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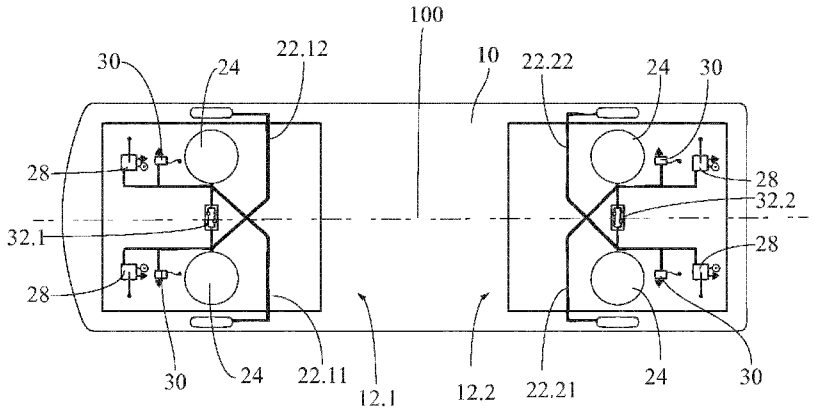


Fig.2

(57) Abstract: A pneumatic suspension (20, 20.1, 20.2) for a vehicle, comprises at least a first pneumatic compression spring (24) located laterally on a first side of the pneumatic suspension, pneumatically connected to a first set of one or more pneumatic traction springs (26) located laterally on a second side of the pneumatic suspension opposite the first side, and a second pneumatic compression spring (24) located laterally on the second side of the pneumatic suspension, pneumatically connected to a second set of one or more pneumatic traction springs (26) located laterally on the first side of the pneumatic suspension. The first pneumatic compression spring (24) is spaced apart from the second set of pneumatic traction springs (26) in a longitudinal and/or lateral direction of the pneumatic suspension and the second pneumatic compression spring (24) is spaced apart from the first set of pneumatic traction springs (26) in a longitudinal or lateral direction of the pneumatic suspension. The pneumatic traction springs (26) can be pneumatic artificial muscles with a monotonically decreasing isobaric load-contraction relation

WO 2015/135587 A1

PNEUMATIC VEHICLE SUSPENSION, VEHICLE PROVIDED WITH SUCH A SUSPENSION AND METHOD FOR RETROFITTING A VEHICLE SUSPENSION

TECHNICAL FIELD OF THE INVENTION

[0001] This invention relates a pneumatic suspension for a vehicle, in particular a rail vehicle or a land vehicle, such as an automotive vehicle, a trailer or semitrailer.

BACKGROUND ART

[0002] The design of a vehicle suspension generally requires a trade-off between the various conflicting design criteria of the suspension. Vertical comfort requires a soft vertical suspension, whereas a stiffer suspension is required for limiting rolling in curves, and a low warp stiffness can be again beneficial for limiting wheel unloading on a non planar or twisted ground or track. With classical suspension designs, it is impossible to combine a high roll stiffness and a low warp stiffness.

[0003] WO06/107080 discloses a pneumatic suspension comprising a plurality of pneumatic compression springs, each comprising a lower air chamber and an upper air chamber on top of the lower chamber. The wheel set is fixed to a load-carrying member sandwiched between the lower and upper air chambers, such that the two air chambers work in opposition. The remote ends of the two opposed air chambers are fixed to a common frame fixed to the car body of the vehicle. Two such pneumatic compression springs located on opposite sides of the vehicle are connected with one another such that the lower air chamber of each of the pneumatic compression springs is in communication with the upper air chamber of the pneumatic compression spring on the opposite side of the vehicle.

[0004] A similar suspension is disclosed in US 3,980,316. Each side of the vehicle is provided with a lower air chamber and an upper air chamber on top of the lower air chamber. The lower end of the upper air chamber and the upper end of the lower air chamber are fixed to a common longitudinal frame member, while the upper end of the upper air chamber and the lower end of the lower air chamber are fixed to a common structure attached to the wheel axle. The effective cross-sectional area of the lower chamber is larger than that of the upper chamber. The lower air chamber on

each side of the vehicle is pneumatically connected with the upper air chamber on the opposite side.

[0005] With such suspensions, it is possible to combine a high roll stiffness and a high pitch stiffness with a lower ride stiffness. However, the resulting pneumatic compression springs are very specific and have a substantial additional height compared to conventional air springs. In particular, they require space below and above the load-carrying member linking the suspension to the wheel set. For these reasons, it is difficult to retrofit these specific air springs to an existing suspension. It is also difficult to design such air springs as standard products adaptable to various vehicles.

SUMMARY OF THE INVENTION

[0006] According to one aspect of the invention, there is provided a pneumatic suspension for a vehicle, comprising at least a first pneumatic compression spring located laterally on a first side of the pneumatic suspension, pneumatically connected to a first set of one or more pneumatic traction springs located laterally on a second side of the pneumatic suspension opposite the first side, and at least a second pneumatic compression spring located laterally on the second side of the pneumatic suspension, pneumatically connected to a second set of one or more pneumatic traction springs located laterally on the first side of the pneumatic suspension, wherein the first pneumatic compression spring is spaced apart from the second set of pneumatic traction springs and the second pneumatic compression spring is spaced apart from the first set of pneumatic traction springs at least in a longitudinal or lateral direction of the pneumatic suspension.

[0007] The pneumatic compression springs can be of any type that produces mechanical work when subjected to an extension and stores potential mechanical energy when contracted, such as an air bag or a pneumatic cylinder. As a result of contraction, the effective pneumatic volume of such compression springs is reduced. By contrast, the pneumatic traction spring can be of any type that produces mechanical work when subjected to a contraction and stores potential mechanical energy when extended. As a result of extension, the internal volume of such a component decreases.

[0008] By suitably placing the pneumatic traction springs on the vehicle, the volume variation of the pneumatic traction spring will compensate the volume variation of the air spring or increase this volume variation, depending on the kind of motion (bounce, roll, twist, etc.). Various properties of the suspension can thus be adjusted. Typically, for a railway vehicle, the pneumatic traction springs can be placed between the bogie frame and the car body (or a bolster if any). As the pneumatic compression springs are longitudinally or laterally spaced apart from the pneumatic traction springs, the actual location and number of pneumatic traction springs can be chosen according to the circumstances. The pneumatic traction springs can be designed as standard components and the stiffness of the suspension adjusted by varying their number and locations relative to the air springs in the longitudinal and/or lateral directions. Depending on the room available and the load of the sprung mass of the vehicle, several first compression springs and several second compression springs can be arranged in parallel with one another.

[0009] Choosing the proper location of the pneumatic traction springs with respect to the pneumatic compression springs is useful for adapting the ratio between bounce stiffness and roll stiffness. According to a preferred embodiment, a distance measured in a transverse direction of the pneumatic suspension between at least one of the pneumatic traction springs of the first set of pneumatic traction springs and one of the pneumatic traction springs of the second set of pneumatic traction springs is greater than a distance measured in the transverse direction between the first compression spring and the second compression spring. This location of the pneumatic traction springs transversally outside the pneumatic compression springs maximises their effect on rolling.

[0010] Preferably, the first pneumatic compression spring, second pneumatic compression spring, first set of pneumatic traction springs and second set of pneumatic traction springs all intersect a common horizontal plane. The first pneumatic compression spring and second set of pneumatic traction springs can be attached at one end to a common car body component or a common bolster and at another end to a common running gear component. The same applies to the second pneumatic compression spring and first set of pneumatic traction springs.

[0011] According to a preferred embodiment, the first pneumatic compression spring is connected with a first levelling valve receptive to a deflection of the first pneumatic compression spring, and the second pneumatic compression spring is connected with a second levelling valve receptive to a deflection of the second pneumatic compression spring. The levelling valve associated to a pneumatic compression spring opens a communication with a main reservoir to feed the associated pneumatic compression spring with air whenever the retraction of the pneumatic compression spring reaches a contraction threshold. Conversely, it opens a communication with the atmosphere to reduce the pressure in the pneumatic compression spring whenever the extension of the pneumatic compression spring reaches an extension threshold. The levelling valves can be mechanically connected to the vehicle body. Alternatively, the levelling valves can be electrically controlled and connected to various sensors on a vehicle and/or to various commands on a control panel of the vehicle.

