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(54) Title: VEHICLE STABILITY APPARATUS AND METHOD

(57) Abstract: A vehicle (10) including an unsuspended body and a data system including an inertial measurement unit positioned on the unsuspended body of the vehicle (10).

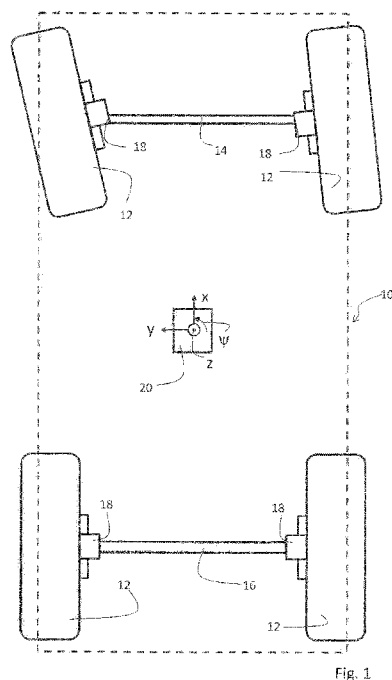


Fig. 1



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Title: Vehicle Stability Apparatus and Method

5 Description of Invention

The invention relates to a vehicle and a method of determining roll over susceptibility, in particular to a method of determining a height of the centre of gravity of the vehicle.

10

The height of the centre of gravity (COG) of commercial vehicles is a very important parameter for determining roll over susceptibility. The COG height of commercial vehicles may vary as a consequence of changing load conditions. It is known to estimate the position COG along a longitudinal axis x of a vehicle 10 (the outline of which is shown in dotted lines in Figure 1 for illustrative purposes only, and is not intended to indicate any particular size or relative proportions of the vehicle 10) from suspension bellows measurements and/or suspension movement measurements, for example. The position of the COG along a lateral axis y is typically the responsibility of the driver, and this can be adjusted by ensuring that loads are evenly distributed along the lateral axis y. However, there is no practical direct or online, i.e. dynamic, method of measuring the position of the COG along a vertical axis z. Bellows pressures are typically equal on the left and right of the vehicle 10, and so measurements of bellows pressures do not give an indication of roll (ϕ).

25

It may be possible to measure the vertical COG position, i.e. COG height, in an 'off-road' setting, for example a laboratory or other testing facility, for example by using tilt tables, axle lifts and/or pendula. However, such methods cannot be used when the vehicle 10 is being driven, i.e. cannot be used to provide dynamic measurements or calculations. Given the importance of the COG height to the roll (ϕ) stability of the vehicle, it is desirable to be able to

30

measure and/or monitor the COG height while the vehicle is in use, for example whilst it is in motion.

5 Previous methods of attempting to estimate COG height have used lateral load transfer. It is not possible to achieve this from bellows pressure measurements or suspension movement measurements. Commercial vehicles are provided with very stiff anti-roll mechanisms, which introduce a large level of uncertainty.

10 Previous attempts to estimate COG height of light weight vehicles from rolling radii of tyres are inappropriate, and/or insufficient for commercial vehicles.

In accordance with the present invention, there is provided a vehicle including an unsuspended body and a data system including an inertial measurement
15 unit positioned on the unsuspended body.

The data system may be a state observer.

20 The data system may be operable to determine instability of the vehicle about at least one axis of the vehicle, dynamically.

The data system may be operable to determine instability of the vehicle about a longitudinal axis of the vehicle.

25 The data system may receive input signals from one or more wheel end units, and compare the input signals from the wheel end units with input signals from the inertial measurement unit.

30 The data system may be operable to determine a load transfer value per axle.

The inertial measurement unit may be positioned on an axle of the vehicle.

The data system may include a plurality of inertial measurement units, and one or more of the inertial measurement units may be positioned on an axle of the vehicle.

5

The or each inertial measurement unit may be positioned near to a centre of gravity of the vehicle along a longitudinal axis of the vehicle.

The data system may be operable to determine the height of the centre of gravity of the vehicle.

