wet, that is, filled with hydraulic fluid. A hydraulic coupling can be direct, without intervening components, or indirect via intervening components.

The term 'interface' in this context refers to the boundary between two parts of a hydraulic system, such as a valve or pump.

First, an active suspension system is described with reference to FIG. 2. FIG. 2 illustrates an example active suspension system 104 of the vehicle 1, connecting a vehicle body 102 to vehicle wheels 12.

The active suspension system 104 comprises a front left active suspension 106 for a front left wheel FL, a front right active suspension 116 for a front right wheel FR, a rear left active suspension 108 for a rear left wheel RL, and a rear right active suspension 118 for a rear right wheel RR. The active suspension for each wheel (e.g. quarter/corner) of the vehicle 1 may be individually controllable by a control system 200.

FIG. 2 also shows a torque source 103 such as an internal combustion engine or electric machine, for driving at least some of the vehicle wheels 12.

The active suspension 106, 116, 108, 118 for each corner of the vehicle 1 comprises a piston actuator 502.

As will be described, the piston actuator 502 is a hydraulic actuator such as a hydraulic fluid-filled chamber containing a piston 24, shown in FIG. 3A. The actuator 502 is therefore a piston actuator of a hydraulic system. The fluid may comprise hydraulic oil. One end of the piston actuator 502 is coupled to a vehicle wheel 12 and the other end is coupled to the vehicle body 102. A spring 504 (e.g. coil or pneumatic) may be in equilibrium and acting in parallel with the piston actuator 502.

When the active suspension system 104 is undisturbed, the piston 24 of the piston actuator 502 sits at a neutral position in the chamber.

The piston 24 shown in FIG. 3A can move in either direction inside the chamber, e.g., due to a road disturbance or body accelerations compressing or extending the piston actuator 502. As will be described, the piston 24

can displace fluid out of the chamber into hydraulic circuits (described later). The hydraulic fluid imparts a restoring force against movement of the piston 24. Energy can be added to and/or extracted from the piston actuator 502 by pumping fluid and/or controlling valves to regulate fluid pressure to either side of the piston 24.

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The damping of the piston actuator 502 can be modified by controlling a damper valve at a constriction, which regulates the force realized by the fluid transferred in and out of the piston actuator 502 by movement of the piston 24. Bump and rebound damping rates could be controlled independently in some examples.

10 Further, energy can be added to or removed from the piston actuator 502 in order to control various suspension characteristics including, but not limited to the damping curve (force-velocity relationship) of the piston actuator 502.

15 In FIG. 2 but not necessarily all examples, the spring 504 comprises an active spring such as a pneumatic spring, enabling control of ride height. The control system 200 may be configured to pump gas (e.g. air) in or out of the pneumatic spring 504 to control ride height.

20 Energy can be added to or removed from the pneumatic spring 504 in order to increase or decrease the volume of the pneumatic spring 504. Increasing the volume can lift the vehicle body 102 in the z-axis. In the example of FIG. 2 this enables the wheel-to-body distance to be changed independently at different ends and/or at different corners of the vehicle 1.

Additionally or alternatively, the spring 504 comprises a passive spring (e.g. coil) or is omitted entirely.

25 Control of the active suspension system 104 relies on one or more sensors. Wheel travel may be sensed by a wheel-to-body displacement sensor 514 (suspension displacement-based sensor), for example. The wheel-to-body displacement sensor 514 is placed somewhere on the active suspension 106, 116, 108, 118 and can sense the position of the wheel 12 along an arc defined by suspension geometry. An example of a wheel-to-body displacement sensor 514 is a rotary potentiometer attached to a lever, wherein one end of the lever is
30 coupled to the vehicle body 102, and the other end is coupled to a suspension link.

In some examples, the control system 200 more accurately determines the wheel travel and/or its associated derivatives by fusing information from the wheel-to-body displacement sensor 514 with information from hub accelerometers 516.

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In at least some examples the control system 200 is configured to control the active suspension system 104 by transmitting a force request to the active suspension 106, 116, 108, 118 or to a low-level controller thereof. The force request may be an arbitrated force request based on requests from various requestors and information from various sensors.

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FIG. 2 illustrates additional optional features that may interact with the control system 200 to influence force request calculations. These include any one or more of:

- A hub-mounted accelerometer 516 for each wheel 12, coupled to an unsprung mass 101 of the vehicle 1.
- At least one vehicle body accelerometer 522 coupled to the vehicle body 102 (sprung mass). A particular example includes a 3DOF or 6DOF inertial measurement unit (IMU). A unit may comprise an accelerometer or a multi-axis set of accelerometers.

FIGS. 3A to 3C illustrate an example actuator system 16 comprising a piston actuator 502 and a hydraulic control apparatus 17 for the piston actuator 502. A topology of the hydraulic control apparatus 17 is shown.

The hydraulic control apparatus 17 comprises hydraulic circuits 28, 29. The hydraulic control apparatus 17 is hydraulically coupled or couplable to the piston actuator 502 by galleries 30, 32.

The illustrated hydraulic control apparatus 17 is comprised in one of the active suspensions 106, 116, 108, 118 of the vehicle 1. In other examples, a single hydraulic control apparatus 17 may comprise both replicated and shared parts to provide the functionality of a plurality of the active suspensions 106, 116, 108, 118.

In FIG. 3A, the piston actuator 502 includes a cylinder 22 containing the piston 24. The cylinder 22 is part of the unsprung mass 101 of the vehicle 1 and is secured to a respective vehicle wheel 12. The piston 24 of the piston actuator 502 is secured to the sprung mass 102 of the vehicle 1 via a piston rod 26.

The unsprung mass 101 of the vehicle 1 refers to the mass of components that are not supported by the active suspension system 104. This includes, without limitation, the vehicle wheels FL, FR, RL, RR and their tyres, as well as some suspension components, final driveshafts, and some friction braking components. The sprung mass 102 of the vehicle 1 refers to the mass of components that are supported by the active suspension system 104, including the vehicle body 102 and anything mounted to the vehicle body 102 and supported by the active suspension system 104.

The piston 24 defines a first fluid chamber C1 and a second fluid chamber C2. The piston 24 fluidly isolates the first fluid chamber C1 from the second fluid chamber C2. In the illustrated example, the first fluid chamber C1 is an annulus chamber and the second fluid chamber C2 is a piston chamber.