[0012] According to one embodiment, the first pneumatic compression spring and the second pneumatic compression spring are not pneumatically connected with one another and constitute two independent circuits if one excepts their connections to the common main reservoir, which can be considered more or less as an infinite pressure source.

[0013] According to an alternative embodiment, the first pneumatic compression spring and the second pneumatic compression spring are connected to one another via a pressure differential valve, which may open when a pressure differential between the first and second pneumatic compression springs is above a pressure differential threshold.

[0014] The suspension of the invention can be applied to an automotive vehicle or a trailer e.g. with four independent wheels or several wheel axles. It can also be applied as secondary suspension or a primary suspension of a rail vehicle.

[0015] According to one embodiment, the first pneumatic compression spring is located at a front of the pneumatic suspension, the second pneumatic compression spring is located at the front of the pneumatic suspension, a third pneumatic

compression spring is located at a rear of the pneumatic suspension laterally on the first side of the pneumatic suspension, a fourth pneumatic compression spring is located at the rear of the pneumatic suspension laterally on the second side of the pneumatic suspension, the first set of one or more pneumatic traction springs comprises at least one pneumatic traction spring located at the front of the pneumatic suspension and at least one pneumatic traction spring located at a rear of the pneumatic suspension and the second set of one or more pneumatic traction springs comprises at least one pneumatic traction spring located at the front of the pneumatic suspension and at least one pneumatic traction spring located at the rear of the pneumatic suspension. The two rear pneumatic compression springs are preferably connected with one another. This so-called three-point configuration is intended to provide a high roll stiffness thanks to the front pneumatic traction springs and a low warp stiffness thanks to the direct connection between the air springs at the rear of the suspension.

[0016] According to an alternative embodiment, the first pneumatic compression spring is located at a front of the pneumatic suspension, the first set of one or more pneumatic traction springs is located at a rear of the pneumatic suspension, the second pneumatic compression spring is located at the rear of the pneumatic suspension and the second set of one or more pneumatic traction springs is located at the front of the pneumatic suspension. The pneumatic suspension further comprises a third pneumatic compression spring located laterally on the first side and at the rear of the pneumatic suspension and pneumatically connected to a third set of one or more pneumatic traction springs located on the second side and at the front of the pneumatic suspension, and a fourth pneumatic compression spring located on the second side and at the front of the pneumatic suspension and pneumatically connected to a fourth set of one or more pneumatic traction springs located on the first side and at the rear of the pneumatic suspension. This embodiment can be applied to the front and rear wheels of an automotive vehicle or of a trailer or to a front and a rear running gears of a rail vehicle or to the front and rear part of a running gear, e.g. a so-called Jacob-type running gear between a front vehicle body and a rear vehicle body.

[0017] Preferably, the third pneumatic compression spring is connected with a third levelling valve receptive to a deflection of the third pneumatic compression spring, and the fourth pneumatic compression spring is connected with a fourth levelling valve receptive to a deflection of the fourth pneumatic compression spring.

[0018] Preferably, the first pneumatic compression spring and the fourth pneumatic compression spring are connected to one another via a front pressure differential valve, and the second pneumatic compression spring and the third pneumatic compression spring are connected to one another via a rear pressure differential valve.

[0019] According to a preferred embodiment, each of the pneumatic traction springs has a monotonically decreasing isobaric load-contraction relation, preferably a strictly decreasing isobaric load-contraction relation. The relation is linear or non-linear.

[0020] One embodiment of a pneumatic traction spring is a rebound chamber of a double acting cylinder. Generally, the internal volume of such a component decreases when it is extended, by opposition to a pneumatic compression spring. According to a preferred embodiment, the pneumatic traction springs are pneumatic artificial muscles.

[0021] According to another aspect of the invention, there is provided a pneumatic suspension for a vehicle, comprising at least a first pneumatic compression spring located laterally on a first side of the pneumatic suspension, pneumatically connected to a first set of one or more pneumatic traction springs located laterally on a second side of the pneumatic suspension opposite the first side, and a second pneumatic compression spring located laterally on the second side of the pneumatic suspension, pneumatically connected to a second set of one or more pneumatic traction springs located laterally on the first side of the pneumatic suspension, wherein each of the pneumatic traction springs has a monotonically decreasing isobaric load-contraction relation. According to a preferred embodiment, each of the pneumatic traction springs or at least some of them are pneumatic artificial muscles. The first pneumatic compression spring is preferably spaced apart

from the second set of pneumatic traction springs and the second pneumatic compression spring is spaced apart from the first set of pneumatic traction springs at least in a longitudinal or lateral direction of the pneumatic suspension.

[0022] According to another aspect of the invention, there is provided a vehicle comprising a car body assembly comprising one or more car bodies, a running gear assembly comprising one or more running gears, and a pneumatic suspension as disclosed above between the car body assembly and the running gear assembly.

[0023] According to one embodiment, the first pneumatic compression spring and second set of pneumatic traction springs are located between the car body assembly and a first running gear of the running gear assembly, and the second pneumatic compression spring and first set of pneumatic traction springs are located between the car body assembly and a second running gear of the running gear assembly.

[0024] According to one embodiment, the first pneumatic compression spring and second set of pneumatic traction springs are located between a first car body of the car body assembly and the running gear assembly, and the second pneumatic compression spring and first set of pneumatic traction springs are located between a second car body of the car body assembly and the running gear assembly.

[0025] According to one embodiment, the first pneumatic compression spring and second set of pneumatic traction springs, and the second pneumatic compression spring and first set of pneumatic traction springs are located between a common car body of the car body assembly and a common running gear of the running gear assembly.

[0026] According to one embodiment, each running gear of the running gear assembly comprises a frame, a set of wheels and a primary suspension between the frame and the set of wheels and in that the pneumatic suspension is a pneumatic suspension between the car body assembly and each frame of each running gear of the running gear assembly. A bolster supporting a king pin or pivot can be provided between the running gear frame and the car body assembly, in which case the

pneumatic compression springs and sets of pneumatic traction springs are preferably located between frame and bolster. The suspension of the invention can also be applied to bogies without bolster.

[0027] According still to another aspect of the invention, there is provided a method of retrofitting a vehicle suspension comprising at least a first pneumatic compression spring located laterally on a first side of the pneumatic suspension, and a second pneumatic compression spring located laterally on a second side of the pneumatic suspension opposite the first side, comprising the steps of pneumatically connecting the first pneumatic compression spring with a first set of one or more pneumatic traction springs located laterally on the second side of the pneumatic suspension, and spaced apart from the second pneumatic compression spring at least in a longitudinal or lateral direction of the pneumatic suspension, and pneumatically connecting the second pneumatic compression spring with a second set of one or more pneumatic traction springs located laterally on the first side of the pneumatic suspension, and spaced apart from the first pneumatic compression spring at least in a longitudinal or lateral direction of the pneumatic suspension. Thanks to this method, it is possible to retrofit an existing suspension, with its original pneumatic compression springs or with pneumatic compression springs similar to the original pneumatic compression springs in terms of size. The additional pneumatic traction springs can be located at the most suitable location depending on the available space and on the desired effect. Obviously, the method may include steps to provide the retrofitted suspension with some or all the features of one or the other of the embodiments of the pneumatic suspension of the invention as disclosed above. As the retrofitted suspension extends a classical suspension system, functionalities such as a levelling system, a pressure difference limitation, etc. are natively present. The roll stiffness of the system is thus automatically adapted when the payload is modified.

[0028] In particular, the first pneumatic compression spring, second pneumatic compression spring, first set of pneumatic traction springs and second set of pneumatic traction springs may be located such that they all intersect a common horizontal plane. The first pneumatic compression spring and second set of pneumatic traction springs can be attached at one end to a common car body

component or a common bolster and at another end a common running gear component. The same applies to the second pneumatic compression spring and first set of pneumatic traction springs.

[0029] According to a preferred embodiment, a distance measured in a transverse direction of the pneumatic suspension between at least one of the pneumatic traction springs of the first set of pneumatic traction springs and one of the pneumatic traction springs of the second set of pneumatic traction springs is greater than a distance measured in the transverse direction between the first compression spring and the second compression spring. This location of the pneumatic traction springs transversally outside the pneumatic compression springs maximises their compensation effect on rolling.