10

There is also provided a method of determining a height of the centre of gravity of a vehicle, including providing a data system on an unsuspended body of the vehicle, using the data system to derive a first value relating to a vehicle parameter, comparing the first value derived by the data system with a second value relating to the vehicle parameter derived in an alternative way, and using the comparison of the first and second values to determine the height of the centre of gravity of the vehicle dynamically.

15

The first and second values of more than one vehicle parameter may be derived.

20

The or each vehicle parameter may include one or more of yaw rate, lateral acceleration of the vehicle, a rolling radius of one or more wheels, a load transfer per axle, a speed of one or more wheels, and steering angle data.

25

The centre of gravity height determined may be used to determine dynamic roll instability of the vehicle.

The invention will now be described, by way of example only, with reference to the accompanying figures, of which:

30

FIGURE 1 is an illustrative plan view of a vehicle;

FIGURE 2 is an illustrative rear view of the vehicle of Figure 1;

FIGURE 3 shows a relationship between loaded versus effective rolling radius of a tyre, as a function of vertical load, and

5 FIGURE 4 shows a cross-sectional view of a part of the vehicle.

Referring to the figures, there is illustrated a vehicle 10, which may be a commercial vehicle, for example a lorry having a large vertical height. Such vehicles may have a height of up to approximately 4m in accordance with
10 European regulations, or may be even higher in other countries or regions. Four wheels 12 are shown in Figures 1 and 2. However, this is for illustrative purposes only, and it will be understood that the vehicle 10 may have any number of wheels 12. The vehicle 10 is illustrated as having a front axle 14 and a rear axle 16. The vehicle 10 may have more than two axles 14, 16, and
15 may have twin axles or any other arrangement of axles as is appropriate for the type of vehicle. The vehicle 10 is shown as having a wheel 12 at each end of each axle 14, 16. However, it will be understood that more than one wheel 12 may be provided at each end of one or more of the axles 14, 16 (or any other axles, not shown).

20

Vehicles of the type described above are typically provided with anti-roll mechanisms, which provide chassis stiffness and strength, and assist in stabilising the vehicle.

25 Vehicles of the type described above typically include one or more Inertial Measurement Units (IMUs). The or each IMU may form part of a state observer. In known systems, the or each IMU is provided on the chassis rails or in the vehicle cab. In known systems, the or each IMU is provided on a suspended part of the vehicle. The or each IMU is used to determine vehicle
30 dynamics, for example yaw (ψ) rate and/or lateral acceleration. Yaw ψ rate and lateral acceleration may also be determined from individual wheel speeds,

which may be measured, for example by wheel sensors, for example Hall Effect sensors, and communicated to an ECU 18 associated with the respective wheel 12 (or wheel arrangement, where multiple wheels are provided at each end of the axle 14, 16, for example). It will be understood
 5 that a separate ECU 18 need not be provided for each wheel 12 or wheel arrangement, and that the or each ECU 18 need not necessarily be located adjacent the respective wheel 12 or wheel arrangement (i.e. the or each ECU need not be located in a wheel end unit). It may be desirable to locate electronics components in wheel end units (i.e. near to a respective wheel 12
 10 or wheel arrangement). For example, the vehicle's braking system may necessitate locating at least a proportion of the electronic components at or near the wheel end. The or each ECU 18 may include a respective IMU 20.

Where an IMU 20 is incorporated into a wheel end unit or axle electronics, this
 15 enables a dynamic (i.e. in use) estimate of effective tyre rolling radius of the associated tyre(s) 12. This dynamic estimate of the tyre 12 rolling radii can be used to determine load transfer per axle, which in turn may be translated into an estimate of COG height.

