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(54) Title: SUSPENSION SYSTEMS USING HYDRAULIC DAMPERS

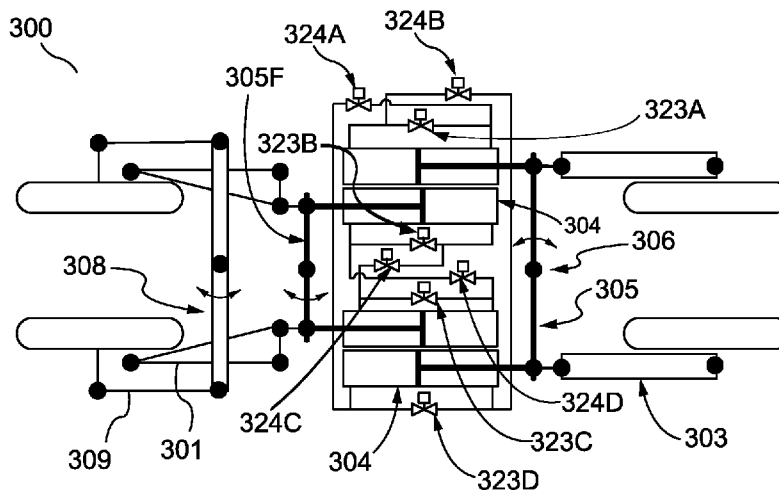


FIG. 3A

(57) Abstract: A dual-mode suspension system using hydraulic dampers is disclosed. One or more dampers on each side of the four-wheel suspension system are coupled to a respective damper on the other side via a damper valve. One or more leaf springs may be arranged between the leading links coupled to some of the dampers, and trailing links coupled to other of the dampers. The suspension system may advantageously engage, lock, or partially disengage the respective dampers connected by the valve on each side of the system. Manipulating the valve to control engagement of the dampers, which may depend on the speed and related issues, provides control over whether heave motions should be separated from roll. In another embodiment, one or more single or double acting hydraulic cylinders may be used to engage dampers.



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## SUSPENSION SYSTEMS USING HYDRAULIC DAMPERS

### CROSS-REFERENCE TO RELATED APPLICATION

- [0001] This application claims the benefit of U.S. Patent Application No. 15/829,845, entitled "SUSPENSION SYSTEMS USING HYDRAULIC DAMPERS" and filed on December 1, 2017, which is expressly incorporated by reference herein in its entirety.

### BACKGROUND

#### Field

- [0002] The present disclosure relates generally to transport structures, and more specifically to versatile suspension systems that use dynamic leaning techniques.

#### Background

- [0003] Additive manufacturing (AM) introduces numerous practical advantages and beneficially complements conventional machining in automotive and related industries. Due to AM's continued development and refinement, manufacturers in these industries are understandably eager to incorporate AM into their build strategy. One application that may derive substantial benefits from AM is the use of solar energy to power, in part or in whole, cars, aircraft, boats and other transport structures.
- [0004] Conventional approaches to developing solar-powered cars have been circumscribed by practical limitations including, for example, the inability to harness adequate amounts of solar energy to power the vehicles given the limited surface area to place panels, the vehicle weight, drag of the vehicle while in motion, and other factors.
- [0005] Other problems include the need for an adequate suspension system and related components that increase the capability of the solar vehicle and that further act to reduce energy consumption of the vehicle.

### SUMMARY

- [0006] Several aspects of suspension systems used in solar extended range electric vehicles and other transport structures will be described more fully hereinafter with reference to various illustrative aspects of the present disclosure.

- [0007] In one aspect of the present disclosure, a quadricycle suspension system for a vehicle quadricycle suspension system for a vehicle includes a first damper arranged on a first side of the suspension system and a second damper arranged on a second side of the suspension system, wherein the first damper is coupled to the second damper via at least one interconnect, each at least one interconnect comprising a valve configured to control the motion of the first damper relative to the second damper.
- [0008] In another aspect of the present disclosure, a quadricycle suspension system for a vehicle includes a first damper coupled respectively to first trailing and leading links, a second damper coupled respectively to second trailing and leading links, a first active valve coupled to first inlet compression and rebound ports of the first damper, and a second active valve coupled to second inlet compression and rebound ports of the second damper, wherein the first and second active valves are configured to damp heave and pitch of the vehicle by controlling relative motion of the first and second dampers based on an at least one input.
- [0009] Different suspension systems are disclosed that have not previously been developed or proposed. It will be understood that other aspects of suspension systems will become readily apparent to those skilled in the art based on the following detailed description, wherein only several embodiments are described by way of illustration. As will be appreciated by those skilled in the art, these suspension systems can be realized with other embodiments without departing from the spirit and scope of the invention. Accordingly, the drawings and detailed description are to be regarded as illustrative in nature and not as restrictive.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

- [0010] Various features of quadricycle suspension systems will now be presented in the detailed description by way of example, and not by way of limitation, in the accompanying drawings, wherein:
- [0011] FIG. 1 is a perspective view of a solar extended range electric vehicle.
- [0012] FIG. 2A is a plan view of a solar extended range electric vehicle in mobile mode.
- [0013] FIG. 2B is a perspective view of the solar extended range electric vehicle in mobile mode.
- [0014] FIG. 3A is a plan view of the suspension and wheel system of the solar extended range electric vehicle.