DESCRIPTION OF THE FIGURES

[0030] Other advantages and features of the invention will become more clearly apparent from the following description of a specific embodiment of the invention given as non-restrictive example only and represented in the accompanying drawings, in which:

- Fig. 1 is a schematic side of a rail vehicle provided with a two-point suspension according to one embodiment of the invention;
- Fig. 2 is a schematic view from above of a rail vehicle provided with a four-point suspension according to one embodiment of the invention;
- Fig. 3 is a schematic view from behind of a bounce motion of the rail vehicle of Fig. 1;
- Fig. 4 is a schematic view from behind of a roll motion of the rail vehicle of Fig. 1;
- Fig. 5 is a diagram of a monotonically decreasing isobaric load-contraction relation of a pneumatic traction spring preferably used in the embodiment of Fig. 1;

- Fig. 6 is a schematic view from behind of a rail vehicle according to another embodiment of the invention;

- Fig. 7 is a schematic view from behind of an automotive vehicle according to another embodiment of the invention;

- Fig. 8 is a schematic view from above of a rail vehicle provided with a four-point suspension according to another embodiment of the invention;

- Fig. 9 is a schematic view from above of a rail vehicle provided with a four-point suspension according to another embodiment of the invention;

- Fig. 10 is a schematic view from above of a rail vehicle provided with a three-point suspension according to another embodiment of the invention;

- Fig. 11 is a schematic view from above of a rail vehicle provided with a suspension according to another embodiment of the invention.

[0031] Corresponding reference numerals refer to the same or corresponding parts in each of the figures.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0032] The rail vehicle of Figs. **1** to **4** comprises a car body **10** supported on a front running gear **12.1** and a rear running gear **12.2**. The running gears **12.1**, **12.2** are illustrated as two-axle bogies without bolster, but the invention is not limited to this type of running gears. Each running gear **12.1**, **12.2** comprises a pair of front an rear wheel sets **14**, a frame **16** supported on the pair of wheel sets **14** by means of a primary suspension **18**, and a secondary suspension **20.1**, **20.2** between the bogie frame and the car body **10**.

[0033] The secondary suspension **20.1**, **20.2** of each running gear comprises two pneumatic circuits **22.11**, **22.12**, resp. **22.21**, **22.22**, each comprising a pneumatic compression spring **24**, on one side of a median longitudinal vertical plane **100** that divides the rail vehicle and the suspension into right and left parts and a set of one

more pneumatic traction springs **26** on the opposite side of the median longitudinal plane **100**.

[0034] The pneumatic compression springs **24** can be any type of pneumatic component that produces mechanical work when extended and stores potential mechanical energy when contracted, such as an air bag or a pneumatic cylinder. The pressure in each pneumatic circuit **22.11**, **22.12**, **22.21**, **22.2** is controlled by a levelling valve **28** connected to a main reservoir and receptive to a deflection of the pneumatic compression spring **24** in the same pneumatic circuit. Each pneumatic circuit **21.11**, **21.12**, **21.21**, **21.22**, further comprises a safety valve **30**. Optionally, the two pneumatic circuits **22.11**, **22.12**, resp. **22.21**, **22.22** on the same running gear **12.1** resp. **12.2** can be connected to one another via a pressure differential valve **32.1**, **32.2**. An optional auxiliary tank (not shown) can be connected to each pneumatic circuit to increase the air volume in the circuit. The pneumatic traction springs **26** are located laterally outwardly of and longitudinally at the same level as the pneumatic compression spring **24** located on the same side of the vertical plane **100**. The pneumatic compression springs **24** and pneumatic traction springs **26** preferably overlap each other in the vertical direction, i.e. it is possible to define a horizontal plane **200**, which intersect with the pneumatic traction springs **26** and pneumatic compression springs **24**.

[0035] The pneumatic traction spring **26** can be any type of pneumatic component that produces mechanical work when contracted and stores potential mechanical energy when extended. Generally, the internal volume of such a component decreases when the component is extended, by opposition to a pneumatic compression spring. The pneumatic traction springs **26** have an effective cross-sectional area that is substantially smaller than that of the compression springs **24**, e.g. less than half the cross-sectional area of the pneumatic compression springs **24**. The secondary suspensions **20.1**, **20.2** of the front and rear running gears are identical and are not pneumatically connected with one another.

[0036] The operation of the suspensions **20.1**, **20.2** will now be described with reference to Figs. **3** and **4**. If the suspension **20.1**, **20.2** is crushed in the vertical direction as illustrated in Fig. **3**, the differential valves **32.1**, **32.2** remain closed. The

decrease of volume in each compression spring **24** is partly compensated by an increase of volume of the associated traction spring **26** in the same circuit **22.11**, **22.12**, **22.21**, **22.22**, and the variation of pressure in the circuit is limited, which results in a low bounce stiffness. If on the other hand the vehicle is subjected to rolling as illustrated in Fig. **4**, e.g. when negotiating a curve, the compression spring **24** on one side (on the left-hand side in Fig. **4**) is crushed and its volume decreases. The associated pneumatic traction spring **26** on the other side (the right-hand side) is stretched, leading also to a reduction of its volume. As a result, the total volume of the corresponding pneumatic circuit **22.21** is reduced, leading to a pressure increase in the circuit. Simultaneously, the other compression spring **24** on the same running gear (on the right-hand side) is stretched and its volume increases, while the associated pneumatic traction spring **26** (on the left-hand side) is compressed and its volume also increases, leading to an overall decrease of the pressure in the associated pneumatic circuit **22.22**. These combined reactions result in a high roll stiffness and low bounce stiffness. The differential pressure threshold of the differential valve **32.1**, **32.2** should be high enough for the differential valve to remain closed in response to a rolling motion of the car body **10**. However, the differential pressure threshold should preferably be low enough for the differential valve to open when the vehicle is on a twisted track. The differential valve **32.1**, **32.2** also becomes operative in the case of a leakage in one of the circuit, which results in a pressure drop that exceeds the threshold of the differential valve. In such a case, the corresponding pneumatic suspension **20.1**, **20.2** operates in a fail-soft mode until it can be repaired.

[0037] One embodiment of a pneumatic traction spring **26** is a rebound chamber of a pneumatic cylinder. In such a case, the effective cross-sectional area of the pneumatic traction spring **26** does not change with the deflection. An additional beneficial effect on rolling motion is obtained if the pneumatic traction springs **26** have a monotonically decreasing, preferably strictly decreasing isobaric load-contraction relation. This relation is linear or non-linear, as illustrated in Fig. **5**. The pneumatic traction springs **26** are therefore preferably pneumatic artificial muscles, which exhibit such a non-linear, monotonically decreasing isobaric load-contraction relation.

[0038] The embodiment of Fig. **6** differs from the first embodiment only in that each compression spring **24** is pneumatically connected to a set of several pneumatic traction springs **26** in parallel.

[0039] If the pneumatic traction springs **26** are added to an existing suspension, the lateral position of each pneumatic traction spring **26** in relation to the other components, i.e. to the car body **10**, running gear frame **16** and pneumatic compression springs **24** can be chosen to achieve the desired effects. Other parameters to be fine-tuned include the size of the auxiliary tank, flow rate of the levelling valves **28** and threshold of the differential valve **32.1**, **32.2**.

[0040] Fig. **7** illustrates the rear axle **12** of an automotive vehicle provided with a pneumatic suspension **20** for supporting a car body **10** of the vehicle. In a manner similar to that of the first embodiment, the rear suspension **20** comprises two pneumatic circuits, which may be fully independent or linked via a differential valve **32**. Each circuit comprises a pneumatic compression spring **24** on one side of the vehicle, connected with a pneumatic traction spring **26**, preferably a pneumatic artificial muscle on the other side of the vehicle.

[0041] The automotive or rail vehicle of Fig. **8** comprises a car body **10** supported on a front running gear **12.1** (e.g. a front axle, a front set of wheels or a front bogie) and a rear running gear **12.2** by means of a four-point secondary suspension **20**. The secondary suspension comprises four independent circuits **22.11**, **22.12**, **22.21**, **22.22**, each of which includes at least one pneumatic compression spring **24** located at one end and on one side of the vehicle on one of the running gears **12.1**, **12.2**, connected via a diagonal connection pipe to a set of one or more pneumatic traction springs **26** located at the other end and on the other side of the vehicle, on the other running gear.

