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JP 100324135 A **US 20050269753 A1**

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Other: **WPI; EPODOC**

(54) Title of the Invention: **Vehicle air suspension and its use**
Abstract Title: **An air suspension for a motor vehicle including an equaliser valve**

(57) An air suspension for a motor vehicle is provided. The airsuspension 6 is for at least two axles 2, 3 of a motor vehicle1. Each axle 2, 3 extends from a first side R of the vehicle to a second side L of the vehicle 1. The air suspension 6 comprises for each axle 2, 3 at least one first air bellows 7 on the first side R of the vehicle 1 and at least one second air bellows 8 on the second side L of the vehicle. Furthermore the air suspension 6 comprises a pressure tank 12 for storing compressed air, a valve system 13 connected to the air bellows 7, 8, at least one pressure sensor 9 for detecting a pressure in an air bellows 7, 8, and a control unit 11 for the valve system 13 adapted to electronically control the pressure in the air bellows 7, 8 by operating valves 13.1 to 13.6 of the valve system 13. The valve system 13 comprises at least one equaliser valve 13.1 connecting pneumatically two air bellows 7, 8 for different axles 2, 3 so that opening the equaliser valve 13.1 allows airto flow between the two air bellows 7, 8.

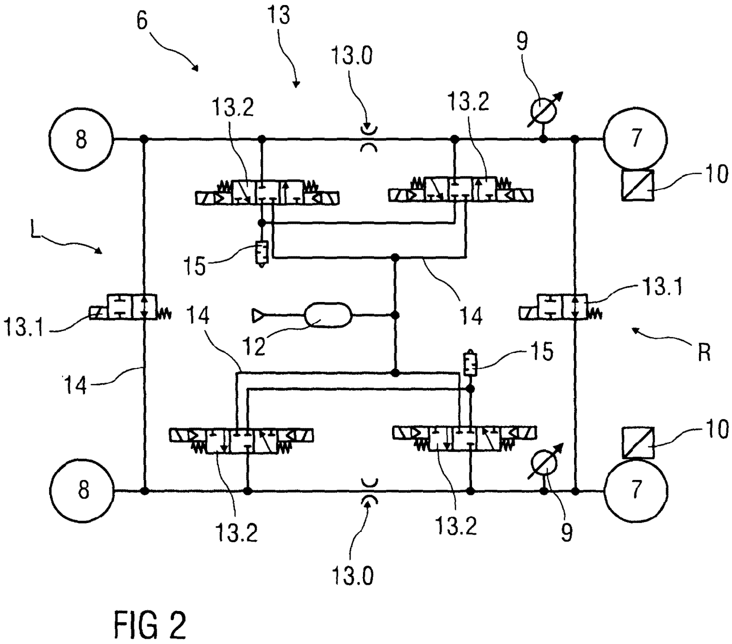

FIG 2

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

The claims were filed later than the filing date but within the period prescribed by Rule 22(1) of the Patents Rules 2007.

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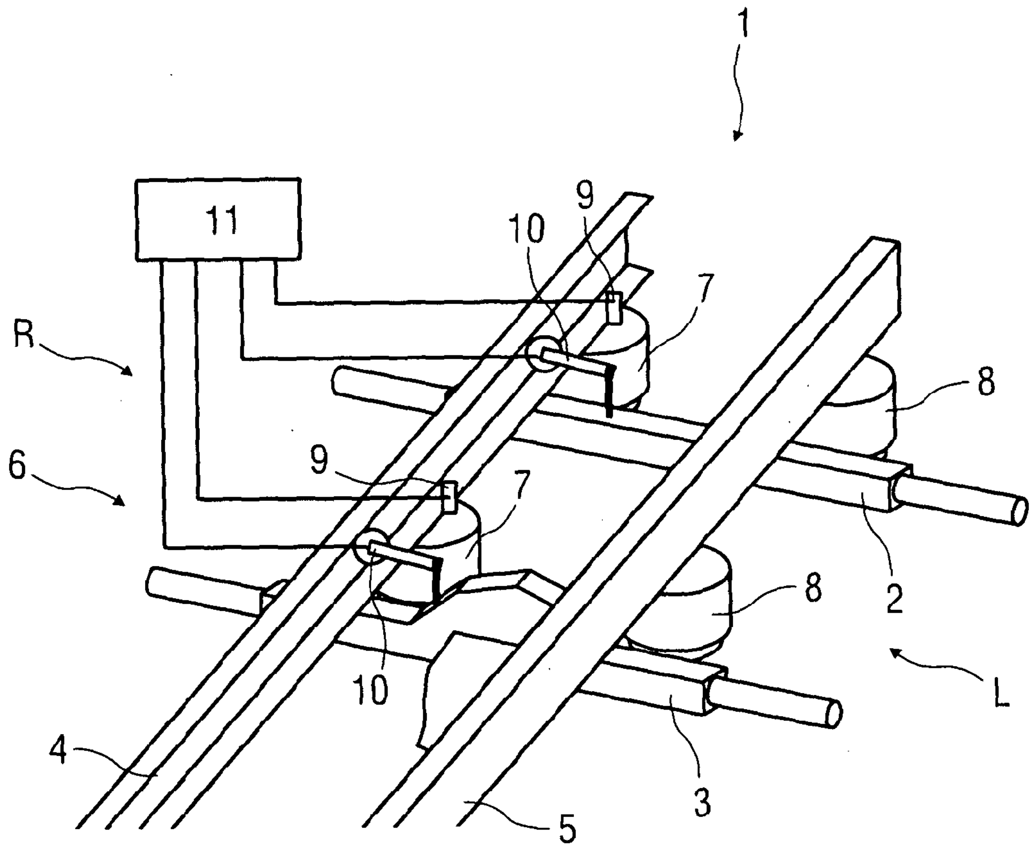