In another example, the direction of the piston actuator 502 is reversed so that the cylinder 22 is secured to the vehicle body 102 via the piston rod 26, and the piston 24 is secured to the wheel 12.

As shown in FIG. 3B, the hydraulic control apparatus 17 includes a hydraulic pump P having a first port PP1 and a second port PP2. In the illustrated example, the pump P is bidirectional so as to selectively generate flow out of the first port PP1 or second port PP2.

The hydraulic control apparatus 17 of FIGS. 3A-3C includes valves V1, V2, V3, and V4.

As shown in FIG. 3C, valve V1 is a damper valve including a variable valve V1A and a check valve (one-way valve) V1B. Similarly, valve V3 is a damper valve including a variable valve V3A and a check valve (one-way valve) V3B.

- 5 The valves V1A, V2, V3A, V4 of FIGS. 3A-3C may be electromagnetically-controlled variable valves. The variable valves V1A, V2, V3A, V4 may be electromagnetically controlled by the control system 200 by varying electrical current.

Valves V2 and V4 are both variable pressure control valves (PCVs). The PCVs are pressure-reducing valves
 10 operable to apply a force counteracting fluid flow in proportion to applied electrical current. Valves V2 and V4 may have a pilot stage and a main stage. Valves V2 and V4 have controllable orifice sizes to control pressure. The pilot stage may have a small, magnetically actuated poppet valve, to generate a pressure in a chamber that then acts on the larger main stage. The main stage may be closed by a spring and forced open by fluid
 15 flow from the piston actuator 502, opposed by the spring and pressure force generated by the pilot stage (or a magnetic force if there is no pilot stage). The valves V2 and V4 may be normally closed and may allow one-way flow. In other examples, the valves V2 and V4 comprise a different type of hydraulic valve.

The illustrated hydraulic control apparatus 17 also includes hydraulic accumulators A1, A2, A3 and hydraulic galleries G1, G2 and G3. The hydraulic control apparatus 17 also includes check valves (one-way valves) X1
 20 and X2.

Gallery G1 hydraulically couples port PP1 of pump P, outlet X1O of check valve X1, inlet V2I of valve V2, hydraulic accumulator A1, and port V1C of damper valve V1. The valves V2 and X1 are shown in parallel fluid passages/branches of gallery G1. The respective valves V2, X1 are configured to control fluid flow through
 25 their respective parallel fluid passages.

Gallery G1 is hydraulically coupled to the port PP1 of pump P via a first coupling in the form of a first flexible hydraulic line H1, such as a hose.

30 Gallery G2 hydraulically couples port PP2 of pump P, outlet X2O of check valve X2, inlet V4I of valve V4, hydraulic accumulator A2, and port V3C of damper valve V3. The valves V4 and X2 are shown in parallel fluid passages/branches of gallery G2. The respective valves V4, X2 are configured to control fluid flow through their respective parallel fluid passages.

35 Gallery G2 hydraulically couples with the port PP2 of pump P via a second coupling in the form of a second flexible hydraulic line H2, such as a hose.

Gallery 30 hydraulically couples with the first fluid chamber C1 of the piston actuator 502 and port V1D of damper valve V1. Similarly, gallery 32 hydraulically couples with the second fluid chamber C2 of the piston
 40 actuator 502 and port V3D of damper valve V3.

Gallery G3 hydraulically couples with outlet V2O of valve V2, outlet V4O of valve V4, inlet X1I of check valve X1, and inlet X2I of check valve X2. In FIG. 3A, but not necessarily in all examples, the gallery G3 is further hydraulically coupled with the accumulator A3, in this case via a third coupling in the form of a third flexible hydraulic line H3, such as a hose.

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As can be seen from FIGS. 3A to 3C, a first hydraulic circuit 28 defined at least by first flexible hydraulic line H1, gallery G1, and gallery 30 hydraulically couples the first port PP1 of the hydraulic pump P to the first chamber C1 of the piston actuator 502. Where the first chamber C1 is an annulus chamber, the first hydraulic circuit 28 can be described as an annulus circuit.

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Similarly, a second hydraulic circuit 29 defined at least by second flexible hydraulic line H2, gallery G2, and gallery 32 hydraulically couples the second port PP2 of the hydraulic pump P with the second chamber C2 of the piston actuator 502. Where the second chamber C2 is a piston chamber, the second hydraulic circuit 29 can be described as a piston circuit. The hydraulic circuits 28, 29 collectively define a compression circuit and

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a rebound circuit.

The first and second galleries G1, G2 are high-pressure galleries because they are connected to (interfaced with) the high-pressure sides (inlet V2I, V4I) of the variable valves V2 and V4, respectively, and are exposed to high pressures from the piston actuator 502 via damper valves V1, V3. The first and second accumulators

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A1 and A2 are high-pressure accumulators because they are connected to (interfaced with) the first and second galleries G1, G2, respectively.

The gallery G3 is a low-pressure gallery bridging the first and second galleries G1, G2 because it is connected to (interfaced with) the low-pressure sides (outlet V2O, V4O) of the variable valves V2 and V4 respectively.

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Optionally, the accumulators A1, A2 may also have stiffer diaphragms (reactors) than the accumulator A3, the accumulator A3 being a low-pressure accumulator relative to the accumulators A1, A2.

In operation, the control system 200 is configured to determine an appropriate setpoint indicative of required hydraulic pressure in one or both of the chambers C1, C2 of the piston actuator 502. The setpoint obtained (received or calculated) by the control system 200 may be a pressure setpoint or an actuator force setpoint, for example.

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In an example, the control system 200 may increase the setpoint for the second fluid chamber C2 of the piston actuator 502 when it is desired to cause an extension force to be generated by the piston actuator 502, for example to counter vehicle body roll in a particular direction. When it is determined that the actual pressure in second fluid chamber C2 of the piston actuator 502 is below the setpoint, then the pump P is operated so as to pump fluid from the first gallery G1 through the pump P into the second gallery G2. As the pressure in gallery G2 rises, hydraulic fluid may flow past check valve V3B of the damper valve V3 causing the hydraulic pressure in gallery 32 and hence in the second fluid chamber C2 of the piston actuator 502 to also rise. Hydraulic

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pressure in hydraulic accumulator A2 will similarly rise. The pressure in gallery G2 relative to the setpoint is controlled by the variable valve V4 by restricting the flow back to the third gallery G3.