[0042] The response of the rail vehicle to rolling motion is basically identical with that of the embodiment of Figs. **1** to **4**. In addition, the diagonal configuration of the four independent pneumatic circuits **22.11**, **22.12**, **22.21**, **22.22** results in a lower warp stiffness: when the vehicle runs on a track that is uneven, e.g. a rail track with a difference of inclination of the rails, one diagonal is crushed while the other one is

extended. The volume increase of the compression springs **24** on the crushed diagonal is at least partly compensated by the volume reduction of the associated pneumatic traction springs **26** on the same diagonal. Similarly, the volume reduction of the compression springs **24** on the extended diagonal is at least partly compensated by a volume increase of the associated pneumatic traction springs **26** on the same diagonal. Hence, this configuration, which can be applied to any vehicle with at least two axles or two bogies, combines a low bounce stiffness, a high roll stiffness and a low warp stiffness.

[0043] The embodiment illustrated in Fig. **9** differs from the previous one in that each compression spring **24** is connected to a levelling valve **28**, a safety valve **30**, and an auxiliary tank **34**. The auxiliary tank **34** increases the volume in the circuit so as to modify its overall stiffness for given dimensions of the compression springs **24** and traction springs **26**. Various auxiliary tank sizes can be used to adapt a standardised compression spring **24** or traction spring **26** to various vehicles or standard operating conditions. Moreover, the two pneumatic circuits **22.11**, **22.12**, comprising the compression springs **24** at the front end of the vehicle are connected to one another via a pressure differential valve **32.1**, and the two other pneumatic circuits **22.21**, **22.22** comprising the compression springs at the rear end of the vehicle are connected with one another via a pressure differential valve **32.2**. These two differential valves prove particularly useful to compensate a potentially detrimental effect of the monotonically decreasing isobaric load-contraction relation of pneumatic artificial muscles **26** on warp stiffness.

[0044] The embodiment of Fig. **10** combines a pneumatic suspension **20.1** similar to that of the first embodiment between the car body **10** of the vehicle and one of the running gears **12.1** (at the front end of the vehicle on Fig. **10**) and a conventional independent pneumatic suspension circuit at the other end of the vehicle between the car body **10** and the other running gear **12.2**. The front pneumatic suspension **20.1** comprises two pneumatic circuits **22.11**, **22.12**, each comprising a pneumatic compression spring **24** on one side of the front running gear **12.1**, a levelling valve **28** on the same side of the front running gear **12.1**, an auxiliary tank **34**, a safety valve **30** and two pneumatic traction springs **26.1**, **26.2** on the other side of the front and

rear running gears **12.1**, **12.2**. The two pneumatic circuits **22.11**, **22.12** are connected with one another via a pressure differential valve **32.1**.

[0045] The embodiment of Fig. **11** illustrates a secondary suspension for a Jacobs bogie **12** placed underneath two car body sections **10.1**, **10.2** of an articulated railway vehicle. Each car body section **10.1**, **10.2** is supported on the bogie frame by means of a secondary suspension similar to the suspension of Fig. **8**, which comprises four independent circuits **22.11**, **22.12**, **22.21**, **22.22**, each of which includes at least one pneumatic compression spring **24** located at one end and on one side of the bogie **12**, connected via a diagonal connection pipe to a set of one or more pneumatic traction springs **26** located at the other end and on the other side of the bogie.

[0046] The suspension of the invention is not limited to the above embodiments but can be implemented in other ways, e.g. as secondary suspension between a bogie frame and a bolster supporting a king pin, as secondary suspension between a car body and one or more one-axle running gears, as primary suspension between a wheel set or a pair of wheel sets and a running gear frame. Features described with respect to one embodiment above or one aspect of the invention can be implemented in other embodiments or aspects of the invention.

CLAIMS

1. A pneumatic suspension (20, 20.1, 20.2) for a vehicle, comprising at least
   - at least a first pneumatic compression spring (24) located laterally on a first side of the pneumatic suspension, pneumatically connected to a first set of one or more pneumatic traction springs (26) located laterally on a second side of the pneumatic suspension opposite the first side,
   - at least a second pneumatic compression spring (24) located laterally on the second side of the pneumatic suspension, pneumatically connected to a second set of one or more pneumatic traction springs (26) located laterally on the first side of the pneumatic suspension,

   characterised in that the first pneumatic compression spring (24) is spaced apart from the second set of pneumatic traction springs (26) in a longitudinal and/or lateral direction of the pneumatic suspension and the second pneumatic compression spring (24) is spaced apart from the first set of pneumatic traction springs (26) in a longitudinal or lateral direction of the pneumatic suspension.

2. The pneumatic suspension (20, 20.1, 20.2) of claim 1, characterised in that a distance measured in a transverse direction of the pneumatic suspension between at least one of the pneumatic traction springs (26) of the first set of pneumatic traction springs (26) and one of the pneumatic traction springs (26) of the second set of pneumatic traction springs (26) is greater than a distance measured in the transverse direction between the first compression spring (24) and the second compression spring (26).

3. The pneumatic suspension (20, 20.1, 20.2) of any one of the preceding claims, characterised in that the first pneumatic compression spring (24), second pneumatic compression spring (24), first set of pneumatic traction springs (26) and second set of pneumatic traction springs all intersect (26) a common horizontal plane.

4. The pneumatic suspension (20, 20.1, 20.2) of any one of the preceding claims, characterised in that the first pneumatic compression spring (24) is connected with a first levelling valve (28) receptive to a deflection of the first pneumatic compression spring (24), and the second pneumatic compression spring (24) is connected with a second levelling valve (28) receptive to a deflection of the second pneumatic compression spring (24).

5. The pneumatic suspension (20, 20.1, 20.2) of any one of the preceding claims, characterised in that the first pneumatic compression spring (24) and the second pneumatic compression spring (24) are not pneumatically connected with one another.

6. The pneumatic suspension (20, 20.1, 20.2) of any one of claims 1 to 4, characterised in that the first pneumatic compression spring (24) and the second pneumatic compression spring (24) are connected to one another via a pressure differential valve (32.1, 32.2).

7. The pneumatic suspension (20, 20.1, 20.2) of any one of the preceding claims, characterised in that the first pneumatic compression spring (24) is located at a front of the pneumatic suspension (20, 20.1, 20.2), the second pneumatic compression spring (24) is located at the front of the pneumatic suspension (20, 20.1, 20.2), a third pneumatic compression spring (24) is located at a rear of the pneumatic suspension (20, 20.1, 20.2) laterally on the first side of the pneumatic suspension (20, 20.1, 20.2), a fourth pneumatic compression spring (24) is located at the rear of the pneumatic suspension (20, 20.1, 20.2) laterally on the second side of the pneumatic suspension (20, 20.1, 20.2), the first set of one or more pneumatic traction springs (26, 26.1, 26.2) comprises at least one pneumatic traction spring (26.1) located at the front of the pneumatic suspension and at least one pneumatic traction spring (26.2) located at a rear of the pneumatic suspension (20, 20.1, 20.2) and the second set of one or more pneumatic traction springs (26, 26.1, 26.2) comprises at least one pneumatic traction spring (26.1) located at the front of the pneumatic suspension (20, 20.1,

20.2) and at least one pneumatic traction spring (26.2) located at the rear of the pneumatic suspension (20, 20.1, 20.2).

8. The pneumatic suspension (20, 20.1, 20.2) of any one of claims 1 to 5, characterised in that the first pneumatic compression spring (24) is located at a front of the pneumatic suspension (20, 20.1, 20.2), the first set of one or more pneumatic traction springs (26) is located at a rear of the pneumatic suspension (20, 20.1, 20.2), the second pneumatic compression spring (24) is located at the rear of the pneumatic suspension (20, 20.1, 20.2) and the second set of one or more pneumatic traction springs (26) is located at the front of the pneumatic suspension (20, 20.1, 20.2) and in that the pneumatic suspension further comprises:

- a third pneumatic compression spring (24) located laterally on the first side and at the rear of the pneumatic suspension (20, 20.1, 20.2) and pneumatically connected to a third set of one or more pneumatic traction springs (26) located on the second side and at the front of the pneumatic suspension (20, 20.1, 20.2), and
- a fourth pneumatic compression spring (24) located on the second side and at the front of the pneumatic suspension (20, 20.1, 20.2) and pneumatically connected to a fourth set of one or more pneumatic traction springs (26) located on the first side and at the rear of the pneumatic suspension (20, 20.1, 20.2).