FIG 1

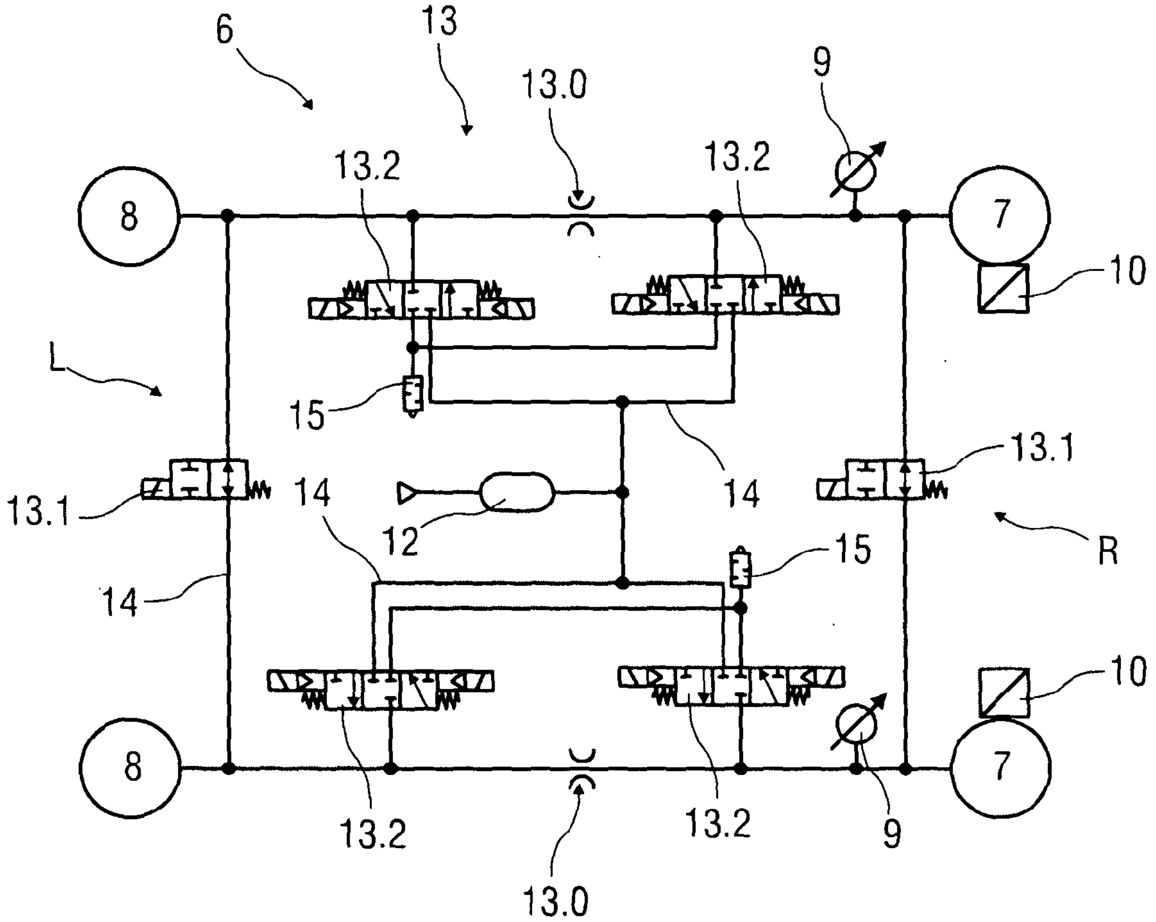
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FIG 2

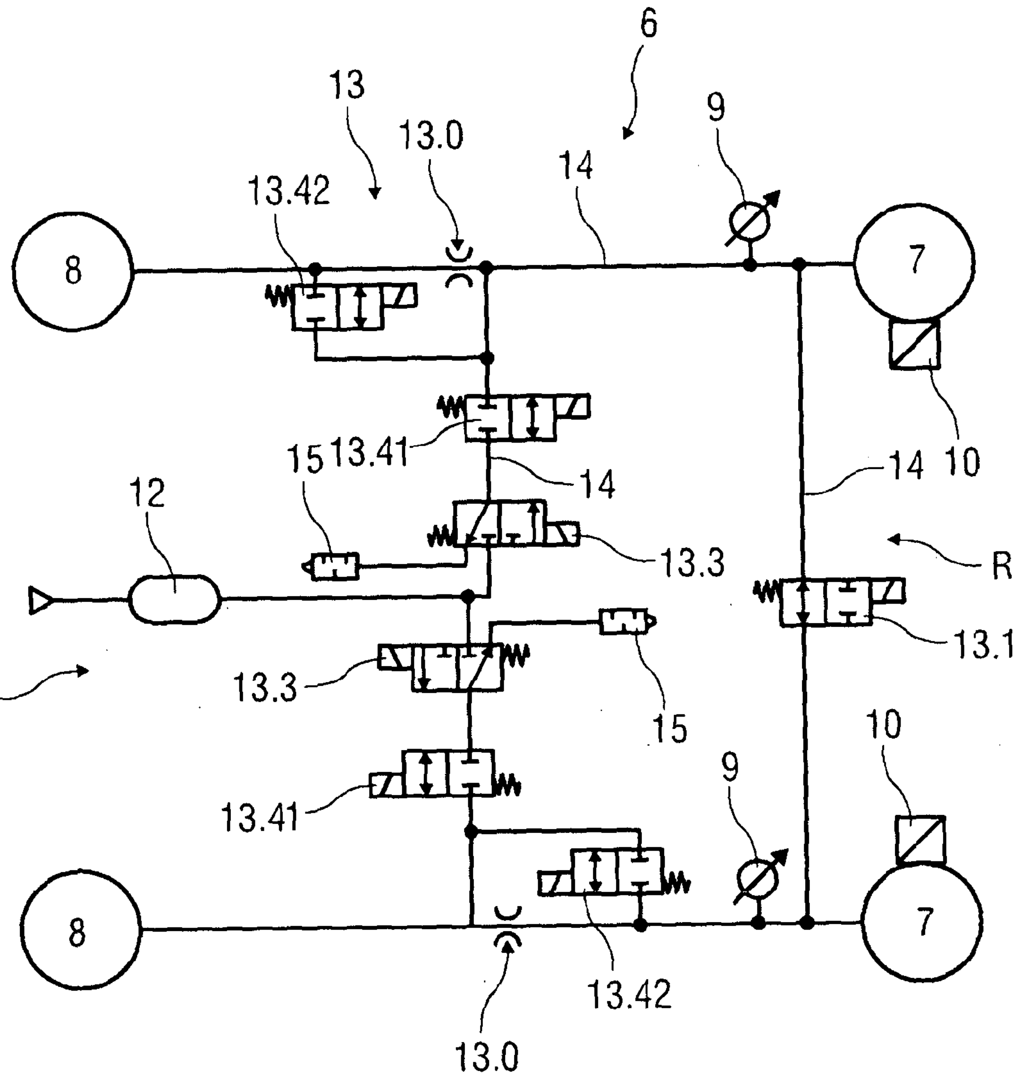
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FIG 3