20 The effective rolling radius R_i of a tyre 12 is a function of multiple parameters and, hence multiple signals. To estimate the COG height, the relationship between the vertical tyre force and rolling radius is important. In its simplest form, the rolling radius R_i of a wheel i is:

25
$$R_i = R_{0j} + \Delta R_i + k_{a_i} a_{y_{ss_i}}$$

where:

R_{0j} is the average nominal rolling radius of the tyres 12 carried by the j^{th} axle 14, 16, and

ΔR_i is a rolling radius offset. The remainder of the equation provides a linear relationship between rolling radius and steady-state lateral acceleration $\alpha_{y_{ss_i}}$ of the wheel i . The parameter k_{a_i} is estimated from a combination of measurements which are available. The parameter k_{a_i} is an indication of rollover susceptibility. It is well understood that radial tyres exhibit non-linear behaviour for effective rolling radius as a function of vertical load. The effective rolling radius R_i and loaded radius will usually have different values. At zero load, these two values are equal and there is typically a cross-over point at a certain load, as shown in Figure 3.

10

Longitudinal slip stiffness of a tyre 12 is a function of vertical load. There are so-called “magic numbers” which are known in the art, which can model these properties reasonably well. In the linear range of operation, the relationship may be set out thus:

15

$$F_x = F_z C_{x0} \lambda$$

Where:

F_x is the tyre contact force (longitudinal)

20 C_{x0} is the slip stiffness per Newton of vertical load,

F_z is the vertical load, and

λ is the tyre slip.

The longitudinal tyre contact force F_x may be determined in more than one way, therefore this relationship may be invoked in the present model to improve COG height estimations.

25

Wheel sensors may be provided to measure rotational velocity of the wheel ω_i , rather than longitudinal velocity of the vehicle 10. Typically such

7

measurements are transformed into a translator velocity value u_{w_i} by multiplying with the effective tyre rolling radius R_i .

For example:

5

$$u_{w_i} = \omega_i R_i$$

where the index i identifies the wheel 12 of the vehicle 10.

- 10 From the results, the axle velocity u_a can be determined, with the help of the average value of the wheel velocities u_{w_i} on either side of an axle j :

$$u_{a_j} = \frac{u_{w_i} + u_{w_{i-1}}}{2}$$

- 15 Odd values of i denote the left hand side of the axle and even values of i denote the right hand side of the axle, hence the axle index j becomes a function of the right hand wheel:

$$j = \frac{i + 1}{2}$$

20

Velocity signals originating on either side of an axle j may also be used to determine the yaw rate r_{a_j} in the linear area of operation, thus:

$$r_{a_j} = \frac{-u_{w_i} + u_{w_{i+1}}}{t_{w_j}}$$

25

The steady state lateral acceleration thus becomes:

$$u_{a_j} \cdot r_{a_j} = \frac{u_{w_i} + u_{w_{i+1}}}{2} \cdot \frac{-u_{w_i} + u_{w_{i+1}}}{t_{w_j}} = \frac{u_{w_{i+1}}^2 - u_{w_i}^2}{2t_{w_j}}$$

The estimate of load transfer per axle 14, 16 may also enable understeer and oversteer characteristics to be identified. These characteristics may be input into one or more directional stability algorithms.

5

It is possible to derive estimates of yaw ψ rate and lateral acceleration via simple kinematic relationships from wheel speeds of the vehicle 10 during motion. The estimated yaw ψ rate and/or the lateral acceleration calculated via wheel speeds may be compared with the equivalent parameters 10 determined by the or each respective IMU 20.

For example,

$$a_y = \dot{v} + ur$$

15 where:

a_y = lateral acceleration,

$\dot{v}$ = first derivative of lateral velocity (body co-ordinates) with respect to time,

u = Longitudinal velocity (body co-ordinates), and

r = yaw rate.

20

The steady state lateral acceleration $a_{y_{ss}}$, i.e. when the first derivatives of local body co-ordinates are zero, is therefore:

$$a_{y_{ss}} = ur$$

25

Rearrangement of this equation implies that the IMU sensors can determine, for example estimate and/or measure the longitudinal velocity of the vehicle when negotiating a curve, i.e. when the yaw rate is not zero.

Steering angle data may also be provided to the state observer in the case of steered axles, and used to estimate the COG height. This may be of particular importance in tight corners.