As the pressure in gallery G2 increases, so the pressure in gallery G1 may fall. Check valve X2 will prevent fluid flow through the valve X2 from gallery G2 to gallery G3 when the pressure in gallery G2 is greater than the pressure in gallery G3. As the pressure in gallery G1 drops to a pressure below the pressure in gallery G3 then check valve X1 will open, therefore equalising the pressure in galleries G1 and G3.

As the pressure in the second fluid chamber C2 of the piston actuator 502 increases, the piston 24 may rise (when viewing FIG. 3A) causing hydraulic fluid to be expelled from the first fluid chamber C1 of the piston actuator 502. The expelled fluid will flow into gallery G1 dependent upon the flow characteristics of the variable valve V1A of the damper valve V1, thus replacing some of the hydraulic fluid lost from gallery G1 to gallery G2 via pump P. Fluid from hydraulic accumulator A1 may pass into gallery G1.

After a period of time a steady equilibrium will be reached wherein the pressure in gallery G2, accumulator A2, gallery 32, and in the second fluid chamber C2 of the piston actuator 502 are all equal. The magnitude of this steady state pressure, equal to the setpoint, will determine the appropriate pump speed and setting of valve V4.

In the scenario where there is a disturbance input in the form of the wheel 12 hitting a bump, the target pressure in the second fluid chamber C2 of the piston actuator 502 is tending to extend the piston actuator 502. The bump in the road will cause the piston actuator 502 to contract causing hydraulic fluid to flow out of the contracting second fluid chamber C2 of the piston actuator 502 and consequently into the expanding first fluid chamber C1 of the piston actuator 502. Fluid flow into the expanding first fluid chamber C1 is provided primarily by hydraulic fluid from accumulator A1 flowing through check valve V1B of the damper valve V1. However, hydraulic fluid flowing out of the contracting second fluid chamber C2 of the piston actuator 502 is damped by variable valve V3A of damper valve V3. Thus variable valve V3A acts as a variable damper valve under these circumstances. Hydraulic fluid passing through variable valve V3A of damper valve V3 will primarily cause fluid to flow into the accumulator A2. Once the bump has been negotiated the piston 24 will return to its steady state position. The bump will create a high frequency road induced input which is accommodated primarily by accumulator A2 which is close to the second fluid chamber C2 of the piston actuator 502 when compared with accumulator A3.

However, as a rate/magnitude of bump travel increases, movement of the piston 24 within the cylinder 22 may cause the pressure in chamber C2 of the piston actuator 502 to rise, causing the pressure in gallery G2 to increase above the valve pressure setting of variable valve V4, in which case the opening of the variable valve V4 will be momentarily increased so as to limit the pressure in gallery G2. Simultaneously, the large bump will cause the volume of chamber C1 of the piston actuator 502 to increase in size. Therefore, hydraulic fluid flows out of accumulator A1 into gallery G1 and on to gallery 30 via check valve V1B of damper valve V1. Hydraulic fluid also flows out of accumulator A2, through gallery G3, into gallery G1 via check valve X1 and into gallery 30 via check valve V1B of damper valve V1.

If the disturbance input is in the opposite direction, such as a rebound, the fluid flow will be in the opposite direction. The rebound will cause the piston actuator 502 to extend therefore causing hydraulic fluid to flow out of the contracting first fluid chamber C1 of the piston actuator 502 and consequently into the expanding second fluid chamber C2 of the piston actuator 502. Fluid flow into the expanding second fluid chamber C2 is provided primarily by hydraulic fluid from accumulator A2 flowing through check valve V3B of damper valve V3. However, hydraulic fluid flowing out of the contracting first fluid chamber C1 of the piston actuator 502 is damped by variable valve V1A of the damper valve V1. Thus valve V1A acts as a variable damper valve under these circumstances. Hydraulic fluid passing through valve V1A of damper valve V1 will primarily cause fluid to flow into accumulator A1. Once the rebound has been negotiated the piston 24 will return to its steady state position. The rebound will create a high frequency road induced input which is accommodated primarily by accumulator A1 which is close to the first fluid chamber C1 of the piston actuator 502 when compared with accumulator A3.

However, as a rate/magnitude of rebound travel increases, movement of the piston 24 within the cylinder 22 may cause the pressure in chamber C1 of the piston actuator 502 to rise, causing the pressure in gallery G1 to increase above the valve pressure setting of variable valve V2 in which case the opening of the variable valve V2 will be momentarily increased so as to limit the pressure in gallery G1. Simultaneously, the large rebound will cause the volume of chamber C2 of the piston actuator 502 to increase in size. Therefore, hydraulic fluid flows out of accumulator A2 into gallery G2 and on to gallery 32 via check valve V3B of damper valve V3.

The volume of the third accumulator A3 may be greater than the volumes of the first and second accumulators A1 and A2.

Overall, the first fluid chamber C1 of the piston actuator 502 can vent fluid to both hydraulic accumulators A1 and A3. The second fluid chamber C2 of the piston actuator 502 can vent fluid to both hydraulic accumulators A2 and A3.

The hydraulic accumulators A1 and A2 are relatively close both physically and hydraulically to the fluid chambers C1 and C2 of the piston actuator 502, so these accumulators A1, A2 can accommodate high frequency road induced inputs which tend to require relatively low amounts of hydraulic fluid to accommodate. If the control system's setpoint is moving, the accumulators A1 and A2 may need to be filled more. Conversely the hydraulic accumulator A3, being larger, is better able to compensate for system volume changes due to fluid temperature changes, system volume changes (e.g., due to piston rod insertion and retraction), and larger relative movements of the piston 24 often associated with low frequency driver-induced inputs.

The variable valve V2 is a variable PCV and the valve pressure setting of valve V2 can be electronically varied by the control system 200 to suit the particular circumstances. The variable valve V2 may comprise a variable restriction (variable orifice). Specifically, the valve pressure setting of variable valve V2 may be dependent upon the setpoint for the first chamber C1 of the piston actuator 502. The valve pressure setting of variable

valve V2 may further be dependent upon the operating point of the pump P. The more electrical current is applied to the variable valve V2, the more counteracting force restricts the flow. The variable valve V2 receives continuous electrical current to counteract that pressure.