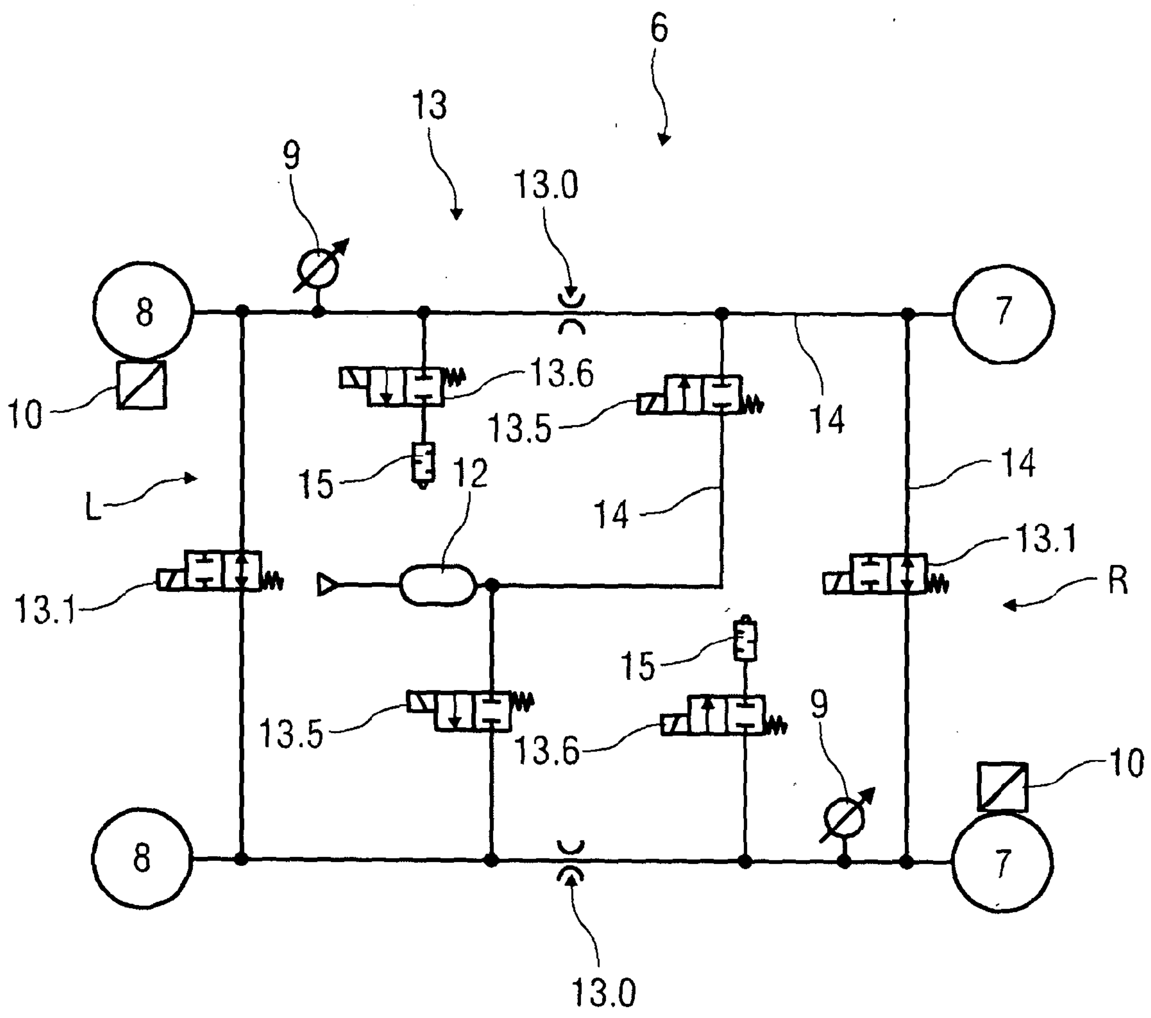
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FIG 4

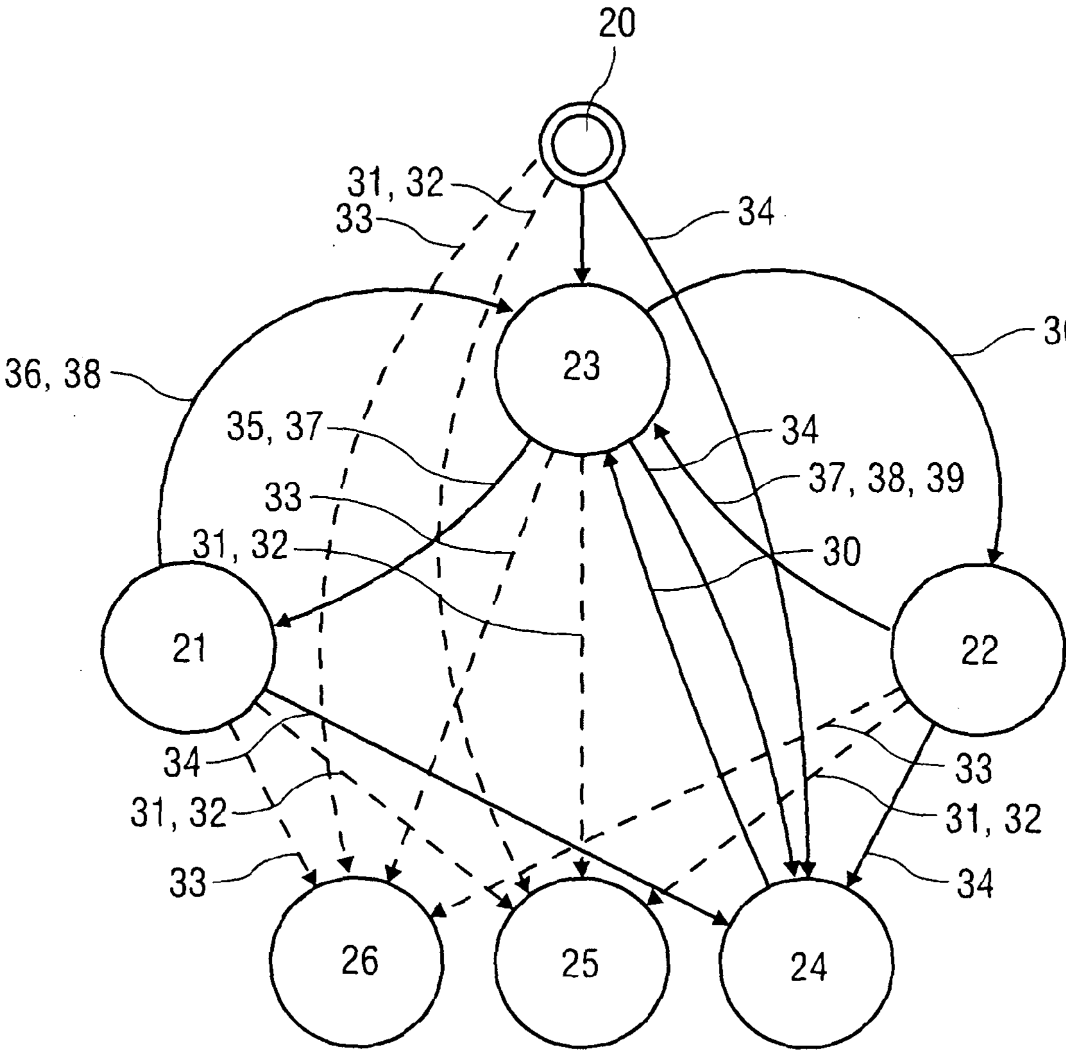
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FIG 5

Vehicle air suspension and its use

The invention relates to an air suspension for at least two axles of a vehicle and to the use of the air suspension.

Air suspension is used particularly as a suspension system for heavy vehicles such as buses or trucks.

It is an object of the present invention to provide an improved air suspension for at least two axles of a vehicle. It is a further object of the invention to provide an improved use of such an air suspension.

These objects are achieved by an air suspension according to claim 1, and a use of an air suspension according to claim 4.

Preferred embodiments of the invention are given in the dependent claims.

An air suspension according to the invention is a suspension for at least two axles of a vehicle extending from a first side of the vehicle to a second side of the vehicle. The air suspension comprises for each axle at least one first air bellow on the first side of the vehicle and at least one second air bellow on the second side of the vehicle. Furthermore it comprises a pressure tank for storing compressed air, a valve system connected to the air bellows, at least one pressure sensor for detecting a pressure in an air bellow, at least one height sensor to determine the distance between the axles and the chassis, and a control unit for the valve system adapted to electronically control the pressure in the air bellows by operating valves of the valve system. The valve system can include at least one equalizer valve pneumatically connecting two air bellows for different axles so that opening the equalizer valve allows air to flow between these two air bellows. No equalizer valves are required to achieve the goals of the system. The equalizer valve(s) enhance performance of the system by increasing the speed by which air pressure is equalized between the two axles. The same effect can be achieved by filling or exhausting air in each axle until an equilibrium or desired pressure is reached. However, the equalizer valves save energy by keeping the pressurized air in a closed system rather than exhausting high pressure air to the environment. Additionally, a system that biases the braking force between the axles to prevent axle lockup could provide the same benefits as using equalizer valve(s).