- 5 Tyre pressure monitoring systems are mandatory in heavy commercial vehicles. Direct systems, i.e. those which measure, rather than estimate, the inflation pressure of a tyre will have a pressure signal available for use in determining the COG height. An indirect system is unlikely to be able to provide signals fast enough for use in a dynamic system.
- 10 Obtaining a measurement of inflation pressure of a tyre provides an indication of variation in the tyre load. This relationship is not linear. The tyre contact area with the ground may vary linearly with a deflected or loaded radius, which would imply the pressure increases more slowly than proportionally with vertical tyre load
- 15 $p = F/A$, if A increases with F , then p increases digressively (i.e. less than proportionally) with F .

- Known direct tyre pressure monitoring systems are unable to update
- 20 frequently enough to be useful in this context of CoG estimations. Such systems do not or cannot provide sufficiently frequent updates owing to battery life requirements.

- Inputs to the or each IMU 20 may have offsets and gains. The effective rolling radii may also have offsets and gains. All of these offsets and gains may be
- 25 estimated by means of estimation techniques, for example Recursive Least Squares, Luenberger or a 'Kalman' based algorithm, or a combination of these techniques. The offsets may be estimated during straight ahead driving; i.e. when yaw rate and lateral acceleration are small, and may be small enough to
- 30 be negligible. The gains may be estimated under significant values of the yaw

rate and lateral acceleration, but within the (approximately) linear operation of vehicle dynamic properties.

5 The lateral load transfer, and thus the COG height, can be estimated with help of the above modelling relationships, since vertical load can be assumed to be a function of the change in lateral acceleration, per axle. Hence the effective rolling radii and slip reactions can become a function of lateral acceleration and an indication of COG height.

10 The COG height may be used in a roll (ϕ) stability algorithm, to enable a determination of dynamic roll (ϕ) instability to be made.

For a state observer to work well, it is important that parameters of the input signals to the state observer are similar, for example parameters such as gain,
15 bandwidth and/or phase lags, for example. This similarity or coherence in parameters is referred to herein by the applicant as the “colour” of the input signals received by the state observer. The “colour” of the input signals may include additional or alternative parameters.

20 In embodiments, the or each IMU 20 is provided on an unsprung body (i.e. an unsuspended part of the vehicle 10, for example a brake calliper, or housing thereof 100, a rigid axle, a housing 102 of a motor 104, as part of an ECU 18). Preferably, the or each IMU 20 may be located near to the COG along the x-axis of the vehicle 10. Only one IMU 20 per axle 14, 16 may be provided. It
25 will be appreciated that more than one IMU 20 may be provided per axle.

Providing the or each IMU 20 on an unsprung or unsuspended part of the body of the vehicle 10 enables the coherence (or “colour”) of the input signals to the state observer to be as similar as possible to one another. Providing signals
30 which are unaffected by suspension movements means that phase lags are unlikely to be introduced, and the bandwidth of the input signals is unlikely to

be affected. This means that the state observer provides an accurate determination of the COG height from the input signals, which, in turn will provide more accurate determinations of dynamic instability.

- 5 When used herein, the term "determined" may mean calculated, estimated or measured.

Representative features are set out in the following clauses, which stand alone or may be combined, in any combination, with one or more features disclosed
10 in the text and/or drawings of the specification.

When used in this specification and claims, the terms "comprises" and "comprising" and variations thereof mean that the specified features, steps or integers are included. The terms are not to be interpreted to exclude the
15 presence of other features, steps or components.

The features disclosed in the foregoing description, or the following claims, or the accompanying drawings, expressed in their specific forms or in terms of a means for performing the disclosed function, or a method or process for
20 attaining the disclosed result, as appropriate, may, separately, or in any combination of such features, be utilised for realising the invention in diverse forms thereof.

Although certain example embodiments of the invention have been described,
25 the scope of the appended claims is not intended to be limited solely to these embodiments. The claims are to be construed literally, purposively, and/or to encompass equivalents.