9. The pneumatic suspension (20, 20.1, 20.2) of claim 8, characterised in that the third pneumatic compression spring (24) is connected with a third levelling valve (28) receptive to a deflection of the third pneumatic compression spring (24), and the fourth pneumatic compression spring (24) is connected with a fourth levelling valve receptive to a deflection of the fourth pneumatic compression spring (24).

10. The pneumatic suspension (20, 20.1, 20.2) of claim 8 or claim 9, characterised in that the first pneumatic compression spring (24) and the fourth pneumatic

compression spring (24) are connected to one another via a front pressure differential valve (32.1, 32.2), and the second pneumatic compression spring (24) and the third pneumatic compression spring (24) are connected to one another via a rear pressure differential valve (32.1, 32.2).

11. The pneumatic suspension (20, 20.1, 20.2) of any one of the preceding claims wherein each of the pneumatic traction springs (26) has a monotonically decreasing isobaric load-contraction relation.

12. The pneumatic suspension (20, 20.1, 20.2) of any one of the preceding claims, characterised in that the pneumatic traction springs (26) are pneumatic artificial muscles.

13. A vehicle comprising a car body assembly comprising one or more car bodies (10, 10.1, 10.2) and a running gear assembly comprising one or more running gears (12, 12.1, 12.2), characterised in that it further comprises a pneumatic suspension (20, 20.1, 20.2) according to any one of the preceding claims between the car body assembly and the running gear assembly.

14. The vehicle of claim 13, characterised in that the first pneumatic compression spring (24) and second set of pneumatic traction springs (26) are located between the car body assembly and a first running gear (12.1) of the running gear assembly, and the second pneumatic compression spring (24) and first set of pneumatic traction springs (26) are located between the car body assembly and a second running gear (12.2) of the running gear assembly.

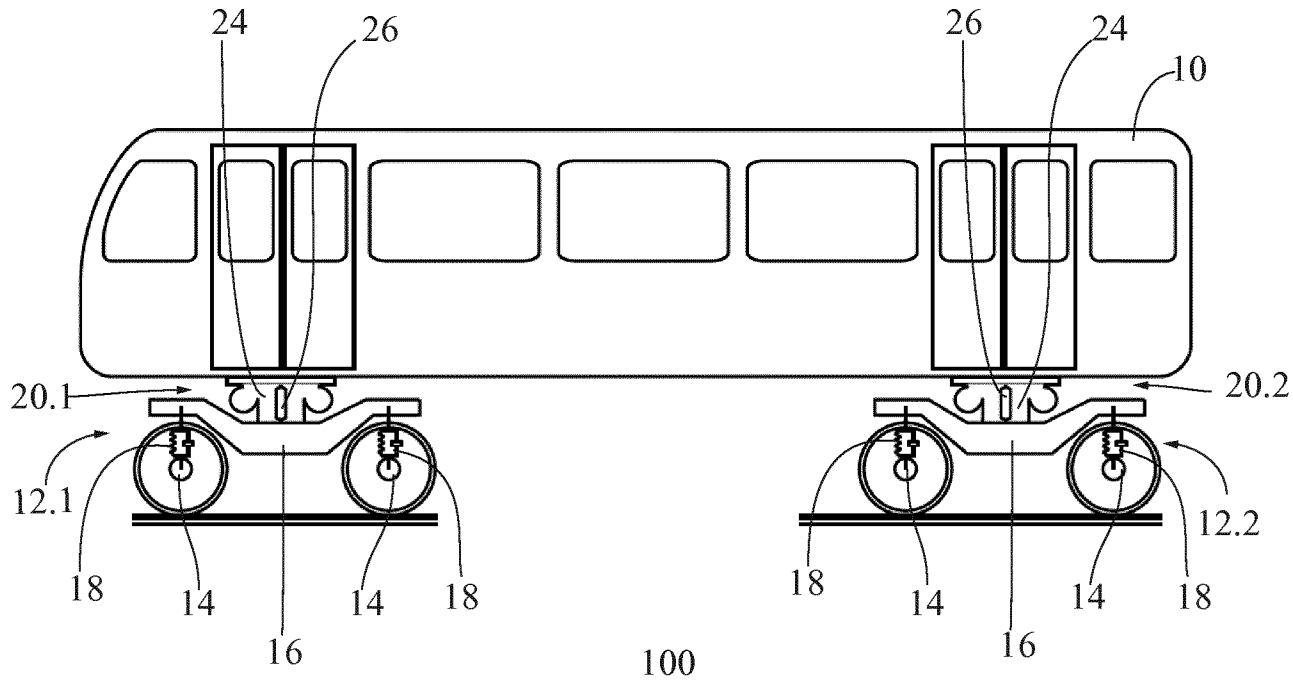
15. The vehicle of claim 13, characterised in that the first pneumatic compression spring (24) and second set of pneumatic traction springs (26) are located between a first car body (10.1) of the car body assembly and the running gear assembly, and the second pneumatic compression spring (24) and first set of pneumatic traction springs (26) are located between a second car body (10.2) of the car body assembly and the running gear assembly.

16. The vehicle of claim 13, characterised in that the first pneumatic compression spring (24) and second set of pneumatic traction springs (26), and the second pneumatic compression spring (24) and first set of pneumatic traction springs (26) are located between a common car body (10) of the car body assembly and a common running gear (12.1, 12.2) of the running gear assembly.

17. The vehicle of any one of the claims 13 to 16, characterised in that each running gear (12, 12.1, 12.2) of the running gear assembly comprises a frame (16), a set of wheels (14) and a primary suspension (18) between the frame (16) and the set of wheels (14) and the pneumatic suspension (20, 20.1, 20.2) is a secondary suspension between the car body assembly and each frame (16) of each running gear of the running gear assembly.

18. A method of retrofitting a vehicle suspension (20, 20.1, 20.2) comprising at least a first pneumatic compression spring (24) located laterally on a first side of the pneumatic suspension (20, 20.1, 20.2), and a second pneumatic compression spring (24) located laterally on a second side of the pneumatic suspension (20, 20.1, 20.2) opposite the first side, comprising the steps of pneumatically connecting the first pneumatic compression spring (24) with a first set of one or more pneumatic traction springs (26) located laterally on the second side of the pneumatic suspension, and spaced apart from the second pneumatic compression spring (24) at least in a longitudinal or lateral direction of the pneumatic suspension, and pneumatically connecting the second pneumatic compression spring (24) with a second set of one or more pneumatic traction springs (26) located laterally on the first side of the pneumatic suspension, and spaced apart from the first pneumatic compression spring (24) at least in a longitudinal or lateral direction of the pneumatic suspension.