5 The valve V4 is a variable PCV and the valve pressure setting of valve V4 can be electronically varied by the control system 200 to suit the particular circumstances. The variable valve V4 may comprise a variable restriction (variable orifice). Specifically, the valve pressure setting of variable valve V4 may be dependent upon the setpoint in the second chamber C2 of the piston actuator 502. The valve pressure setting of variable valve V4 may further be dependent upon the operating point of the pump P. The more electrical current is
10 applied to the variable valve V4, the more counteracting force restricts the flow. The variable valve V4 receives continuous electrical current to counteract that pressure.

In steady state conditions, hydraulic fluid pumped in a first direction from the first port PP1 of pump P flows through the variable valve V2 into gallery G3, then into gallery G2 past the check valve X2, and back to the
15 second port PP2 of the pump P. Hydraulic fluid pumped in the opposite direction from the second port PP2 of the pump P flows through the variable valve V4 into gallery G3, then into gallery G1 past the check valve X1, and back to the first port PP1 of the pump P. The hydraulic pressure in each circuit 28, 29 is determined predominantly or entirely by the controllable pressure through the variable valves V2, V4. Therefore, the function of the bidirectional pump P is to transfer hydraulic fluid between the first and second hydraulic galleries
20 G1, G2 to control hydraulic pressure across the piston actuator 502.

FIG. 3A includes boxes schematically illustrating a sprung arrangement 520 and an unsprung arrangement 518 of the hydraulic control apparatus 17. The sprung arrangement 520 is arranged to be positioned on the sprung mass 102 of the vehicle. The unsprung arrangement 518 is arranged to be positioned on the unsprung
25 mass 101 of the vehicle.

In examples, the unsprung arrangement 518 is a first assembly comprising the hydraulic components which are enclosed by the box annotation labelled 518 in FIG. 3A. This includes: galleries G1, G2, G3, 30, 32; hydraulic circuits 28, 29; variable valves V2, V4; check valves X1, X2; damper valves V1, V3; and accumulators
30 A1, A2. The advantages of providing the variable valves V2, V4, and the check valves X1, X2 in the unsprung arrangement 518, rather than in the sprung arrangement 520, are described in the preceding summary section.

In examples, the sprung arrangement 520 is a second assembly comprising the hydraulic components which are enclosed by the box annotation labelled 520 in FIG. 3A. This includes the pump P and the accumulator
35 A3, both of which are heavy, having a mass of several kilograms. In some examples, the sprung arrangement 520 comprises a plurality of pumps P, for controlling the active suspensions 106, 116, 108, 118 of different vehicle wheels 12 of the vehicle 1.

In examples, the unsprung arrangement 518 is mounted in-use to the piston actuator 502, to minimise the fluid
40 path length to the chambers C1, C2 of the piston actuator 502 and avoid the need for further hoses. The unsprung arrangement 518 may be mounted to the piston actuator 502 inside or proximal to a wheel arch of

the vehicle 1. Specifically, the unsprung arrangement 518 may be mounted to an unsprung part of the piston actuator 502, in this case the cylinder 22. Or, if the piston actuator 502 is mounted the other way around, the unsprung part may be the piston rod 26.

5 In examples, the sprung arrangement 520 is mounted in-use to the vehicle body 102. The sprung arrangement 520 may be mounted to an underside of the vehicle body 102. The sprung arrangement 520 may be mounted to the vehicle body 102 at a laterally inboard location of the vehicle body 102 proximal to the centreline of the vehicle.

10 The sprung and unsprung arrangements 520, 518 of FIG. 3A are hydraulically coupled to each other by the flexible hydraulic lines H1, H2, H3. The flexibility of the flexible hydraulic lines H1, H2, H3 enables relative movement of the unsprung and sprung arrangements 518, 520, the movement of each being decoupled from movement of the other.

15 A first end E1 of the first flexible hydraulic line H1 is connected, directly or indirectly, to the port PP1 of the pump P, and a second opposite end E2 of the first flexible hydraulic line H1 is connected to the first gallery G1, enabling direct fluid transfer between port PP1 and gallery G1.

A first end E1 of the second flexible hydraulic line H2 is connected, directly or indirectly, to the port PP2 of the
20 pump P, and a second opposite end E2 of the second flexible hydraulic line H2 is connected to the second gallery G2, enabling direct fluid transfer between port PP2 and gallery G2.

In examples where the accumulator A3 is hydraulically coupled to the third gallery G3 by a third flexible hydraulic line H3, a first end E1 of the third flexible hydraulic line H3 is connected, directly or indirectly, to the
25 accumulator A3, and a second opposite end E2 of the third flexible hydraulic line H3 is connected to the gallery G3, enabling direct fluid transfer between gallery G3 and accumulator A3.

In some examples, a single accumulator A3 may be shared between the piston actuators 502 of a plurality of active suspensions such as 106 and 116, and/or 108 and 118, for different vehicle wheels 12.

30 FIG. 4 shows a first implementation of this example. The accumulator A3 is hydraulically coupled to a separate middle hydraulic gallery G4, the middle hydraulic gallery G4 being hydraulically coupled to each of the active suspensions 106 and 116 (or 108 and 118) at an appropriate hydraulic connection location enabling the accumulator A3 to compensate for system volume changes. The third flexible hydraulic line H3 may not be
35 required.

FIG. 5 schematically illustrates how parts of the unsprung arrangement 518 may be packaged in or near a wheel arch of the vehicle 1. Parts are represented by cylinders and hydraulic flow paths are represented by lines.

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FIG. 5 illustrates the accumulators A1 and A2, each comprising a housing 600 in the form of a cylinder or sphere, or other shape. Each housing 600 has a pair of opposite ends 602, 604, which may be flat faces, domed faces, or hemispheres, or another shape, depending on the geometry of the accumulator A1, A2.