CLAIMS

1. A vehicle including an unsuspended body and a data system including an inertial measurement unit positioned on the unsuspended body.
- 5
2. A vehicle according to claim 1 wherein the data system is a state observer.
3. A vehicle according to claim 1 or claim 2 wherein the data system is operable to determine instability of the vehicle about at least one axis of the vehicle, dynamically.
- 10
4. A vehicle according to claim 3 wherein the data system is operable to determine instability of the vehicle about a longitudinal axis of the vehicle.
- 15
5. A vehicle according to any one of the preceding claims wherein the data system receives input signals from one or more wheel end units, and compares the input signals from the wheel end units with input signals from the inertial measurement unit.
- 20
6. A vehicle according to any of the preceding claims wherein the data system is operable to determine a load transfer value per axle.
7. A vehicle according to any of the preceding claims wherein the inertial measurement unit is positioned on an axle of the vehicle.
- 25
8. A vehicle according to any of the preceding claims wherein the data system includes a plurality of inertial measurement units, and one or more of the inertial measurement units is positioned on an axle of the vehicle.
- 30

9. A vehicle according to any of the preceding claims wherein the or each inertial measurement unit is positioned near to a centre of gravity of the vehicle along a longitudinal axis of the vehicle.
- 5 10. A vehicle according to any of the preceding claims wherein the data system is operable to determine the height of the centre of gravity of the vehicle.
- 10 11. A method of determining a height of the centre of gravity of a vehicle, including providing a data system on an unsuspended body of the vehicle, using the data system to derive a first value relating to a vehicle parameter, comparing the first value derived by the data system with a second value relating to the vehicle parameter derived in an alternative way, and using the comparison of the first and second values to determine the height of the centre
15 of gravity of the vehicle dynamically.
12. A method according to claim 11 wherein first and second values of more than one vehicle parameter are derived.
- 20 13. A method according to claim 11 or claim 12 wherein the or each vehicle parameter includes one or more of yaw rate, lateral acceleration of the vehicle, a rolling radius of one or more wheels, a load transfer per axle, a speed of one or more wheels, and steering angle data.
- 25 14. A method according to any of claims 11 to 13 wherein centre of gravity height determined is used to determine dynamic roll instability of the vehicle.