- [0015] FIG. 3B is an elevation view of the suspension and wheel system of the solar extended range electric vehicle.
- [0016] FIG. 3C is a plan view of the suspension system of the solar extended range electric vehicle showing the leaf spring and damper valves.
- [0017] FIG. 3D is a perspective view of the leaf spring of the suspension system.
- [0018] FIG. 4 is an elevation view of the solar extended range electric vehicle in the dynamic leaning narrow track mode.
- [0019] FIG. 5 is an elevation view of the solar extended range electric vehicle in the non-tilting wide track mode.

#### **DETAILED DESCRIPTION**

- [0020] The detailed description set forth below with reference to the appended drawings is intended to provide a description of exemplary embodiments of suspension systems in solar extended range vehicles and other transports. The description is not intended to represent the only embodiments in which the invention may be practiced. The term "exemplary" used throughout this disclosure means "serving as an example, instance, or illustration," and should not necessarily be construed as preferred or advantageous over other embodiments presented in this disclosure. The detailed description includes specific details for providing a thorough and complete disclosure that fully conveys the scope of the invention to those skilled in the art. However, the invention may be practiced without these specific details. In some instances, well-known structures and components may be shown in block diagram form, or omitted entirely, to avoid obscuring the various concepts presented throughout this disclosure.
- [0021] In one aspect of the present disclosure, a solar extended range electric vehicle is introduced in which a dual-mode suspension system is used. In one embodiment, the suspension system uses at least a pair of hydraulic dampers which can engage via the use of one or more damper valves, including controlling the relative motion of the dampers, when the vehicle is traveling at low speeds. Alternatively, when other conditions exist such as when the vehicle passes a predetermined speed or the vehicle has crossed some threshold with respect to some magnitude of requested lateral acceleration, the damper valves may be configured to partially disengage the hydraulic dampers to reduce relative motion limitations. In this manner, the

relationship between aspects like heave and roll can be well controlled under different speeds and occupant driving conditions.

[0022] In certain embodiments, a sensor system may be coupled to a control circuit, wherein the control circuit may be configured to automatically open and close the associated valve in response to characteristics measured from the sensor system.

[0023] FIG. 1 is a perspective view of a solar extended range electric vehicle 100. The vehicle 100 may include an aerodynamically contoured frame 102, a transparent or semi-transparent canopy 114, a body structure 112, a suspension system 116 mounted to the body structure 112, center console 120, battery cells 122, and dual inline seating 104 to accommodate two occupants in this embodiment.

[0024] In addition, deployable solar panel arrays 106, 108 are attached to the vehicle. In an embodiment, the arrays 106, 108 may be constructed such that when deployed, they are located on either side of the tail. In this embodiment, the deployed arrays cover a total area of approximately three square meters, although the necessary surface area may in practice vary widely depending on numerous factors including characteristics of the vehicle. Arrays 106, 108 can be stowed during motion to the vehicle to improve aerodynamic characteristics. Solar panel arrays 106, 108 may continue to absorb solar energy and may provide sufficient energy for tasks like commuting and when folded or stowed to their original, low drag position as the vehicle moves. In some embodiments, two-axis solar tracking can improve array effectiveness by a multiple in the range of approximately 1.3-1.8 or potentially greater.

[0025] FIGS. 2A-B are respective plan and perspective views of a solar extended range electric vehicle 200 in mobile mode. As shown in FIGS. 2A-B, the solar panels 106 and 108 are stowable by being foldable substantially flush against tail section 160 of the vehicle 200. Thus, to deactivate the solar panels and prepare for a more aerodynamically efficient mobile mode, lower solar panels 108 may first be folded downward flush along a frame of tail section 160. Thereupon, upper panels 106 may next be folded downward flush along exposed surfaces of upper panels 108. In this way, the amount of surface area and hence the drag decreases substantially, and the vehicle 200 is ready to be driven.

[0026] FIG. 2A further shows the handlebar 126 steering mechanism as described in greater detail below. FIG. 2D shows a portion of battery pack 122 which may be disposed under the passengers in this example. The front passenger shown in FIG. 2A is

adjacent to center console 120, which may include electronics for the various components and in other embodiments, some storage area, or a combination thereof. In certain embodiments, one of nose section or tail section 160 may include modest accommodations for storage (*e.g.*, a few grocery bags). A suspension system 116 (FIG. 1) may be mounted to body structure 112 and coupled to wheel system 110.

[0027] FIGS. 3A and 3B are respective plan and elevation views of the suspension and wheel system of the solar extended range electric vehicle 300 in accordance with an exemplary embodiment. FIG. 3C is a plan view of the suspension system of the solar extended range electric vehicle showing the leaf spring and damper valves. FIG. 3D is a perspective view of the leaf spring of the suspension system of FIG. 3C. FIG. 3A is exemplary in nature and is not drawn to scale. While FIGS. 3A-D illustrate certain structures for carrying out the inventive concepts herein, it should be understood that these structures are exemplary in nature, and numerous other structures and arrangements may be equally suitable and within the understanding of one skilled in the art upon review of this disclosure.