- 5 The ends include a proximal/base end 602 and a distal end 604. The base end 602 is the end which is proximal to a port of the accumulator A1, A2, or comprises the port. The housings 600 are mostly or substantially aligned with each other, and face in opposite directions from each other. Their base ends 602 comprise faces generally facing each other across a gap 606 separating the base ends 602 (facing ends). The variable valves V2, V4 and check valves X1, X2 are positioned in or mostly within the gap 606 between the base ends 602 of the
- 10 housings 600 of the accumulators A1, A2. In examples, valve housings house the valves V2, V4, X1, X2, the valve housings being positioned in or mostly in the gap 606 between the facing base ends 602. The gap 606 provides packaging space for locating the valves V2, V4, X1, X2 physically close to the piston actuator 502, without risk of interference with the unsprung or sprung masses 101, 102 of the vehicle.
- 15 It will be appreciated that various changes and modifications can be made to the present invention without departing from the scope of the present application.

- Features described in the preceding description may be used in combinations other than the combinations explicitly described. Although functions have been described with reference to certain features, those functions
- 20 may be performable by other features whether described or not. Although features have been described with reference to certain embodiments, those features may also be present in other embodiments whether described or not.

CLAIMS

1. A hydraulic control apparatus for a piston actuator of an active suspension system of a vehicle, the hydraulic control apparatus comprising:

5 an unsprung arrangement arranged to be positioned on an unsprung mass of the vehicle, the unsprung arrangement comprising:

a first hydraulic gallery hydraulically couplable to a first fluid chamber of the piston actuator;

a second hydraulic gallery hydraulically couplable to a second fluid chamber of the piston actuator;

a third hydraulic gallery interfaced with the first and second hydraulic galleries by variable valves;

10 the hydraulic control apparatus further comprising:

a sprung arrangement arranged to be positioned on a sprung mass of the vehicle, the sprung arrangement comprising:

a pump, the pump comprising:

15 a first port hydraulically couplable to the first hydraulic gallery by a first coupling, and

a second port hydraulically couplable to the second hydraulic gallery by a second coupling, the first and second couplings enabling the pump to transfer hydraulic fluid between the first and second hydraulic galleries,

20 wherein the first and second couplings extend between the sprung and unsprung arrangements and enable movement of each of the unsprung and sprung arrangements to be decoupled from movement of the other of the unsprung and sprung arrangements.

2. The hydraulic control apparatus of claim 1, wherein the sprung arrangement comprises a hydraulic accumulator.

3. The hydraulic control apparatus of claim 2, wherein the unsprung arrangement further comprises a first hydraulic accumulator connected to the first hydraulic gallery, and a second hydraulic accumulator connected to the second hydraulic gallery, the hydraulic accumulator being a third hydraulic accumulator.

4. The hydraulic control apparatus of claim 3, wherein the variable valves are positioned in a gap (606) between the first and second hydraulic accumulators.

5. The hydraulic control apparatus of claim 2, 3, or 4, wherein the hydraulic accumulator is arranged to be hydraulically shared between a plurality of piston actuators of the active suspension system, for different vehicle wheels.

6. The hydraulic control apparatus of any one of claims 2 to 5, wherein the hydraulic accumulator is hydraulically couplable to the third hydraulic gallery between the variable valves.

7. The hydraulic control apparatus of any preceding claim, wherein the variable valves are arranged to permit variable hydraulic fluid flow into the third hydraulic gallery, wherein the unsprung arrangement further

comprises one-way valves, and wherein the third hydraulic gallery is further interfaced with the first and second hydraulic galleries by the one-way valves arranged to permit one-way hydraulic fluid flow out of the third hydraulic gallery.

- 5 8. The hydraulic control apparatus of claim 7 as dependent through claim 4, wherein the one-way valves are positioned in the gap between the first and second hydraulic accumulators.
9. The hydraulic control apparatus of any preceding claim, wherein the pump is a bidirectional pump operable to transfer hydraulic fluid between the first and second hydraulic galleries to control hydraulic
10 pressure across the piston actuator.
10. The hydraulic control apparatus of any preceding claim, wherein the first and second couplings comprise flexible hydraulic lines arranged in flow paths between the variable valves and the pump, wherein first ends of the flexible hydraulic lines are arranged to be connected to the sprung arrangement, proximal to
15 the pump, and wherein second opposite ends of the flexible hydraulic lines are arranged to be connected to the unsprung arrangement, proximal to the variable valves.
11. The hydraulic control apparatus of any preceding claim, wherein the unsprung arrangement further comprises a plurality of damper valves each connected to a different one of the first and second hydraulic
20 galleries and arranged to control hydraulic fluid flow towards the variable valves.
12. The hydraulic control apparatus of claim 11, wherein each damper valve comprises a variable valve arranged to control hydraulic fluid flow towards the variable valves, and a one-way valve arranged to permit one-way hydraulic fluid flow towards the respective fluid chamber of the piston actuator.
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13. An actuator system comprising the hydraulic control apparatus and the piston actuator, of any one of the preceding claims.
14. The actuator system of claim 13, wherein the unsprung arrangement is secured to the piston actuator.
30
15. A vehicle comprising the actuator system of claim 13 or 14.