Fig.1


24
26
26
24
10
20.1
20.2
12.1
12.2
18
14
14
18
16
18
14
14
18
16

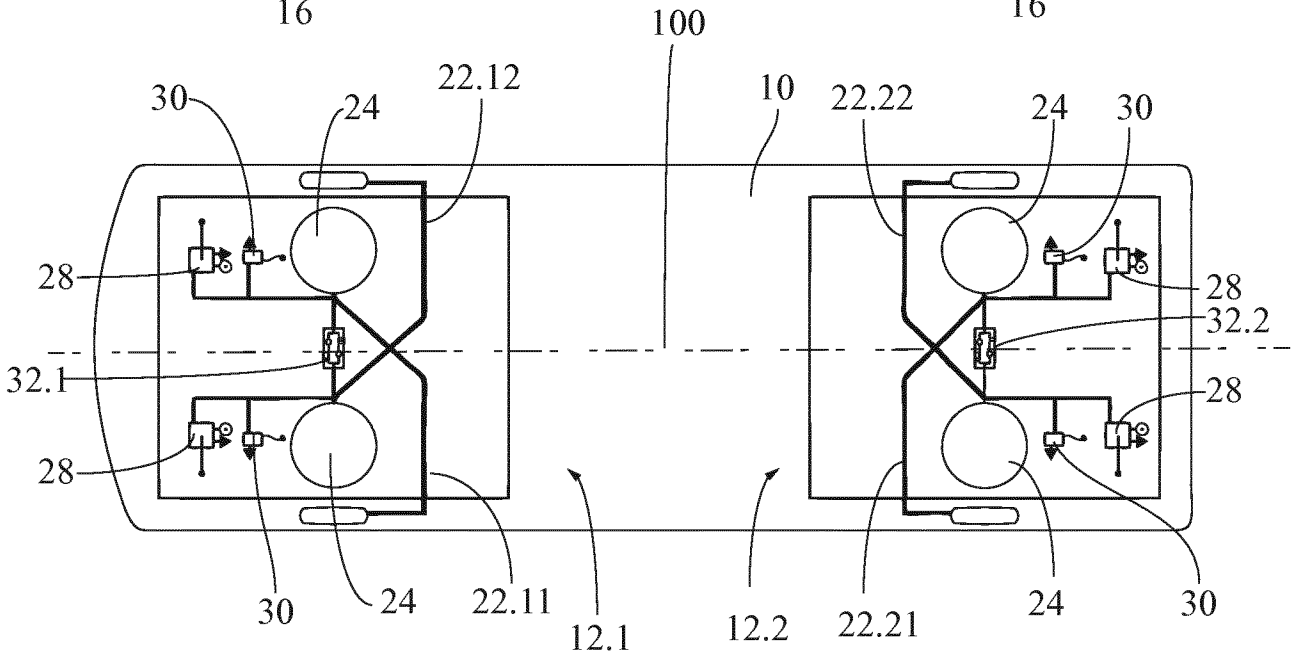

100
30
24
22.12
10
22.22
24
30
28
28
32.2
32.1
28
28
30
24
22.11
12.1
12.2
22.21
24
30

Fig.2

Fig.3

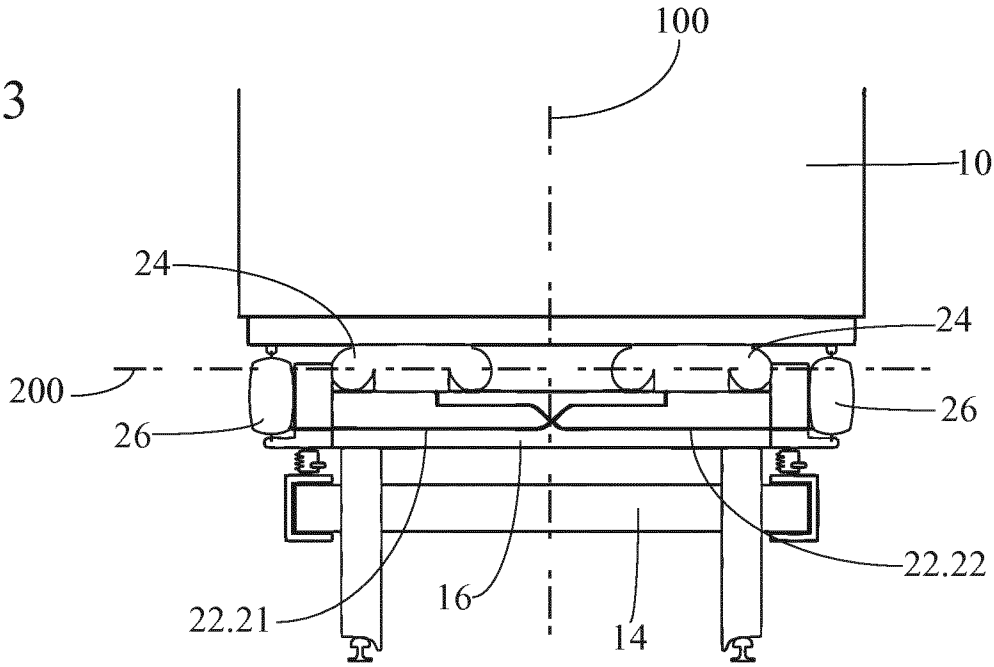
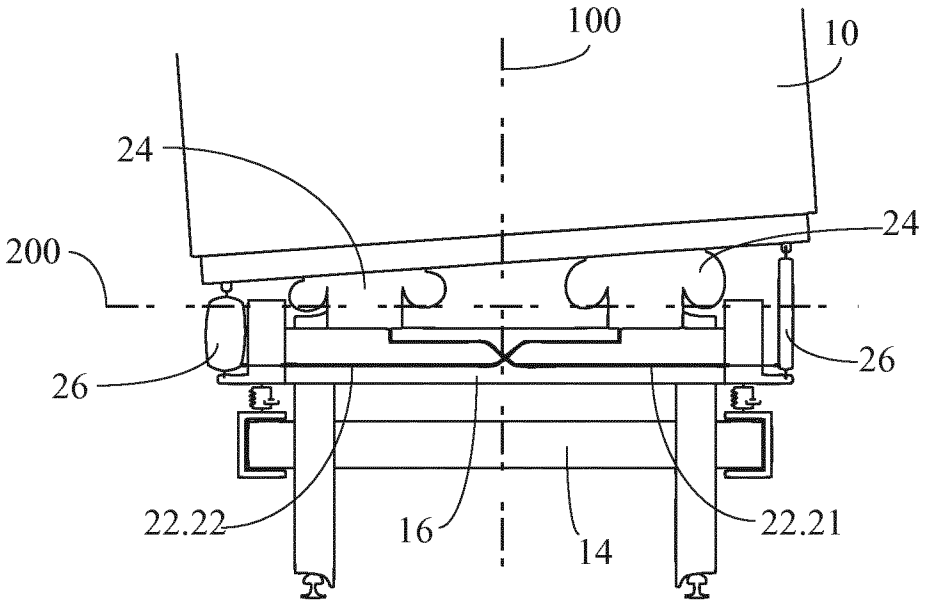