[0028] The wheel system may be coupled to the suspension system via leading links 301 and upright 302 (see FIG. 3B). The rear wheels may be connected via trailing link 303 for the rear suspension. It should be noted that the trailing link is used for exemplary purposes only, and other and different suspension system components can be equally suitable for purposes of this disclosure. Coupled to trailing links 303 on both sides are dampers 304 for controlling wheel motion. Dampers may be used on each wheel. In certain vehicles, such as a dynamic leaning narrow track vehicle, decoupling of roll and heave may be desired, while in other vehicles such as a non-tilting wide track vehicle, decoupling of heave and warp, and/or roll and warp, may be desired.

[0029] Leaf spring 305 associated with the front is coupled with leading links 301 to form the front suspension while leaf spring 305 associated with the rear is coupled with trailing link 303 to form the rear suspension. In this embodiment, dampers 304 each control the motion of one wheel. Center pivots 306 are used with the leaf spring 305 to allow spring rate in heave and none in roll (see also FIG. 3D). In an embodiment, steering link 309 couples the wheels to handlebar 308.

[0030] Static stability is key for full exposure-controlled, aerodynamic bodywork. In an embodiment, dampers 304 may be hydraulically interconnected on the compression and rebound circuits (separately) with active valve control via valves 323A-D for

heave/pitch control and valves 324A-D for roll control (see FIGS. 3A, 3C). Valves 323A-D in the embodiment of FIG. 3A damp heave and pitch. Valves 324A-D in FIG. 3A damp roll. Low speed damping forces are typically much larger than desired for roll control. Roll represents rotational movement about an axis longitudinal to the length of the vehicle. Thus, in an embodiment, the active valves 324A-D are generally kept open to minimize forces resisting roll and modulated at parking lot speeds to allow forces resisting roll. In another embodiment, a torsion centering spring 306 (see FIG. 3A, 3D) is used concentric with leaf spring pivot 305 for self-centering / roll control -- decoupled from the heave loads. This passive centering may also be implemented in a depowered operation, such as parking the vehicle 300. In an embodiment, the state of the valves, and hence the mode of the vehicle, may be determined automatically using a control system that issues commands to circuits associated with the valves based, for example, on the mode of the vehicle including speed, lateral acceleration, perceived road conditions, and any other number of factors that may cause a desire for an particular operation of the vehicle.

**[0031]** Hydraulic interconnect lockout may also provide a mechanism for simplifying controls for autonomous vehicle operation. A double acting hydraulic cylinder with an orifice between the compression and rebound side of the piston allows damping by restricting flow. If the valve has an actively variable area, it results in hydraulic lockout as well as variable damping force. Cross-vehicle hydraulic connectors between the laterally opposite compression and rebound circuits can completely decouple heave from roll. The hydraulic cylinders can be connected cross-vehicle to allow variable roll resistance via active valving of valves 324A-D in the above embodiment. For low dynamic performance operation (i.e. lower speeds and with proscribed maximum cornering speeds), the roll-control interconnect can be locked out (i.e., no hydraulic fluid communication) such that the autonomous controller does not have to handle the extra degree of freedom related to dynamic leaning. In this fashion, the vehicle is a very conventional four-wheel passenger vehicle from a controls perspective, albeit with lower ultimate cornering performance. With a skilled driver, the interlocks can be put into active mode (open for low roll resistance) for much higher dynamic performance thresholds.



- [0032] In addition to the active valves, hydraulic motors can be used to move fluids across the vehicle to induce lean or to actively roll the vehicle.
- [0033] As noted above, static stability is important for full-exposure controlled, aerodynamic bodywork. Stability issues are governed by the suspension system. In addition, dynamic leaning may be used in some embodiments to enable the solar panel canopy to track the emitter. Dynamic emitting may in some embodiments be performed in conjunction with a processing system that uses a GPS or other means for emitter tracking. The processing system may be embodied in a deployment motor or, in some embodiments, as part of an independent component.
- [0034] FIG. 4 is an elevation view of the solar extended range electric vehicle 400 in the dynamic leaning narrow track mode. Reference 402 depicts the dynamic leaning of the vehicle and wheel system 410. The arrow 401 represents the direction of leaning over time.
- [0035] FIG. 5 is an elevation view of the solar extended range electric vehicle 510 in the non-tilting wide track mode. Vehicle 510 includes leaf spring 520, trailing link 522, hydraulic damper 524 and wheel system 530. The dashed lines indicate the movement of leaf spring 520, trailing link 522 and damper 524 over time.
- [0036] Table 1, below, illustrates the various exemplary characteristics of warp, roll, heave and pitch as a function of the mode.