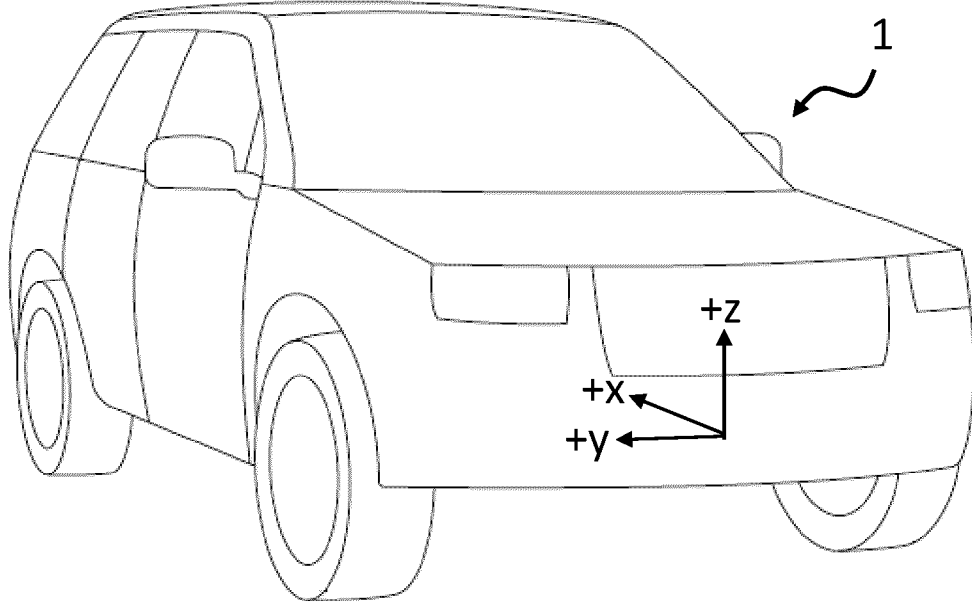


FIG. 1

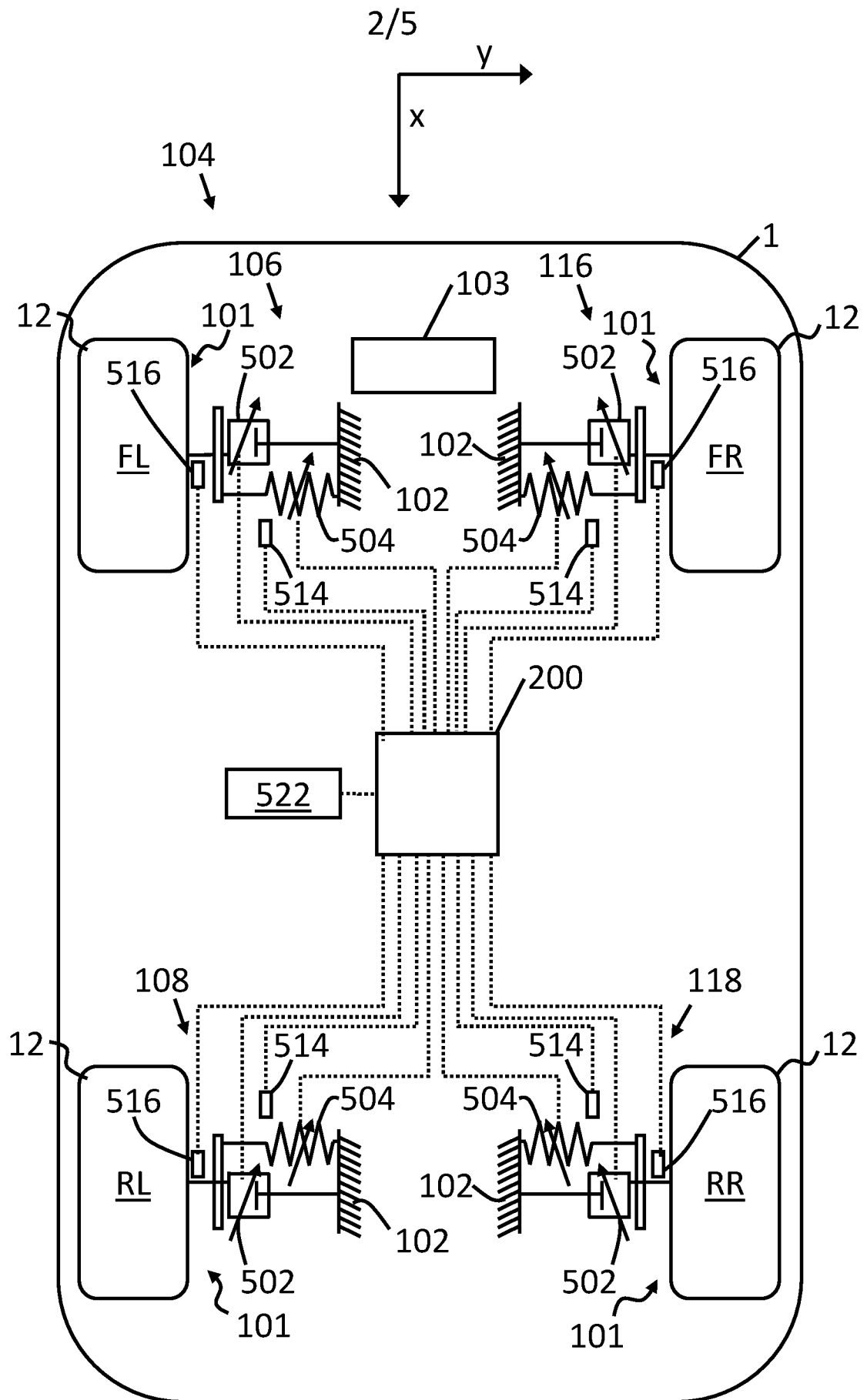


FIG. 2

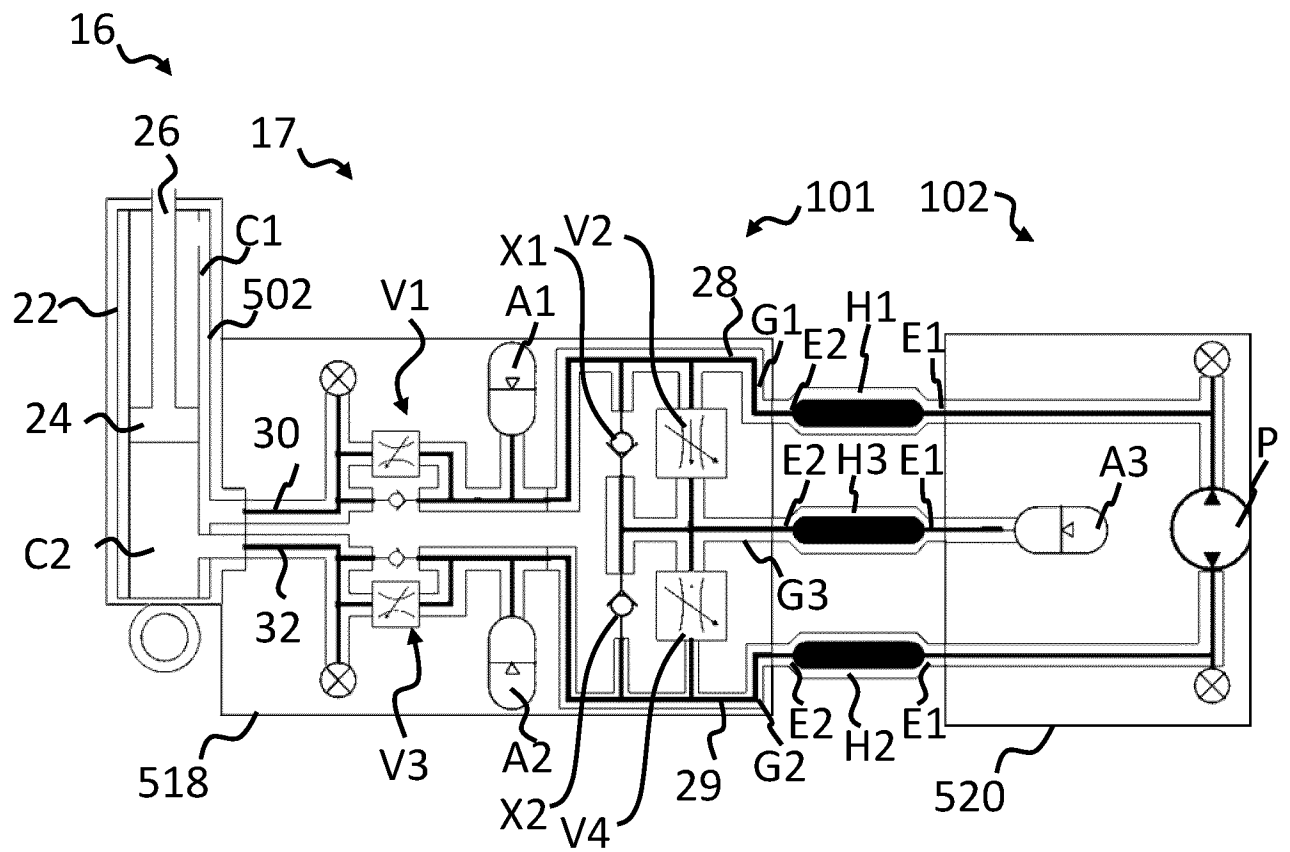


FIG. 3A

4/5

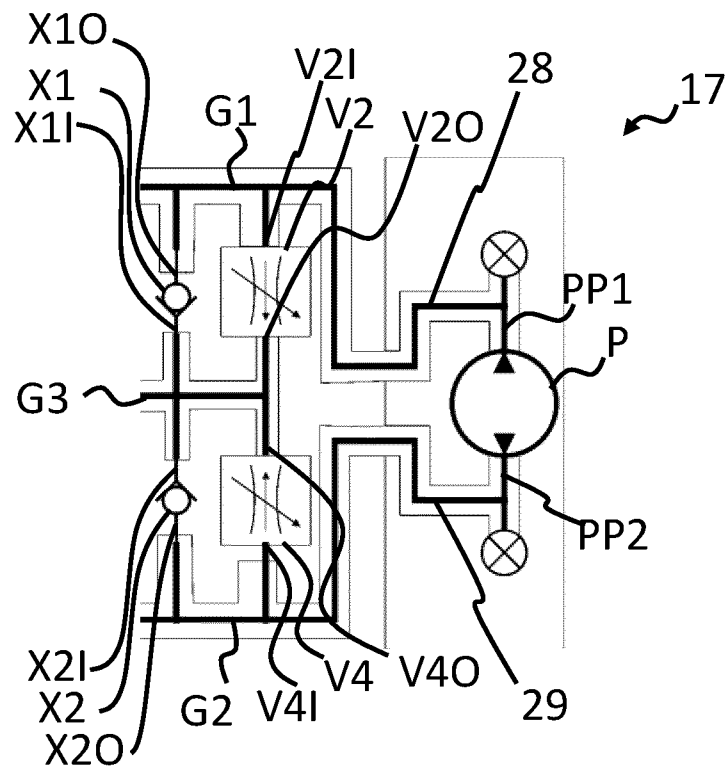


FIG. 3B

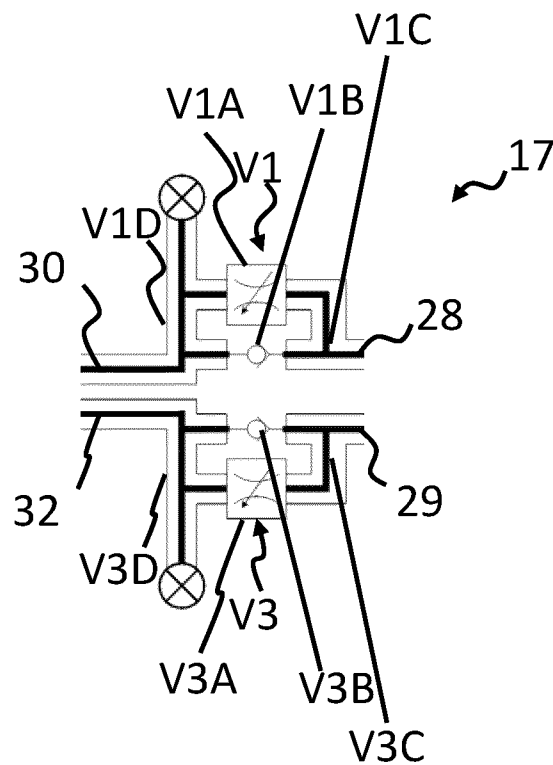


FIG. 3C

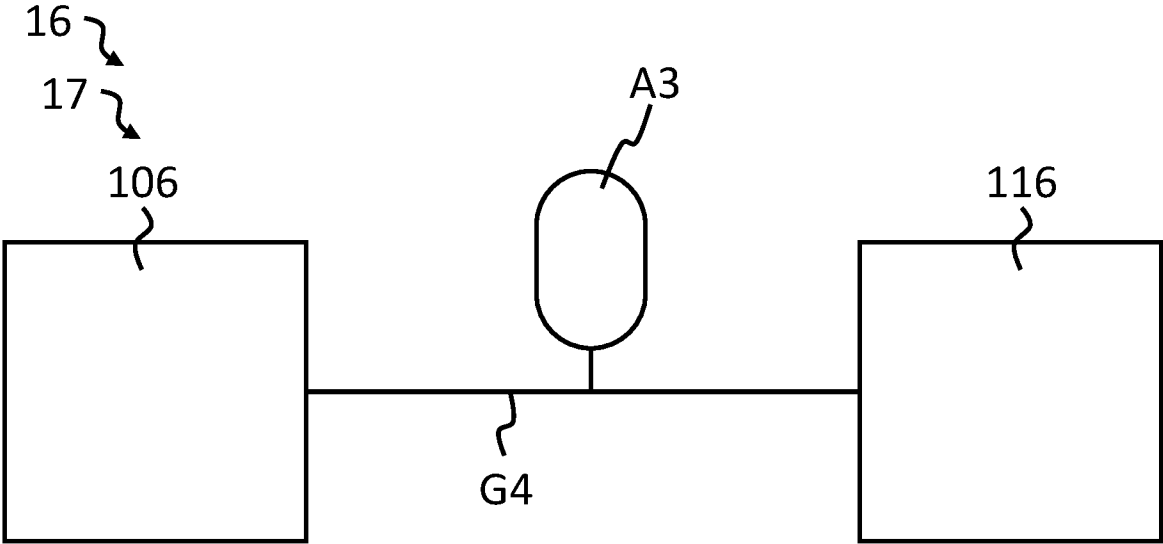


FIG. 4

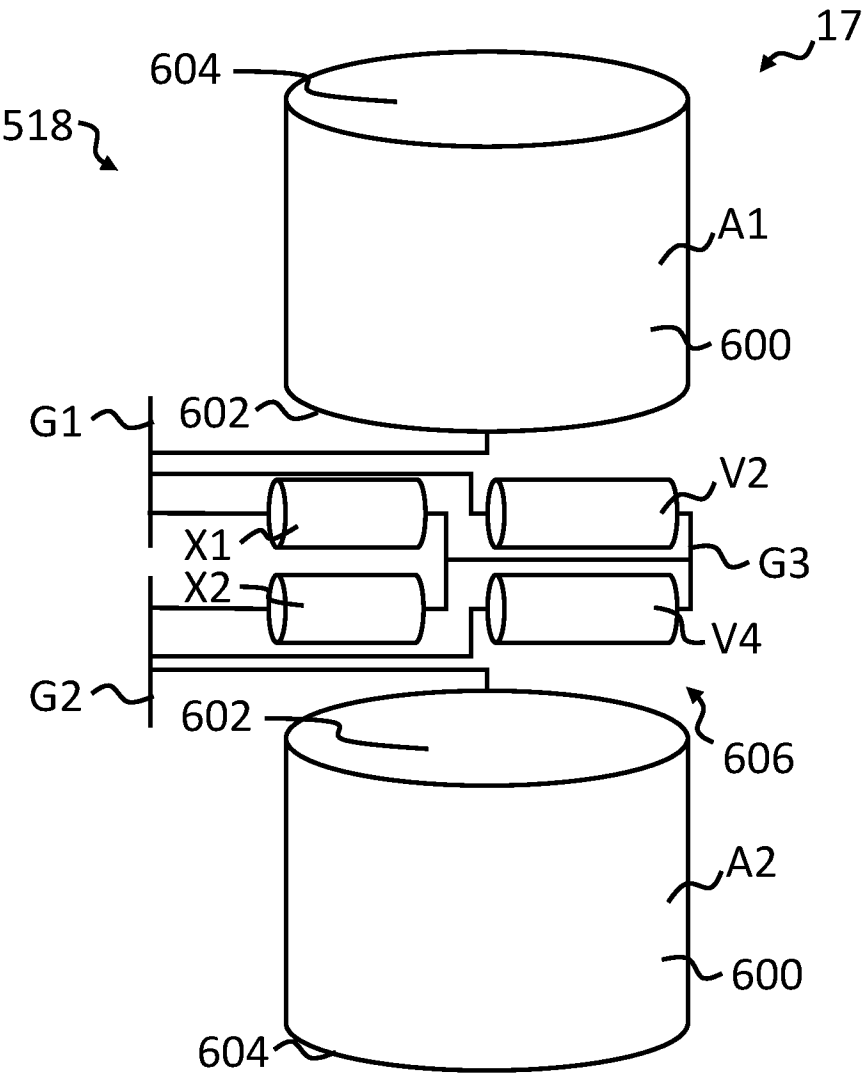


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2024/068207

A. CLASSIFICATION OF SUBJECT MATTER

INV. B60G17/056 B60G17/08
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B60G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2 566 543 A (JAGUAR LAND ROVER LTD [GB]) 20 March 2019 (2019-03-20) page 12, line 19 - page 13, line 9; figures page 14, line 26 - page 15, line 2 page 15, lines 4-11 -----	1 - 15