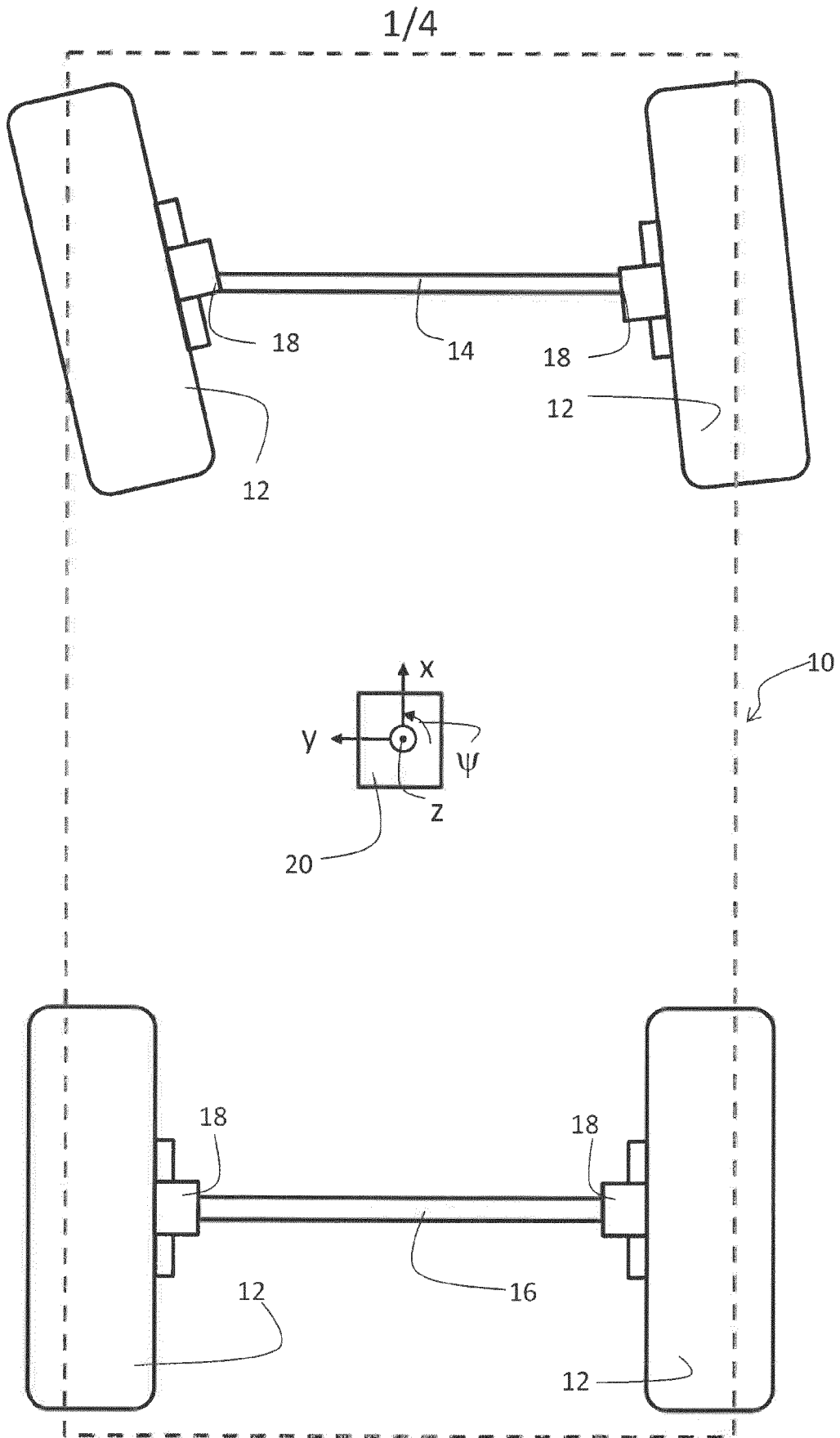


Fig. 1

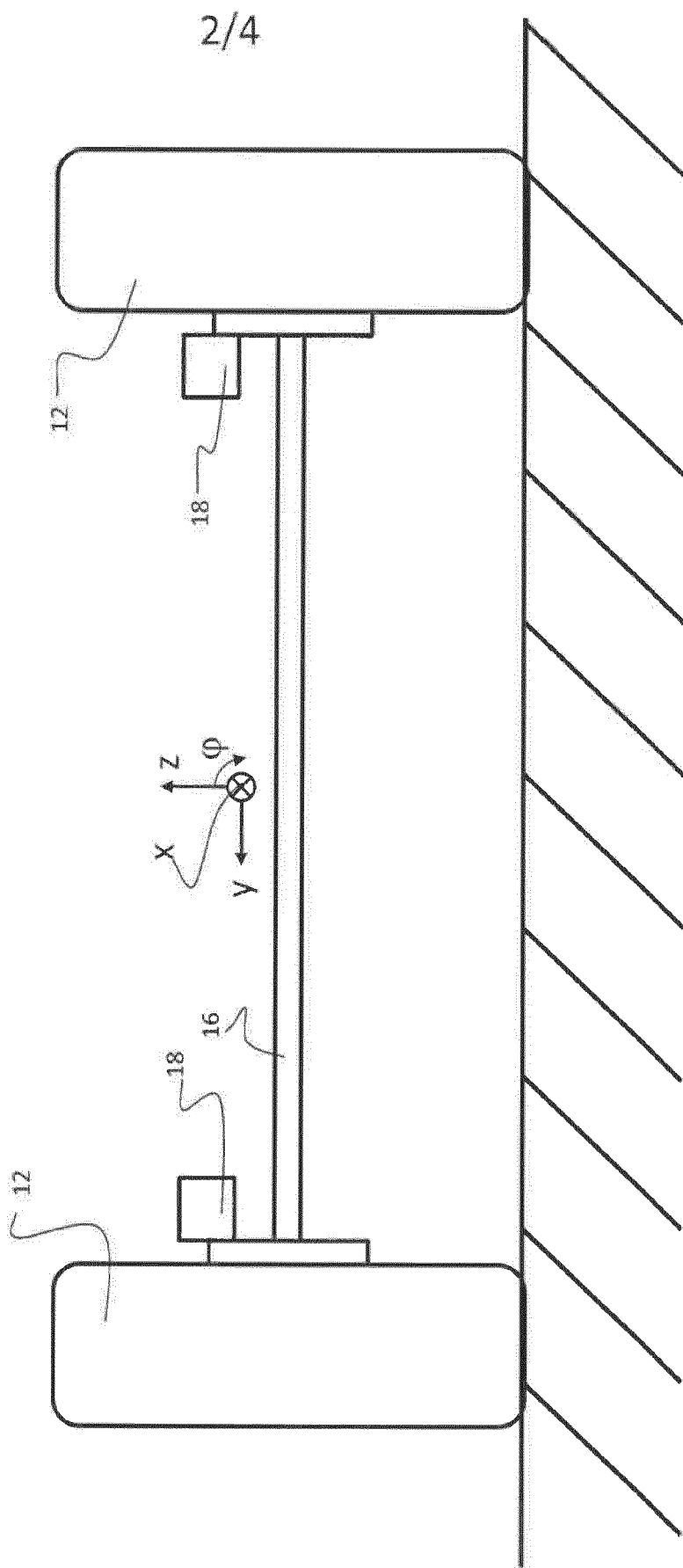