**Table 1 – Directional Characteristics and Suspension Mode**

<b>MODE</b>	<b>DYNAMIC LEANING NARROW TRACK</b>	<b>NON-TILTING WIDE TRACK</b>
Warp	Soft for single wheel bump absorption	Soft for single wheel bump absorption
Roll	Very Soft for fastest time to desired lean angle	Stiff for best tire camber control
Heave	Driven by desired ride rate	Driven by desired ride rate
Pitch	Stiff for attitude control or desired ride rate	Stiff for attitude control or desired ride rate

[0037] The previous description is provided to enable any person skilled in the art to practice the various aspects described herein. Various modifications to the exemplary embodiments presented throughout this disclosure will be clear to those skilled in the art, and the concepts disclosed herein may be applied to other solar vehicles and techniques for panel deployment and emitter tracking in solar vehicles. Thus, the claims are not intended to be limited to the exemplary embodiments presented throughout the disclosure, but are to be accorded the full scope consistent with the language claims. All structural and functional equivalents to the elements of the exemplary embodiments described throughout this disclosure that are known or later come to be known to those of ordinary skill in the art are intended to be encompassed by the claims. Moreover, nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the claims. No claim element is to be construed under the provisions of 35 U.S.C. §112(f), or analogous law in applicable jurisdictions, unless the element is expressly recited using the phrase “means for” or, in the case of a method claim, the element is recited using the phrase “step for.”

**WHAT IS CLAIMED IS:**

1. A quadricycle suspension system for a vehicle, comprising:  
a first damper arranged on a first side of the suspension system; and  
a second damper arranged on a second side of the suspension system,  
wherein the first damper is coupled to the second damper via at least one interconnect, each at least one interconnect comprising a valve configured to control the motion of the first damper relative to the second damper.
2. The suspension system of claim 1, wherein the valve corresponding to each at least one interconnect is further configured to at least partially disengage the first and second dampers in response to control system commands.
3. The suspension system of claim 1, wherein the control system commands comprise at least one of vehicle speed and vehicle lateral acceleration.
4. The suspension system of claim 1, wherein the first and second dampers are coupled to leading links respectively located on the first and second sides.
5. The suspension system of claim 4, further comprising:  
a third damper arranged on the first side; and  
a fourth damper arranged on the second side,  
wherein the third damper is coupled to the fourth damper via at least one second interconnect, each at least one second interconnect comprising a valve configured to control the motion of the third damper relative to the fourth damper.
6. The suspension system of claim 5, wherein the valve corresponding to each at least one second interconnect is further configured to at least partially disengage the third and fourth dampers in response to control system commands.
7. The suspension system of claim 6, wherein the control system commands comprise at least one of vehicle speed and vehicle lateral acceleration.

8. The suspension system of claim 5, wherein the third and fourth dampers are coupled to trailing links respectively located on the first and second sides.
9. The suspension system of claim 3, wherein the first damper is coupled to the second damper via a first leaf spring.
10. The suspension system of claim 4, wherein the first leaf spring is coupled between the leading links.
11. The suspension system of claim 6, wherein the third damper is coupled to the fourth damper via a second leaf spring.
12. The suspension system of claim 10, wherein the second leaf spring is coupled between the trailing links.
13. The suspension system of claim 9, wherein the first leaf spring further comprises a torsion centering spring arranged concentric with a pivot of the first leaf spring, the torsion centering spring configured to decouple heave loads from roll loads.
14. The suspension system of claim 8, wherein at least one of the leading links or the trailing links comprise a girder suspension.
15. The suspension system of claim 1, wherein the first and second dampers comprise double-acting hydraulic cylinders performing compression and rebound connection functions..
16. The suspension system of claim 1, wherein the vehicle comprises a dynamic leaning narrow track vehicle.
17. The suspension system of claim 1, wherein the vehicle comprises a non-tilting wide track vehicle.
18. A quadricycle suspension system for a vehicle, comprising:

a first damper coupled respectively to first trailing and leading links;  
a second damper coupled respectively to second trailing and leading links;  
a first active valve coupled to first inlet compression and rebound ports of the first damper; and  
a second active valve coupled to second inlet compression and rebound ports of the second damper,  
wherein the first and second active valves are configured to damp heave and pitch of the vehicle by controlling relative motion of the first and second dampers based on an at least one input.

19. The suspension system of claim 18, further comprising a control system having one or more outputs coupled to the at least one input, the control system configured to provide an output for controlling a state of the first and second active valves.

20. The suspension system of claim 18, wherein:  
a compression port of the first damper is further coupled via a third active valve to a rebound port of the second damper;  
a rebound port of the first damper is further coupled via a fourth active valve to a compression port of the first damper; and  
the third and fourth active valves are configured to damp roll in response to at least one input.

21. The suspension system of claim 20, further comprising a control system having one or more outputs coupled to the at least one input, the control system configured to provide an out for controlling a state of the third and fourth active valves.

22. The suspension system of claim 18, wherein the first damper is further coupled to the second damper via a leaf spring.

23. The suspension system of claim 22, wherein the leaf spring is coupled between leading links, one of the leading links coupled to the first damper and another of the leading links coupled to the second damper.

24. The suspension system of claim 23, wherein the leaf spring further comprises a torsion centering spring arranged concentric with a pivot of the leaf spring, the torsion centering spring configured to enable passive decoupling of heave loads from roll loads.

25. The suspension system of claim 20, further comprising:  
a third damper adjacent the first damper and coupled to a fourth damper adjacent the second damper; and  
a plurality of active valves associated, at least in part, with the third damper and the fourth damper,  
wherein the plurality of valves are configured to control the associated dampers based on information from a controller.

26. The suspension system of claim 25, wherein the third damper is further coupled to the fourth damper via another leaf spring.