X	GB 2 566 546 A (JAGUAR LAND ROVER LTD [GB]) 20 March 2019 (2019-03-20) page 4, lines 25-27; figures page 11, lines 11-35 page 13, lines 9-19 -----	1 - 15
A	DE 10 2016 213957 A1 (ZAHNRADFABRIK FRIEDRICHSHAFEN [DE]) 1 February 2018 (2018-02-01) paragraph [0028]; figure 1 ----- - / - -	1 - 15



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

20 September 2024

Date of mailing of the international search report

30/09/2024

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2024/068207

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2018/281550 A1 (MASAMURA TATSUYA [JP]) 4 October 2018 (2018-10-04) figures 8-9 -----	5

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2024/068207

Patent document cited in search report	Publication date	Patent family member(s)	Publication date	
GB 2566543	A	20-03-2019	DE 102018215504 A1	21-03-2019
			GB 2566543 A	20-03-2019
			US 2019084367 A1	21-03-2019

GB 2566546	A	20-03-2019	DE 102018215137 A1	21-03-2019
			GB 2566546 A	20-03-2019
			US 2019084366 A1	21-03-2019

DE 102016213957 A1	01-02-2018	NONE		

US 2018281550	A1	04-10-2018	CN 108136869 A	08-06-2018
			EP 3357722 A1	08-08-2018
			JP 6663197 B2	11-03-2020
			JP 2017065470 A	06-04-2017
			KR 20180048881 A	10-05-2018
			US 2018281550 A1	04-10-2018
			WO 2017057099 A1	06-04-2017