Fig.4



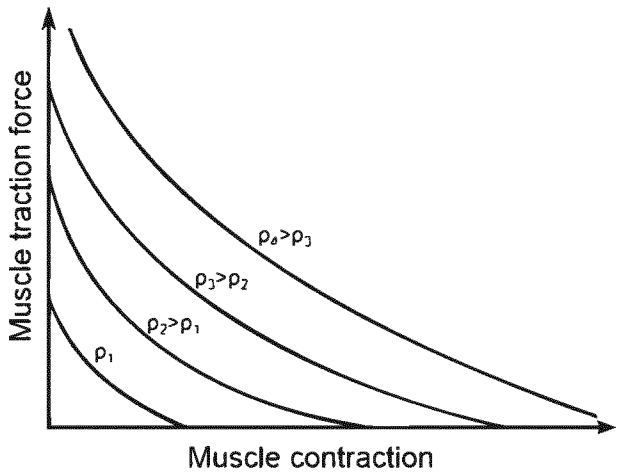
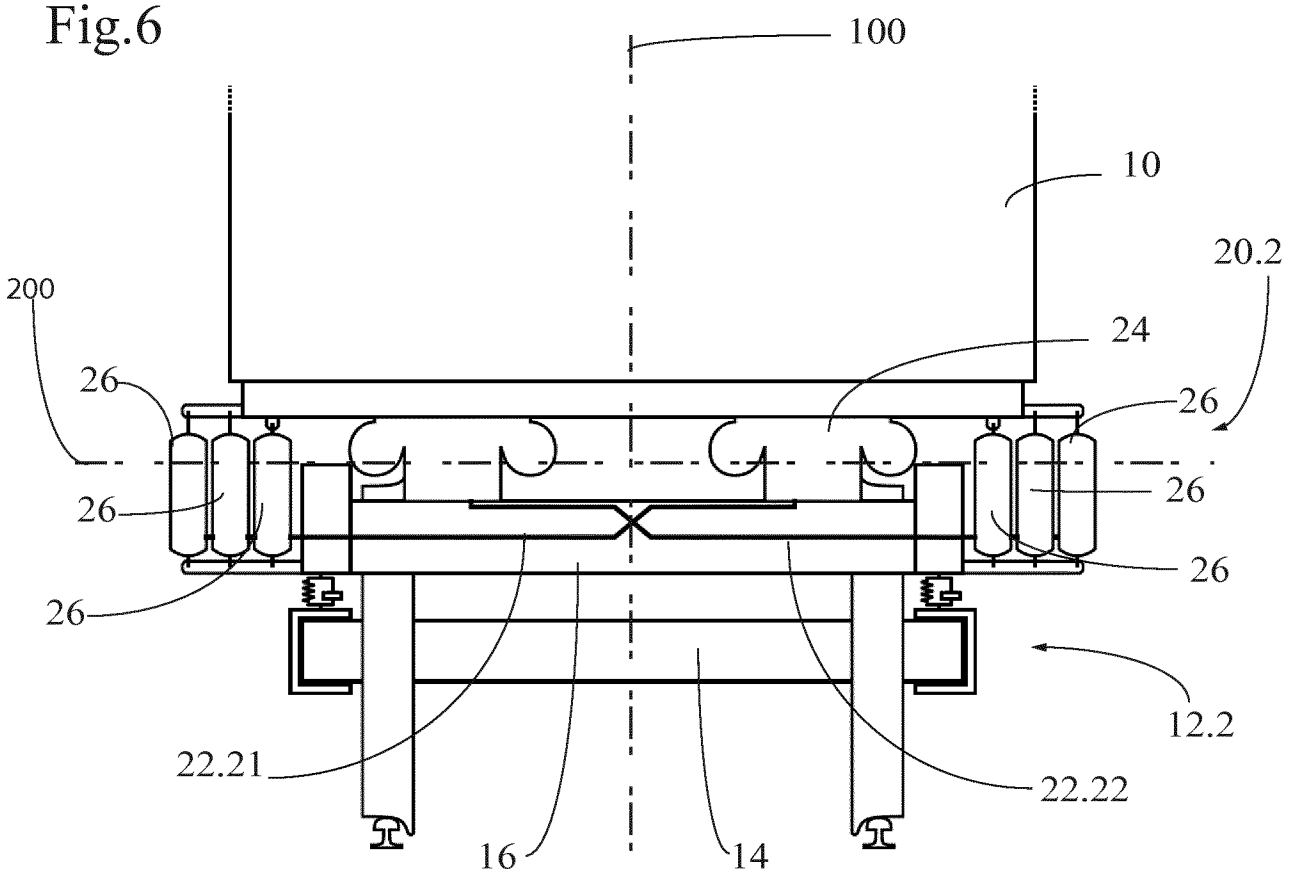


Fig.5

Fig.6


100
10
20.2
200
24
26
26
26
26
26
26
12.2
22.21
22.22
16
14

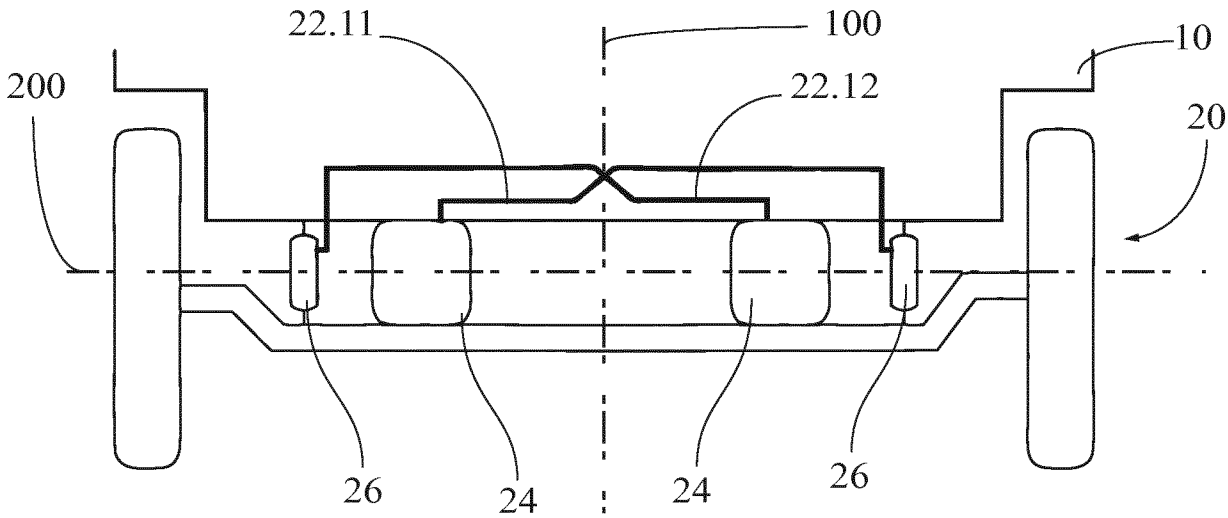
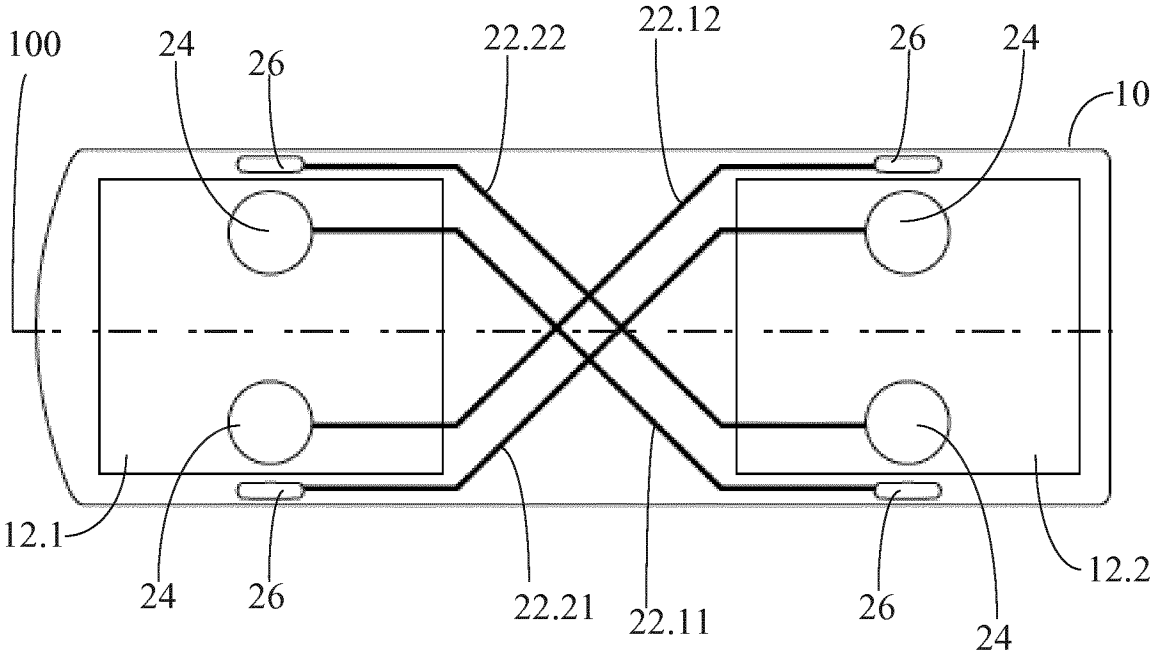