27. The suspension system of claim 18, wherein the leading links comprise a girder suspension.

28. The suspension system of claim 18, wherein the trailing links comprise a girder suspension or a swing arm suspension.

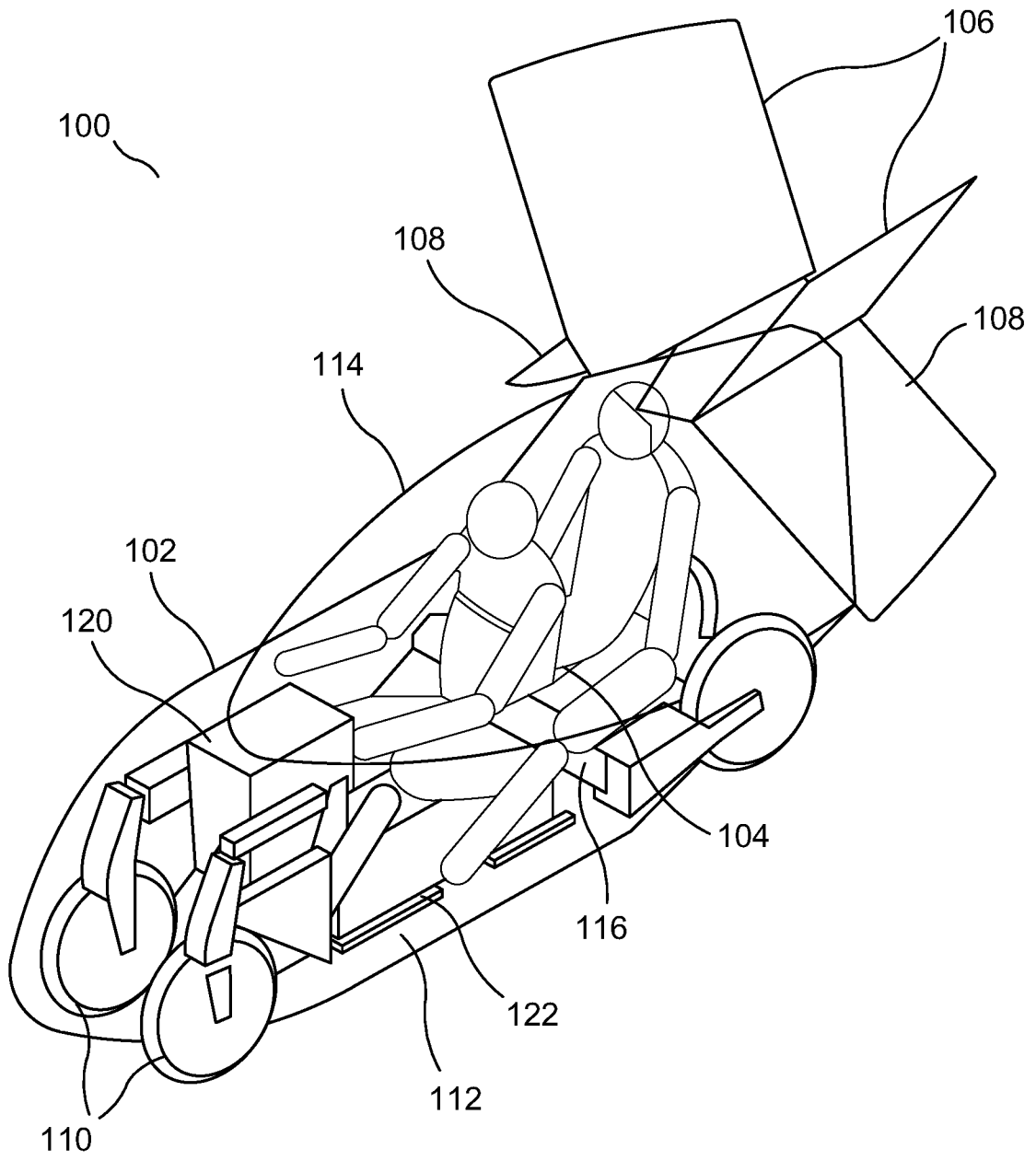


FIG. 1

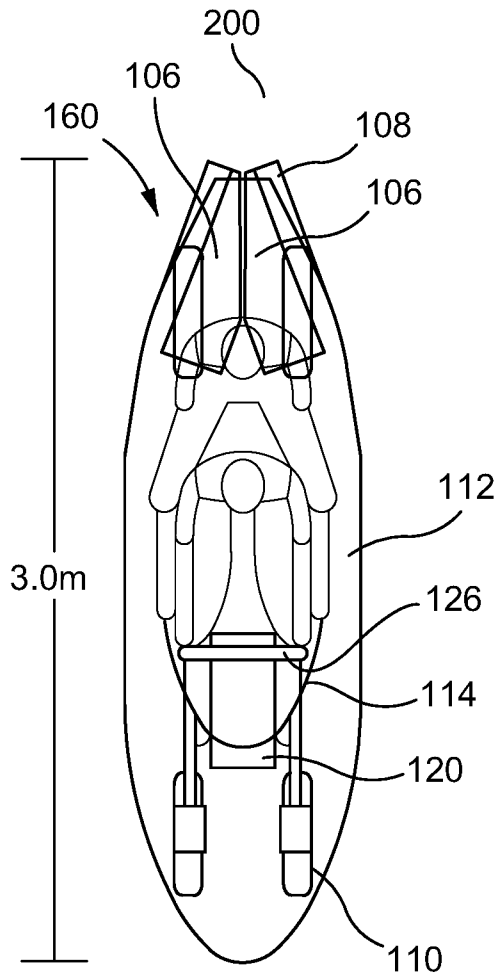


FIG. 2A

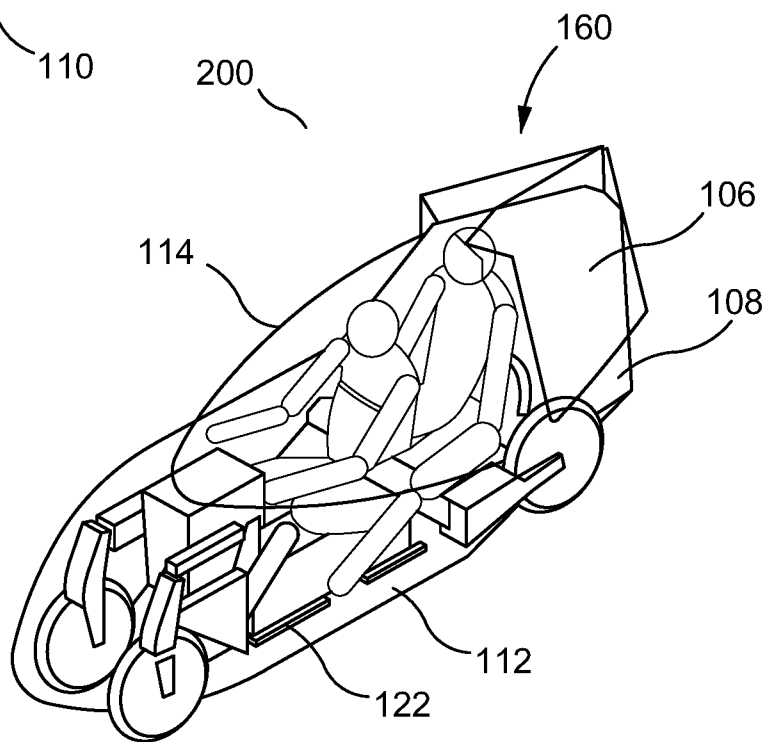


FIG. 2B



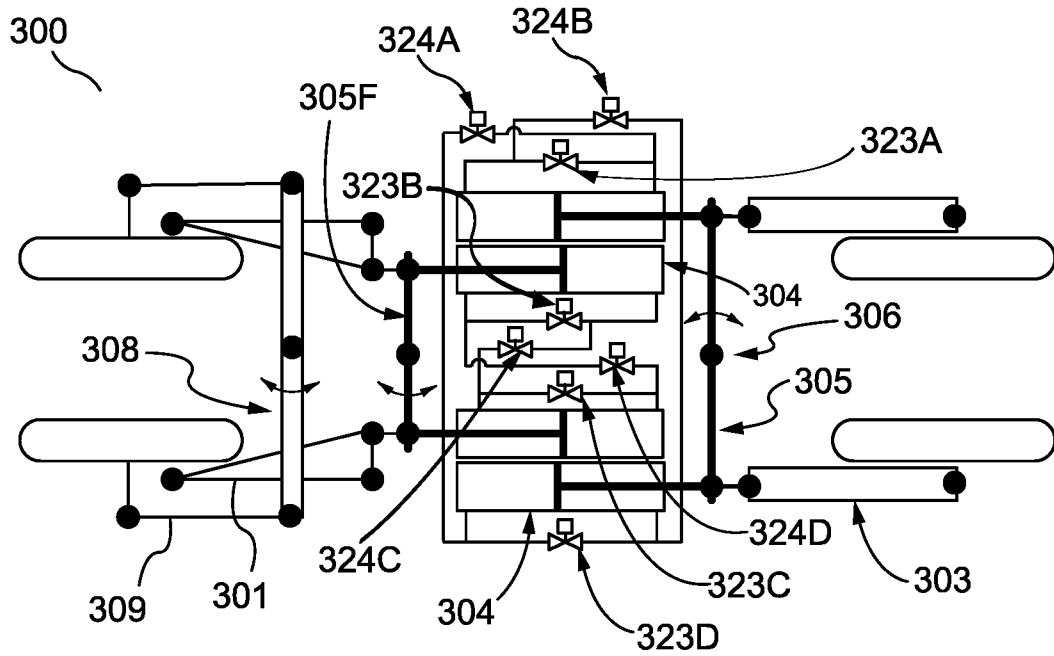


FIG. 3A

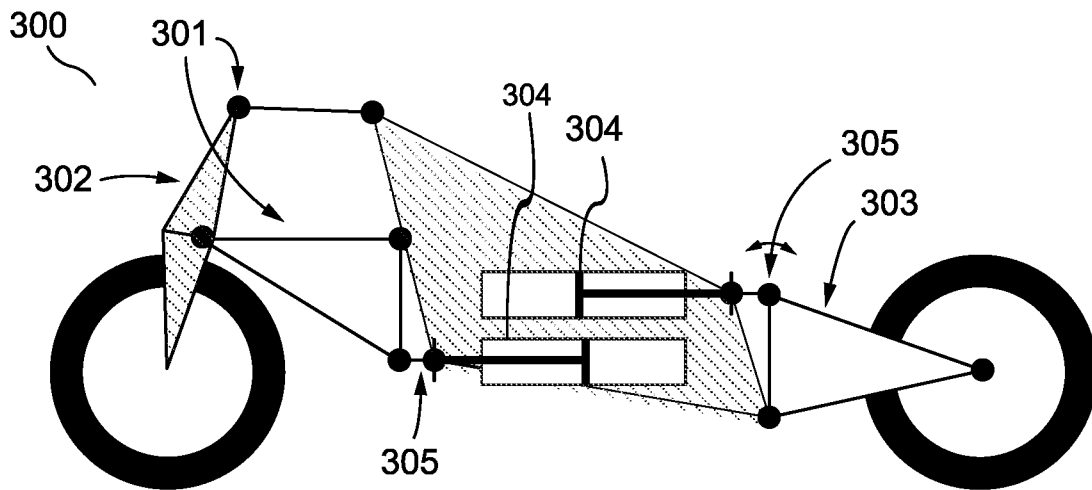


FIG. 3B

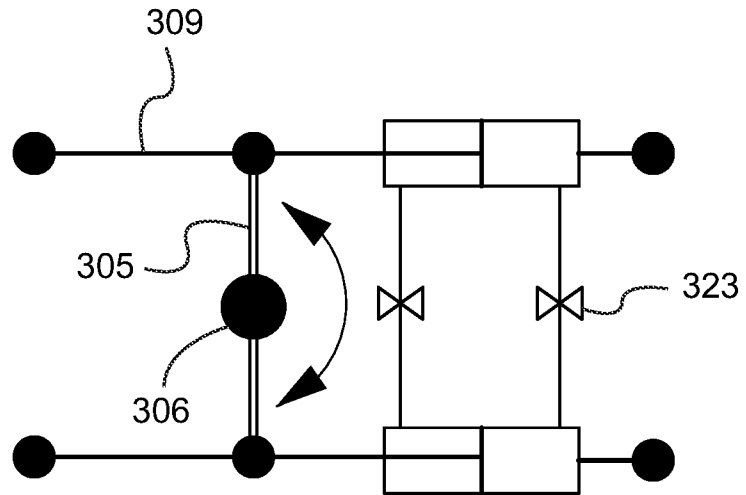


FIG. 3C

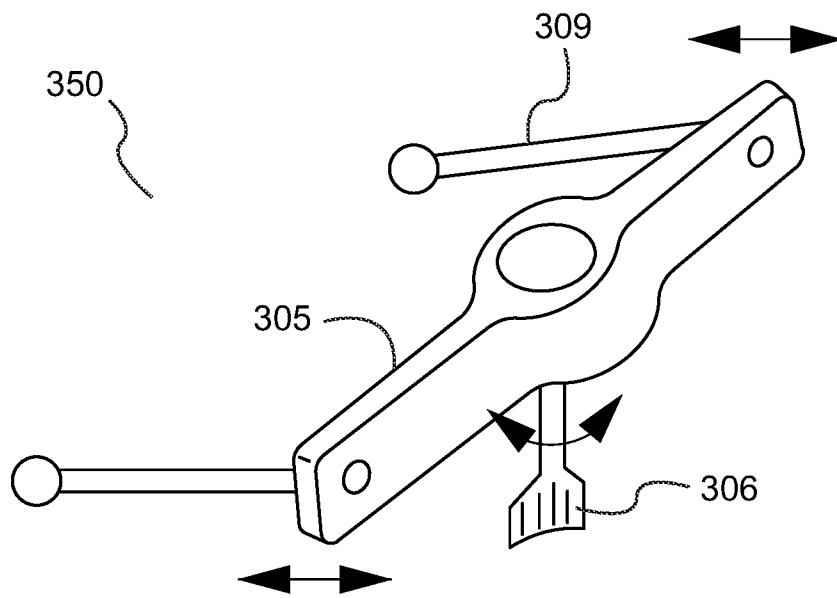


FIG. 3D

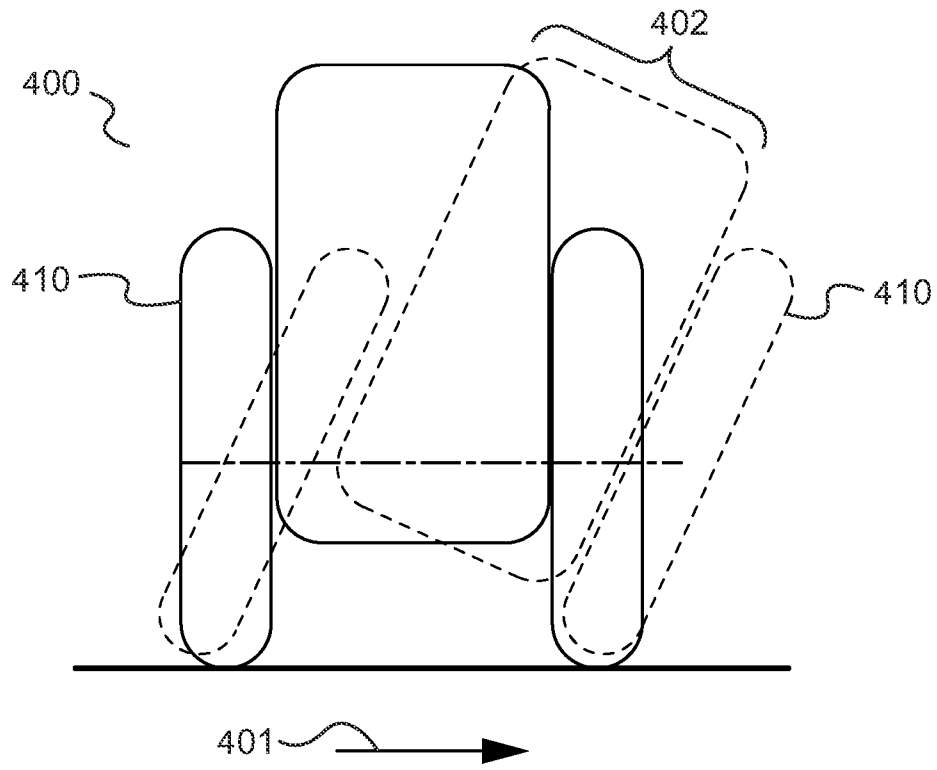


FIG. 4

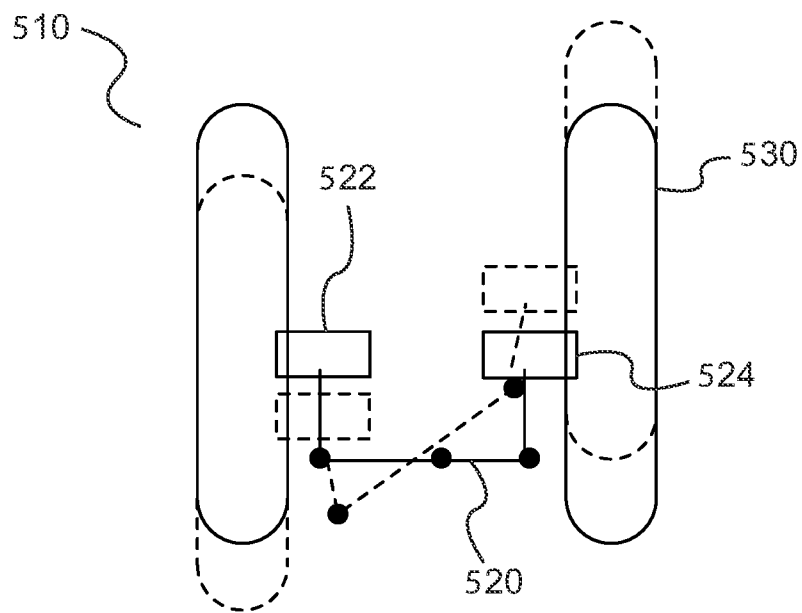