This air suspension allows adapting the pressure in the air bellows of the axles advantageously to different driving situations. For instance, at low speeds of the vehicle the air bellows of driven axles can be pressurized greater than the air bellows of undriven axles. This advantageously increases traction. At high speeds of the vehicle, the air bellows of undriven axles can be pressurized greater than the air bellows of the driven axles. This advantageously reduces the total rolling resistance of the vehicle and thus also reduces fuel consumption, if the tires of wheels on an undriven axle have lower rolling resistance than the tires of wheels on a driven axle. Furthermore, in the case of a hard brake event of the vehicle or in the case of a failure of the system, the pressure in air bellows of different axles can be rapidly equalized by opening equalizer valves. This advantageously provides equal weight distribution for equal braking force between the different axles and enhances the operating reliability of the vehicle.

The present invention will become more fully understood from the detailed description given hereinbelow and the accompanying drawings which are given by way of illustration only, and thus, do not limit the present invention, wherein:

Fig. 1 shows a perspective view of two rear axles of a vehicle, components of an air suspension for these axles and two frame rails of the chassis of the vehicle,

Fig. 2 shows a first embodiment of an air suspension for two axles of a vehicle,

Fig. 3 shows a second embodiment of an air suspension for two axles of a vehicle,

Fig. 4 shows a third embodiment of an air suspension for two axles of a vehicle,

Fig. 5 shows a control algorithm state diagram to illustrate the use of an air suspension.

Corresponding parts are marked with the same reference symbols in all figures.

Figure 1 shows a perspective view of two rear axles 2, 3 of a vehicle 1 (shown only by parts relevant to the invention), two frame rails 4, 5 of the chassis of the vehicle 1, and components of an air suspension 6 for the rear axles 2, 3. A first frame rail 4 is located at a first side R (right side) of the vehicle 1, the second frame rail 5 is located at a second side L (left side) of the vehicle 1 (where right and left refer to the perspective of a driver of the vehicle 1). The rear axles 2, 3 extend from the first side R to the second side L of the vehicle 1.

The vehicle 1 is, for instance, a heavy duty commercial truck. A first rear axle 2 is an undriven axle. The second rear axle 3 is a driven axle. In addition the vehicle 1 has an undriven front axle which is not shown in figure 1. The rear axles 2, 3 and the front axle carry two wheels-ends, respectively, so that the vehicle 1 has six wheel-ends in a so-called 6x2 configuration, i.e. the vehicle 1 has six wheel-ends with two driven wheel-ends (mounted on the driven second rear axle 3). A wheel-end can have one or more wheels on it, typically either two wheels (dual wheels or a dually) or a single wheel.

The air suspension 6 comprises for each rear axle 2, 3 one pair of air bellows 7, 8 consisting of a first air bellow 7 on the first side R of the vehicle 1 and a second air bellow 8 on the second side L of the vehicle 1. Furthermore the air suspension 6 comprises for each pair of air bellows 7, 8 a pressure sensor 9, for each rear axle 2, 3, a height sensor 10; and a control unit 11. The pressure sensors 9 and height sensors 10 are connected to the control unit 11, respectively, and transmit the detected pressure or height signals to the control unit 11.

Each pressure sensor 9 detects a pressure in the corresponding pair of air bellows 7, 8. This advantageously allows for accurate determination of the weight of the load on each rear axle 2, 3 for this weight can be calculated depending on the pressure-force relationship of the air bellows 7, 8 and the geometry of the air suspension 6.

By means of the height sensors 10 a height of the first frame rail 4 relative to the corresponding rear axle 2, 3 is determined. Actually, only one height sensor 10 is required, i.e. the air suspension 6 also works with only height sensor 10. However, a second height sensor 10 is useful because it provides redundancy should the other height sensor 10 fail.

In addition, the air suspension 6 comprises a pressure tank 12 for storing compressed air and a valve system 13 which is connected to the air bellows 7, 8 and to the control unit 11. The pressure tank 12 and the valve system 13 are not shown in figure 1 but in figures 2 to 4 for various embodiments of air suspensions 6. As will be described in detail below, in all these embodiments, the air suspension 6 is formed to selectively increase or decrease pressure in one or both pairs of air bellows 7, 8, or to rapidly equalize pressure between each pair of air bellows 7, 8. This is accomplished by electronically controlling the valve system 13 by means of the control unit 11 depending on the desired mode.

More precisely, as will also be described in more detail below, at low speeds of the vehicle 1, the air bellows 7, 8 of the driven second rear axle 3 are pressurized greater than the air bellows 7, 8 of the undriven first rear axle 2. This advantageously increases traction and decreases tire wear. At high speeds of the vehicle 1, the air bellows 7, 8 of the undriven first rear axle 2 are pressurized greater than the air bellows 7, 8 of the driven second rear axle 3. This advantageously reduces the total rolling resistance of the vehicle 1 and thus also reduces fuel consumption, for the tires of the wheels of the undriven first rear axle 2 have lower rolling resistance than the tires of the wheels of the driven second rear axle 3. In the case of a hard brake event of the vehicle 1 at speeds above a predetermined value or in the case of a failure of the system, the pressure in the two first air bellows 7 and in the two second air bellows 8 is rapidly equalized, respectively. This advantageously provides equal weight distribution for equal braking force between the two rear axles 2, 3 and enhances the operating reliability of the vehicle 1.

Figure 2 shows a first embodiment of an air suspension 6 for two axles 2, 3 of a vehicle 1.

The valve system 13 of this embodiment comprises two equalizer valves 13.1 and four Fill/Hold/Dump selector valves 13.2. All these valves 13.1, 13.2 are solenoid-controlled and electronically connected to the control unit 11 (not shown in figure 2). Air pipes 14 connect these valves 13.1, 13.2 mutually, as well as to the pressure tank 12 and to the air bellows 7, 8. Optionally, the two air bellows 7, 8 of each rear axle 2, 3 are pneumatically connected with a small orifice restrictor valve 13.0 between them, respectively, so that air cannot quickly go from one of these air bellows 7, 8 to the other, which can affect vehicle dynamics. However, the valve system 13 can also be configured without such restrictor valves 13.0 connecting the air bellows 7, 8 of the same axle 2, 3 to allow for left to right leveling of the vehicle. Additionally, no directly connecting air pipe 14 between bellows 7, 8 of the same axle 2, 3 is needed, thus bellows 7, 8 may be connected only by way of valves 13.2. To individually control each bellow 7, 8, a pressure sensor is required for each bellow 7, 8.

The first air bellows 7 and the second air bellows 8 are connected by an equalizer valve 13.1, respectively. The equalizer valves 13.1 are so-called 2/2 valves (2 ports, 2 positions), i.e. each of them is either closed or open. The equalizer valves 13.1 are closed during normal operation, but during a braking event, a mode transition, or error in the system they open to allow the air pressure to equalize between the rear axles 2, 3. This neutral position ensures equal weight distribution for equal braking force between the rear axles 2, 3. The equalizer valves 13.1 also save energy by not exhausting air to the atmosphere and refilling the air suspension 6 using an air compressor.