22.11
100
10
200
22.12
20
26
24
24
26

Fig.7

Fig.8


100
24
26
22.22
22.12
26
24
10
12.1
24
26
22.21
22.11
26
24
12.2

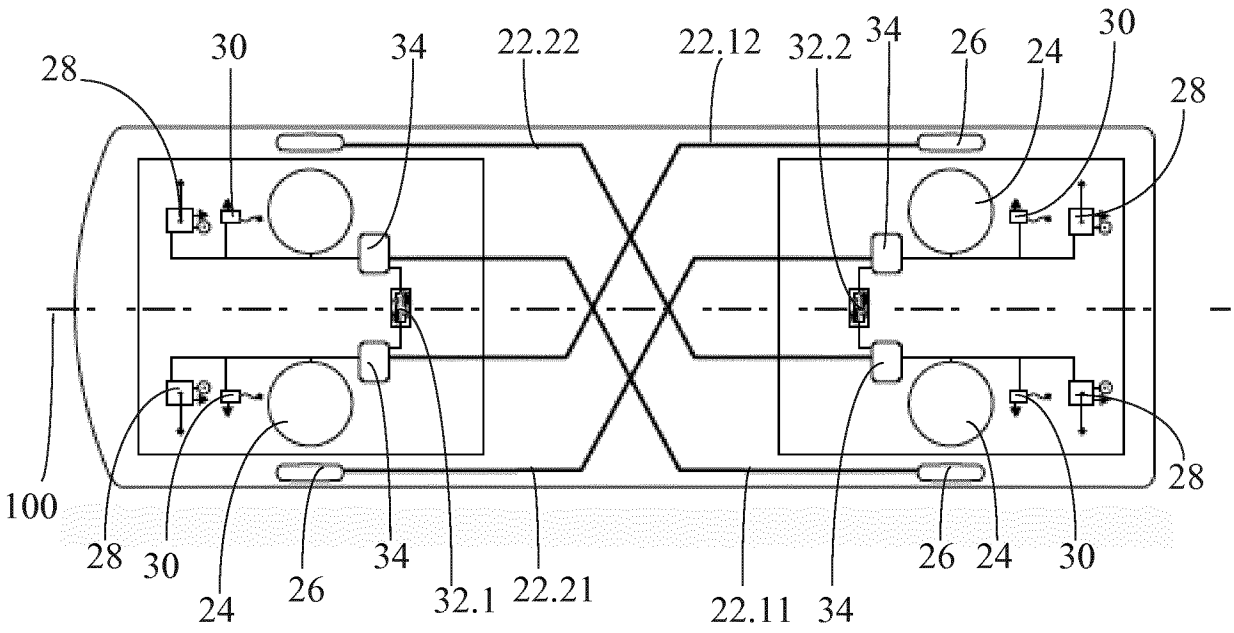
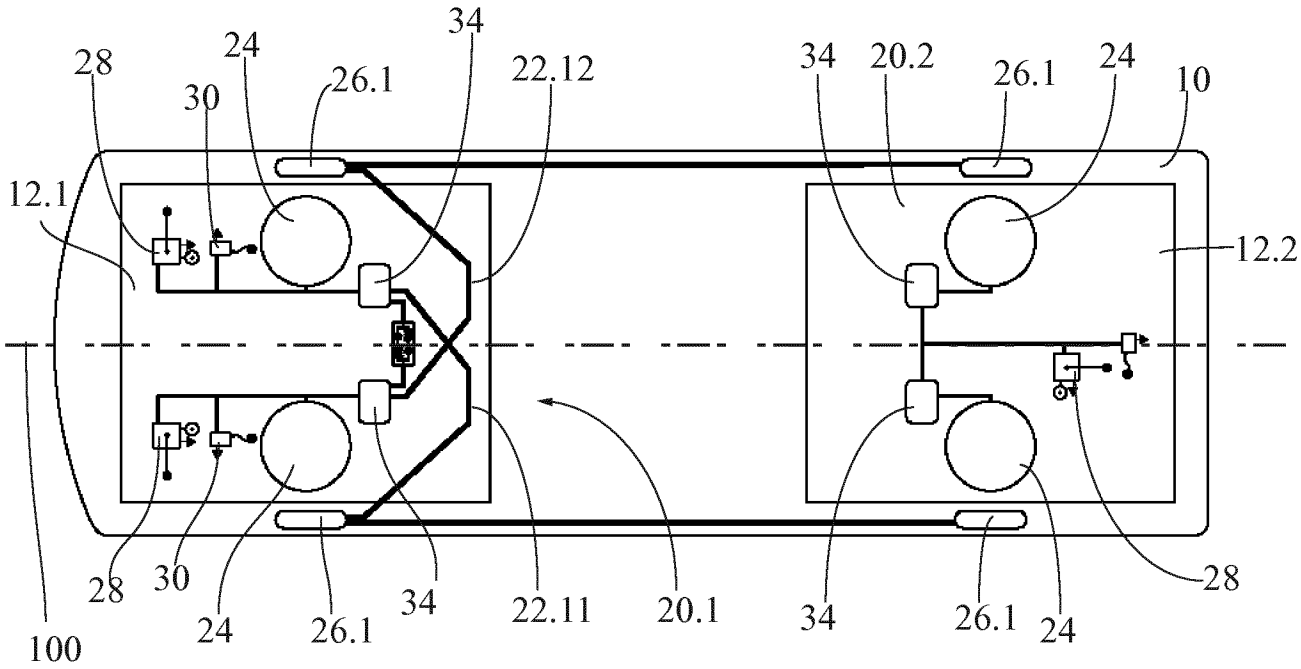

28
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34
22.22
22.12
32.2
34
26
24
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28
100
28
30
24
26
34
32.1
22.21
22.11
34
26
24
30
28

Fig.9

Fig.10


28
24
34
26.1
22.12
34
20.2
26.1
24
10
30
12.1
12.2
28
30
24
26.1
34
22.11
20.1
34
26.1
24
28
100

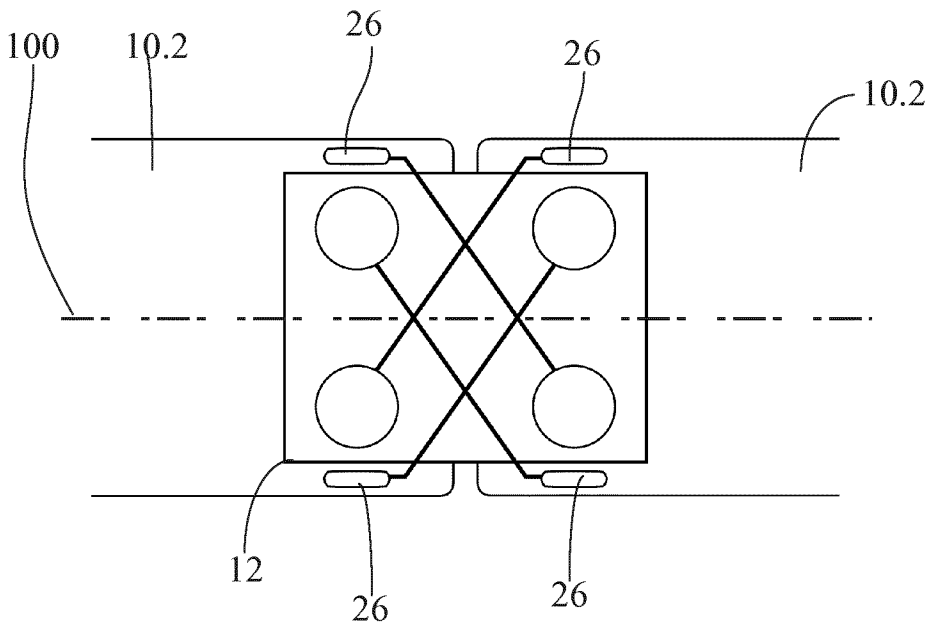

100
10.2
26
26
10.2
12
26
26

Fig.11

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2014/055072

A. CLASSIFICATION OF SUBJECT MATTER
INV. B60G11/27 B60G17/016 B60G99/00 B60G17/052 B60G17/015
B60G21/073 B60G21/067 B61F5/24
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 B61F

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, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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X	DE 295 12 043 U1 (LIN CHION DONG [TW]) 16 November 1995 (1995-11-16) figures 1-5	1-18

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 July 2014	22/07/2014

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Cavallo, Frédéric

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A	WO 2008/065436 A1 (SHOTTER NICHOLAS RICHARD [GB]) 5 June 2008 (2008-06-05) page 17, line 5 - page 20, line 15; figures 16-17	11,12
A	OSTASEVICIUS ET AL: "Investigation of Active Car Suspension with Pneumatic Muscle", SAE INTERNATIONAL- INTERNATIONAL BODY ENGINEERING CONFERENCE & EXHIBITION AND AUTOMOTIVE & TRANSPORTATION TECHNOLOGY CONGRESS - PARIS, FRANCE, JULY 9 - 11, 2002, SAE INTERNATIONAL, US, no. Paper Nr. 2002-01-2206, 9 July 2002 (2002-07-09), pages 1-5, XP008170541, DOI: 10.4271/2002-01-2206 ISBN: 0-7680-1066-7 the whole document	11,12
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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2014/055072

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
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