FIG. 5

## INTERNATIONAL SEARCH REPORT

International application No.  
**PCT/US2018/059627****A. CLASSIFICATION OF SUBJECT MATTER****B60G 17/018(2006.01)i, B60G 17/08(2006.01)i, B60G 13/00(2006.01)i, B60G 11/34(2006.01)i, B60G 3/18(2006.01)i, B60L 8/00(2006.01)i**

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 17/018; B60G 11/08; B60G 17/00; B60G 21/02; B60G 21/06; B60G 3/28; B60G 7/00; B60G 17/08; B60G 13/00; B60G 11/34; B60G 3/18; B60L 8/00

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

Korean utility models and applications for utility models  
Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) &amp; keywords: vehicle, suspension, damper, valve, leaf spring, torsion centering spring

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 103434364 A (CHANGZHOU WANAN AUTOMOBILE PARTS SCIENCE & TECHNOLOGY CO., LTD) 11 December 2013 See paragraphs [0030], [0031], [0034] and figure 2.	1-8, 14-21, 25, 27, 28
Y		9-12, 22, 23, 26
A		13, 24
Y	EP 2540533 B1 (AUDI AG.) 09 August 2017 See claim 1 and figures 1, 2.	9-12, 22, 23, 26
A	US 8573618 B2 (SCHRODER et al.) 05 November 2013 See column 3, lines 50-60 and figures 1, 2.	1-28
A	US 4652010 A (SUGASAWA, FUKASHI) 24 March 1987 See column 3, line 61 - column 5, line 56 and figures 1, 2.	1-28
A	US 2015-0102575 A1 (CLUB CAR, L.L.C.) 16 April 2015 See paragraphs [0008]-[0010], [0022] and figures 1-3.	1-28

 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

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"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

"&amp;" document member of the same patent family

Date of the actual completion of the international search

20 February 2019 (20.02.2019)

Date of mailing of the international search report

**21 February 2019 (21.02.2019)**

Name and mailing address of the ISA/KR

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**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.

**PCT/US2018/059627**

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