The Fill/Hold/Dump selector valves 13.2 are so-called 3/3 (3 ports, 3 positions) valves allowing to select between the states Fill, Hold, and Dump on either side of the restrictor valves 13.0, i.e. they selectively allow air from the pressure tank 12 to flow into the air bellows 7, 8 ("Fill"), allow air to be exhausted to the atmosphere from the air bellows 7, 8 through outlets 15 ("Dump"), or hold the air in the air bellows 7, 8 ("Hold").

In case of a pressure increase request for the two air bellows 7, 8 of a particular rear axle 2, 3 the control unit 11 energizes the solenoids to change the Fill/Hold/Dump selector valves 13.2 for the desired rear axle 2, 3 from Hold to Fill. This causes pressurized air from the pressure tank 12 to flow through the two Fill/Hold/Dump selector valves 13.2 and to enter the air bellows 7, 8 on the desired rear axle 2, 3, bypassing the respective restrictor valve 13.0. When the desired pressure has been reached, the control unit 11 de-energizes the solenoids and the Fill/Hold/Dump selector valves 13.2 return to Hold.

In case of a pressure decrease request for the two air bellows 7, 8 of a particular rear axle 2, 3 the control unit 11 energizes the solenoids to change the Fill/Hold/Dump selector valves 13.2 for the desired rear axle 2, 3 from Hold to Dump. This causes air to flow from the air bellows 7, 8 through the Fill/Hold/Dump selector valves 13.2 and the corresponding outlet 15 to exhaust to the atmosphere. When the desired pressure has been reached, the control unit 11 de-energizes the solenoids and the Fill/Hold/Dump selector valves 13.2 return to Hold.

In case of an equalize pressure request, the control unit 11 de-energizes the solenoids of the equalizer valves 13.1 so that these valves are open. This causes the air pressure between the two first air bellows 7 and between the two second air bellows 8 to equalize. When the difference in pressure of the respective air bellows 7, 8 is below a preset value, the control unit 11 re-energizes the equalizer valve solenoids to close the equalizer valves 13.1.

Figure 3 shows a second embodiment of an air suspension 6 for two axles 2, 3 of a vehicle 1.

The valve system 13 of this embodiment comprises one equalizer valve 13.1; two 3/2 (3 ports, 2 positions) Fill/Dump selector valves 13.3; four 2/2 (2 ports, 2 positions) Open/Closed valves 13.41 and 13.42; and two restrictor valves 13.0. This valve system 13 only requires one equalizer valve 13.1 because one of the Open/Closed valves 13.42 can be opened to bypass the restrictor valve 13.0 on each axle 2, 3. This valve system 13 is simpler than the one shown in figure 1, but does not allow for individual air bellows 7, 8 to be filled. The equalizer valve 13.1 and the Fill/Dump selector valves 13.3 and Open/Closed valves 13.41 and 13.42 are solenoid controlled by means of the control unit 11.

In case of a pressure increase request for the two air bellows 7, 8 of a particular axle 2, 3 the control unit 11 energizes the solenoid of the Fill/Dump selector valve 13.3 for the desired axle 2, 3 so that it selects Fill. Furthermore, the control unit 11 energizes the solenoids of the two Open/Closed valves 13.41 and 13.42 on the desired axle 2, 3 so that they are Open. This causes pressurized air from the pressure tank 12 to flow through the Fill/Dump selector valve 13.3 and the two Open/Closed valves 13.41 and 13.42 into the air bellows 7, 8 of the respective axle 2,3, bypassing the corresponding restrictor valve 13.0. When the desired pressure has been reached, the control unit 11 de-energizes solenoids 13.3, 13.41 and 13.42 and the Open/Closed valves 13.41 and 13.42 return to Closed and the Fill/Dump selector valve 13.3 returns to Dump.

A pressure decrease request is treated similarly but in this case the control unit 11 does not energize the Fill/Dump selector valve 13.3 on the desired axle 2, 3, i.e. the Fill/Dump selector valve 13.3 remains in the Dump state.

In case of an equalize pressure request the control unit 11 de-energizes the solenoid of the equalizer valve 13.1 to open this valve and energizes the solenoids of the Open/Closed valves 13.42 bypassing the restrictor valves 13.0 so that these Open/Closed valves 13.42 are open. This causes the air pressure between the air bellows 7, 8 on both axles 2, 3 to equalize. When the difference in pressure of the air bellows 7, 8 of both axles 2, 3 is below a preset value, the control unit 11 re-energizes the equalizer valve solenoid to close the equalizer valve 13.1 and de-energizes valves 13.42 to close valves 13.42.

Figure 4 shows a third embodiment of an air suspension 6 for two axles 2, 3 of a vehicle 1.

The valve system 13 of this embodiment is a simple system that fills axle 2 on the first side R and axle 3 on the second side L and dumps axle 2 on the second side L and axle 3 on the first side R. This cross fill and dump should keep the vehicle level when dumping from one axle 2, 3 and filling on the other axle 3, 2. For each axle 2, 3 there is one 2/2 Fill valve 13.5 connected to the pressure tank 12, one 2/2 Dump valve 13.6 connected to an outlet 15, and one restrictor valve 13.0. In addition there is one equalizer valve 13.1 connecting the first air bellows 7 and another equalizer valve 13.1 connecting the second air bellows 8. The Fill valves 13.5, Dump valves 13.6 and equalizer valves 13.1 are solenoid controlled by means of the control unit 11. This valve system 13 does not allow for pressure control of individual air bellows 7, 8.

In case of a pressure increase request for the two air bellows 7, 8 of a particular axle 2, 3 the control unit 11 energizes the solenoid of the Fill valve 13.5 for the desired axle 2, 3 so that this valve is open. This causes pressurized air from the pressure tank 12 to enter the desired air bellows 7, 8. Air will fill the air bellow 7, 8 on the same side of the restrictor valve 13.0 as the Fill valve 13.5 more quickly than the other air bellow 8, 7 because on the way to the latter air bellow 8, 7 the air must flow through the corresponding restrictor valve 13.0. When the desired pressure has been reached, the control unit 11 de-energizes the solenoid of the Fill valve 13.5 so that this valve is closed again.

A pressure decrease request is treated similarly except that the solenoid of the Dump valve 13.6 for the desired axle 2, 3 is operated to open this valve to dump air from the air bellows 7, 8 on this axle 2, 3 until the desired pressure has been reached.

In case of an equalize pressure request the control unit 11 de-energizes the solenoids of both equalizer valves 13.1 so that they are open. This causes the air pressure between the air bellows 7, 8 on both axles 2, 3 to equalize. When the difference in pressure of the air bellows 7, 8 of both axles 2, 3 is below a preset value, the control unit 11 re-energizes the equalizer valve solenoids to close the equalizer valves 13.1.

Figure 5 shows a control algorithm state diagram to illustrate the use of an air suspension 6 as shown in one of the figures 2 to 4.

The control unit 11 supports different operating modes 20 to 26 of the air suspension 6 using a control algorithm which essentially realizes the following functions (details will be given below):

- Maintain a set ride height (= distance between a member of a vehicle chassis, such as a frame rail 4, 5, and an axle 2, 3) or heights within a predetermined tolerance. If more than one ride height is desired, then the control unit 11 determines at what speed and time the height should change.

- Below a predetermined speed and/or after a predetermined time at that set speed, or determined by any other controller 11 input parameter, the pressure in the air bellows 7, 8 of the driven second rear axle 3 is increased to some predetermined maximum that equates to some load on that axle 3, such as an legal load limit (e.g., 20,000 lbs). All the while, the ride height is maintained. Optionally the pressure in the air bellows 7, 8 of the undriven first rear axle 2 may be simultaneously decreased and/or balanced. This operating mode is called Traction Mode 21.

- Above a predetermined speed and/or after a predetermined time at that set speed, the pressure in the air bellows 7, 8 of the driven second rear axle 3 is decreased and the pressure in the air bellows 7, 8 of the undriven first rear axle 2 is increased until the pressure in the air bellows 7, 8 of the undriven first rear axle 2 reaches a predetermined maximum that equates to some load on that axle 2 and the pressure in the air bellows 7, 8 of the driven second rear axle 3 is not lower than a predetermined minimum necessary to maintain driving traction. E.g. load the undriven axle 2 to a legal limit (e.g., 20,000 lbs) while not unloading the driven axle 3 lower than 7,000 lbs. All the while, the ride height is maintained. This operating mode is called Eco Mode 22.

- If a hard brake event (e.g., a deceleration exceeding some predetermined value) is detected above a predetermined speed then the equalizer valves 13.1 will open until the pressure in the bellows 7, 8 of both axles 2, 3 is equal. Normal operation will resume after a predetermined time. This operating mode is called Equal Mode 23.

- Allow for manual control of the ride height when the vehicle 1 is stationary, for instance for trailer loading and unloading. This operating mode is called Suspension Dump Mode 24.

- In addition the control unit 11 supports a Failsafe Mode 25 and a Fault Mode 26 in the cases of height sensor, pressure sensor, or air bellow failure, as well as a Power On Reset Mode 20 which are described below.

In the following, the use of an air suspension 6 is described in more detail. In an initial vehicle setup the following control unit parameters can be set up by the manufacturer or customer prior to vehicle operation:

- **Height, Pressure, Load Relationship:** Based on the suspension geometry and relationship between force on and pressure in the air bellows 7, 8, a parameter is set in the control unit 11 so that a pressure signal received from a pressure sensor 9 can be converted to a weight that an axle 2, 3 transmits to the ground. The pressure sensor reading to axle load relationship can also be established by placing the axle 2, 3 on scales and inflating the air bellow 7, 8 from zero to its max pressure rating, recording the pressure and weight on the scale at a certain interval, and determining the relationship between the pressure reading and the axle load.
- **System Ride Height:** The target ride height ("ride height") is set by increasing the pressure in the air bellows 7, 8 until the target ride height is reached (usually determined by using a gauge or ruler between the top of an axle 2, 3 and bottom of a frame rail 4, 5) and the control unit 11 records this height sensor reading as the target ride height. A parameter is set for the allowable variance from this value.
- **Air bellow Pressure Range:** Parameters are set for the maximum and minimum air bellow pressure allowable.
- **Axle Load Range:** Parameters are set for minimum and maximum axle load for each axle. E.g. maximum/minimum a driven axle 3 would be 20,000 lbs/7,000 lbs while maximum/minimum for an undriven axle 2 would be 20,000 lbs/2,000 lbs. The higher limit of the driven axle minimum aids high speed traction and reduces tire wear.
- **Vehicle Speed Transition Values:** Parameters are set for the speed at which the system transitions to Eco Mode 22, e.g. above 35 mph, and transitions to Traction Mode 21, e.g. below 30 mph. Parameters are set for a timeout for transitioning to Eco Mode 22 or Traction Mode 21, e.g. "transition to Eco Mode 22 when the vehicle has been traveling above 35 mph for at least 10 seconds." The timeout prevents premature transitions if in heavy traffic.

- **Load Change Temporal Sensitivity:** Parameters are set for the amount of time before the control unit 11 will adjust the pressure to compensate for a change in ride height due to a load change.

The control unit 11 executes a vehicle ECU (= Electronic Control Unit) firmware which controls the amount of weight placed on each of the two rear axles 2, 3 of the vehicle 1. Reduced total vehicle rolling resistance is possible if the rolling resistance of tires mounted on the undriven axle's wheels is less than the rolling resistance of the tires mounted on the driven axle's wheels. The control algorithm of the firmware maximizes the cost benefit tradeoff seen when adjusting the ratio of weight placed on the driven axle 3 over the weight placed on the undriven axle 2. When this ratio places more weight on the driven axle 3 the benefit will be an increase in vehicle traction and an associated reduction in tire wear for the tires mounted on the driven axle 3. However, this benefit comes at the cost of increased fuel use. Alternately, if the ratio places more weight on the undriven axle 2, the benefit will be a decrease in fuel use at the cost of a reduction in vehicle traction. The control algorithm uses signals obtained from the vehicle data bus along with internal system states to determine the ideal time for mode transitions between different operating modes 20 to 26, which alter the ratio of weight placed on the driven and undriven axles 2, 3.

The control algorithm uses knowledge of the vehicle state, which includes, but is not limited to, vehicle speed, vehicle load, service brake use, powertrain torque, engine brake settings, and current ambient conditions as inputs to the control algorithm. Additionally, the control algorithm receives input from sensors directly or indirectly (over a vehicle data bus) connected to the ECU, such as the pressure sensors 9 and height sensors 10 which sense air pressure in the air bellows associated with the driven and undriven axles, as well as the instantaneous ride height of the vehicle. The state diagram in figure 5 details the operating modes 20 to 26 the control algorithm dictates as well as mode transition triggers 30 to 39 which trigger a mode transition from one operating mode 20 to 26 to another. In figure 5 arrows indicate the direction of a mode transition wherein arrows with dashed lines indicate transitions of higher priority concerning execution order than transitions indicated by arrows with continuous lines.

Below is a list of these mode transition triggers 30 to 39. A particular mode transition trigger 30 to 39 can occur more than once in figure 5 because it can trigger transitions between various operating modes 20 to 26.

Suspension Dump End Trigger 30: A means of detecting the end of a suspension dump request by a user is employed. When a suspension dump request ends the system is triggered to pass to Equal Mode 23.

Flat Air Bellow Trigger 31: Air pressure is measured by pressure sensors 9 in the pairs of air bellows 7, 8 of both axles 2, 3. If the difference in these two pressures exceeds a predetermined threshold then it is assumed that one of the associated air bellows 7, 8 has failed and will no longer accumulate pressure when air is pumped into it. This fault condition triggers a transition to the Failsafe Mode 25.

Pressure Sensor Fault Trigger 32: A means of diagnosing the pressure sensors 9 is executed to determine if any of the associated sensing devices is defective or improperly wired. This can include but is not limited to testing for plausibility of the increase or decrease of measured pressure when air is either pumped into or purged out of the air bellows 7, 8 whose pressure is measured. If the values returned by the means of sensing do not pass this plausibility test than it is assumed that either the pressure sensor 9 is faulty or the wiring to the pressure sensor 9 is improper. Additionally, if the sensor values fall above or below the physical possibilities for the system, for instance if a pressure sensor 9 reports a higher pressure than the air bellow system is rated for or reports a value inconsistent with another sensed aspect of the system such as ride height and vehicle load then the system assumes that the pressure sensor 9 is faulty or the wiring to the pressure sensor 9 is improper. This fault triggers a transition to the Failsafe Mode 25.

Height Sensor Fault Trigger 33: A means of diagnosing faults associated with vehicle height sensors 10 is employed to determine if a height sensor 10 or associated wiring is defective or improperly installed. This means of diagnosing may contain, but is not limited to, comparing the measure height value with that of a redundant height sensor 10 as well as checking the plausibility of the current vehicle height with current pressure in the associated air bellow 7, 8 and the current vehicle load. Failure of this diagnostic test triggers a transition to the Fault Mode 26.

Suspension Dump Request Trigger 34: A means of detecting suspension dump is employed. This can be realized by vehicle user interface elements such as switches, levers, knobs, buttons, touch screens, or other methods of user interface. Alternately, suspension dump can be actuated pneumatically and subsequently sensed through the means of pressure sensing. When a user requests a suspension dump this triggers a transition to the Suspension Dump Mode 24.

Wheel Slip Trigger 35: Commercial vehicles 1 employ means of sensing the individual wheel speed of each wheel on the vehicle 1. These speeds are compared and if a wheel associated with the driven axle 3 has a speed that exceeds that of a wheel from the undriven axle 2, then the system assumes that the driven wheel is "slipping" on the pavement. That is, the wheel speed of the driven wheel exceeds the speed of the ground, thus the driven wheel has seen a reduction in traction. The system responds to wheel slip by transitioning to an operating mode 20 to 26 where there is a greater amount of weight placed on the driven axle 3 to subsequently increase the traction of the driven axle 3. Depending on the source operating mode 20 to 26 the target operating mode 20 to 26 will differ. If wheel slip is encountered in the Eco Mode 22, then the system transitions to the Equal Mode 23. If Wheel Slip 35 occurs in the Equal Mode 23, then the system transitions to Traction Mode 21.

Increasing Speed Trigger 36: Commercial vehicles 1 employ a means of sensing individual wheel speed and this can be used to determine the overall speed of the vehicle 1 relative to the ground. If the current vehicle speed exceeds the threshold for Traction Mode 21 or Equal Mode 23, then a timeout period begins. If during this timeout period the vehicle speed is reduced below a given threshold, then this timeout is reset. If the vehicle speed remains above the given threshold for a time greater than the timeout period, then this triggers a transition to an operating mode 20 to 26 which places more weight on the undriven axle 2. If the vehicle is in Traction Mode 21, then this increase in vehicle velocity will trigger a transition to Equal Mode 23. If the vehicle is in Equal Mode 23, then this increase in vehicle velocity will trigger a transition to Eco Mode 22.

Decreasing Speed Trigger 37: Commercial vehicles 1 employ a means of sensing individual wheel speed and this can be used to determine the overall speed of the vehicle 1 relative to the ground. If the current vehicle speed falls below a predetermined threshold for the current system state, then the vehicle 1 will transition to an operating mode 20 to 26 which places a greater amount of weight on the driven axle 3 of the vehicle 1. Thus if the vehicle 1 is in Eco Mode 22 and the vehicle speed falls below the threshold for that mode, then the system passes to Equal Mode 23. If the system is in Equal Mode 23, then the system passes to Traction Mode 21.

Wheel Skid Trigger 38: Commercial vehicles 1 employ a means of sensing the individual wheel speed of each wheel on the vehicle 1. These speeds are compared and if a wheel associated with the driven axle 3 has a speed that is less than that of a wheel from the undriven axle 2 by at least a specified amount, then the system assumes that the driven wheel is "skidding" against the pavement. That is, the wheel speed of the braking wheel is exceeded by the speed of the ground. The system responds to this wheel skid by passing to Equal Mode 23, where the weight is equalized between the axles 2, 3.

Braking Trigger 39: Commercial vehicles 1 employ a means of sensing wheel speed. If the rate of decrease of wheel speed exceeds a predetermined threshold or if the wheel speed of one of the vehicle's tires has a value that when subtracted from the current overall vehicle speed exceeds a predetermined threshold, then the vehicle 1 is assumed to be braking. This state of braking triggers a transition to Equal Mode 23.

Below additional details on the various operating modes 20 to 26 and transitions between them are described.

Power On Reset Mode 20: The Power On Reset Mode 20 is intended to safely assess the current physical state and transition the logical state of the control algorithm to match the current physical state of the vehicle 1. A Power On state is the default state when a vehicle's key is moved from an Off position to any other position. The system observes a timeout before transitioning to any other operating mode 20 to 26 to ensure that full knowledge of the system has been obtained.

Transition from Power On Reset Mode 20 to Equal Mode 23: The control unit 11 opens the equalizer valves 13.1 that equalize the pressure in the air bellows 7, 8 associated with the driven axle 3 with those associated with the undriven axle 2. These valves remain open until a timeout expires at which time they are closed.

Transition from Power On Reset Mode 20 to Failsafe Mode 25: The equalizer valves 13.1 are closed and the system ignores any trigger until it is reset via a power cycle.

Transition from Power On Reset Mode 20 to Fault Mode 26: The equalizer valves 13.1 are opened and the system ignores any trigger until the system is reset via a power cycle.

Transition from Power On Reset Mode 20 to Suspension Dump Mode 24: The equalizer valves 13.1 are opened and the system awaits the end of the Suspension Dump Mode 24.

Traction Mode 21: The Traction Mode 21 loads the driven axle 3 as heavily as possible given the total weight of the vehicle 1, while maintaining ride height and minimum weight on the undriven axle 2. These conditions serve to maximize vehicle traction and minimize driven wheel slipping or scrub which subsequently minimizes tire wear for the driven wheels. These benefits come at the cost of increased fuel consumption due to the higher rolling resistance of driven wheel tires.

Transition from Equal Mode 23 to Traction Mode 21: The control unit 11 opens those pneumatic valves 13.2, 13.3, 13.41, 13.42, 13.5 which fill the driven axle air bellows 7, 8 and opens those pneumatic valves 13.2, 13.3, 13.41, 13.42, 13.6 that exhaust air from the undriven axle air bellows 7, 8. While in this state the following control loops are executed:

- Air pressure is monitored in the driven air bellows 7, 8 associated with the driven axle 3. If the pressure in these air bellows 7, 8 exceeds the value calculated to correspond with the maximum axle load intended then the valves 13.2, 13.41, 13.42, 13.5 filling the air bellows 7, 8 associated with the driven axle 3 are closed and 13.3 are switch to dump.
- Air pressure is monitored in the air bellows 7, 8 associated with the undriven axle 2. If the pressure in these air bellows 7, 8 falls below the value calculated to correspond with the minimum axle load intended then the valves 13.2, 13.41, 13.42, 13.6 exhausting the air bellows 7, 8 associated with the undriven axle 2 are closed.
- Vehicle ride height is monitored. If the vehicle ride height increases, the valves 13.2, 13.41, 13.42, 13.5 filling the driven axle air bellows 7, 8 are closed and 13.3 are switched to dump.
- Vehicle ride height is monitored. If the vehicle ride height decreases, the valves 13.2, 13.41, 13.42, 13.6 exhausting the air bellows 7, 8 associated with the undriven axle 2 are closed and 13.3 are switched to dump.

Eco Mode 22: The Eco Mode 22 loads the undriven axle 2 as heavily as possible, given the total weight of the vehicle 1, while maintaining ride height and minimum weight on the driven axle 3. These conditions serve to minimize vehicle rolling resistance subsequently increasing vehicle fuel efficiency. This benefit comes at the cost of a reduction in vehicle traction.

Transition from Equal Mode 23 to Eco Mode 22:

- Air pressure is monitored in the air bellows 7, 8 associated with the driven axle 3. If the pressure in these air bellows 7, 8 exceeds the value calculated to correspond with the maximum axle load intended then the valves 13.2, 13.41, 13.42, 13.5 filling the air bellows 7, 8 associated with the driven axle 3 are closed and 13.3 are switch to dump.

- Air pressure is monitored in the air bellows 7, 8 associated with the undriven axle 2. If the pressure in these air bellows 7, 8 falls below the value calculated to correspond with the minimum axle load intended then the valves 13.2, 13.41, 13.42, 13.6 exhausting the air bellows 7, 8 associated with the undriven axle 2 are closed and 13.3 are switch to dump.
- Vehicle ride height is monitored. If the vehicle ride height increases, the valves 13.2, 13.41, 13.42, 13.5 filling the air bellows 7, 8 of the driven axle 2 are closed and 13.3 are switch to dump.
- Vehicle ride height is monitored. If the vehicle ride height decreases, the valves 13.2, 13.41, 13.42, 13.6 exhausting the air bellows 7, 8 associated with the undriven axle 2 are closed and 13.3 are switch to dump.

Equal Mode 23: The Equal Mode 23 loads both pairs of air bellows 7, 8 associated with the driven and undriven axles 2, 3 evenly. This equal weighting minimizes the braking distance of the vehicle 1. This benefit comes at the cost of both a decrease in vehicle traction in comparison to Traction Mode 21 and an increase in vehicle rolling resistance compared to Eco Mode 22.

Fault Mode 26: The Fault Mode 26 is the same mode as the Equal Mode 23, except that the system will not transition out of Fault Mode 26 until a Power On Reset is seen.

Failsafe Mode 25: The Failsafe Mode 25 maintains the same weight distribution between driven and undriven axles 2, 3 from its originating operating mode 20 to 26. The system stays in this mode until a power on reset occurs.

Suspension Dump Mode 24: The Suspension Dump Mode 24 allows for manual height adjustment using a keypad directly connected to the control unit 11. A request to raise the suspension height will increase pressure in all the air bellows 7, 8 and a request to decrease the suspension height will decrease pressure in all the air bellows 7, 8.

Transition from Suspension Dump Mode 24 to Equal Mode 23: The equalizer valves 13.1 are opened until a timeout occurs at which time they are closed.

It should be understood that the detailed description and specific examples illustrated by the figures, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description. In particular the invention is not limited to air suspensions 6 for rear axles 2, 3 or only two axles 2, 3 but applies analogously to front and combinations of front and rear axles 2, 3, as well as to more than two axles 2, 3.

List of references

1	vehicle
2	first rear axle (undriven axle)
3	second rear axle (driven axle)
4	first frame rail
5	second frame rail
6	air suspension
7	first air bellow
8	second air bellow
9	pressure sensor
10	height sensor
11	control unit
12	pressure tank
13	valve system
13.0	restrictor valve
13.1	equalizer valve
13.2	Fill/Hold/Dump selector valve
13.3	Fill/Dump selector valve
13.41	Flow control Open/Closed valve
13.42	Restrictor bypass Open/Closed valve
13.5	Fill valve
13.6	Dump valve
14	air pipe
15	outlet
20	Power On Reset Mode
21	Traction Mode
22	Eco Mode
23	Equal Mode
24	Dump Mode
25	Failsafe Mode
26	Fault Mode
30	Suspension Dump End Trigger
31	Flat Air Bellow

32 Pressure Sensor Fault Trigger
33 Height Sensor Fault Trigger
34 Suspension Dump Request Trigger
35 Wheel Slip Trigger
36 Increasing Speed Trigger
37 Decreasing Speed Trigger
38 Wheel Skid Trigger
39 Braking Trigger
R first side
L second side

Claims

1. Air suspension (6) for at least two axles (2, 3) of a vehicle (1), each axle (2, 3) extending from a first side (R) of the vehicle (1) to a second side (L) of the vehicle (1), the air suspension (6) comprising
- for each axle (2, 3) at least one first air bellow (7) on the first side (R) of the vehicle (1) and at least one second air bellow (8) on the second side (L) of the vehicle (1),
- a pressure tank (12) for storing compressed air,
- a valve system (13) connected to the air bellows (7, 8),
- at least one pressure sensor (9) for detecting a pressure in an air bellow (7, 8),
- and a control unit (11) for the valve system (13) adapted to electronically control the pressure in the air bellows (7, 8) by operating valves (13.1 to 13.6) of the valve system (13),
characterized in that the valve system (13) comprises at least one equalizer valve (13.1) pneumatically connecting two air bellows (7, 8) for different axles (2, 3) so that opening the equalizer valve (13.1) allows air to flow between these two air bellows (7, 8).

2. Air suspension (6) according to claim 1,
characterized in that
the valve system (13) comprises at least one orifice restrictor valve (13.0) connecting pneumatically a first air bellow (7) and a second air bellow (8) for the same axle (2, 3) so that quick air flow between these two air bellows (7, 8) is restrained.

3. Air suspension (6) according to claim 1 or 2,
characterized by at least one height sensor (10) adapted to determine a height of a

member of the chassis of a vehicle (1) relative to an axle (2, 3) of the vehicle (1).

4. Use of an air suspension (6) according to any of the preceding claims for at least two axles (2, 3) of a vehicle (1),
characterized in that
at least one equalizer valve (13.1) is opened if a hard brake event above a predetermined speed is detected.

5. Use according to claim 4,
characterized in that
an opened equalizer valve (13.1) is shut after a predetermined time or when a difference in pressure in the air bellows (7, 8) connected by the equalizer valve (13.1) drops below a preset value.

Application No:	GB1219743.0	**Examiner:**	Mr Kevin Hewitt
Claims searched:	1 to 5	**Date of search:**	24 February 2013

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
A	-	US 2005/0269753 A1 (GEIGER ET AL) See especially the Abstract; and Figures 1 & 2.
A	-	EP 1321320 A2 (KNORRE-BREMSE) See especially the WPI Abstract Accession Number 2003-507403 [48]; and Figures 1 & 2.
A	-	WO 2010/089088 A2 (KNORR-BREMSE) See especially the Abstract; and Figures 5 & 6.
A	-	JP 10324135 A (ISUZU MOTOR) See especially WPI Abstract Accession Number 1999-089660 [08]; and Figures 1, 2 & 7.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

B60G

The following online and other databases have been used in the preparation of this search report

WPI; EPODOC

International Classification:

Subclass	Subgroup	Valid From
B60G	0017/015	01/01/2006
B60G	0017/052	01/01/2006
B60G	0017/056	01/01/2006