Fig. 2

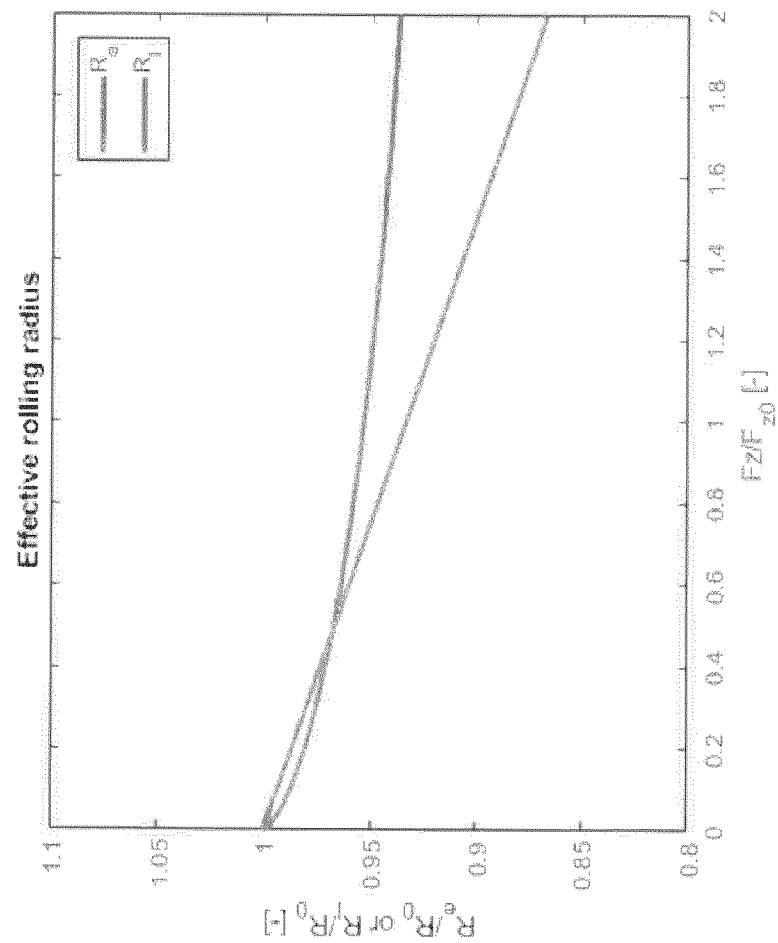
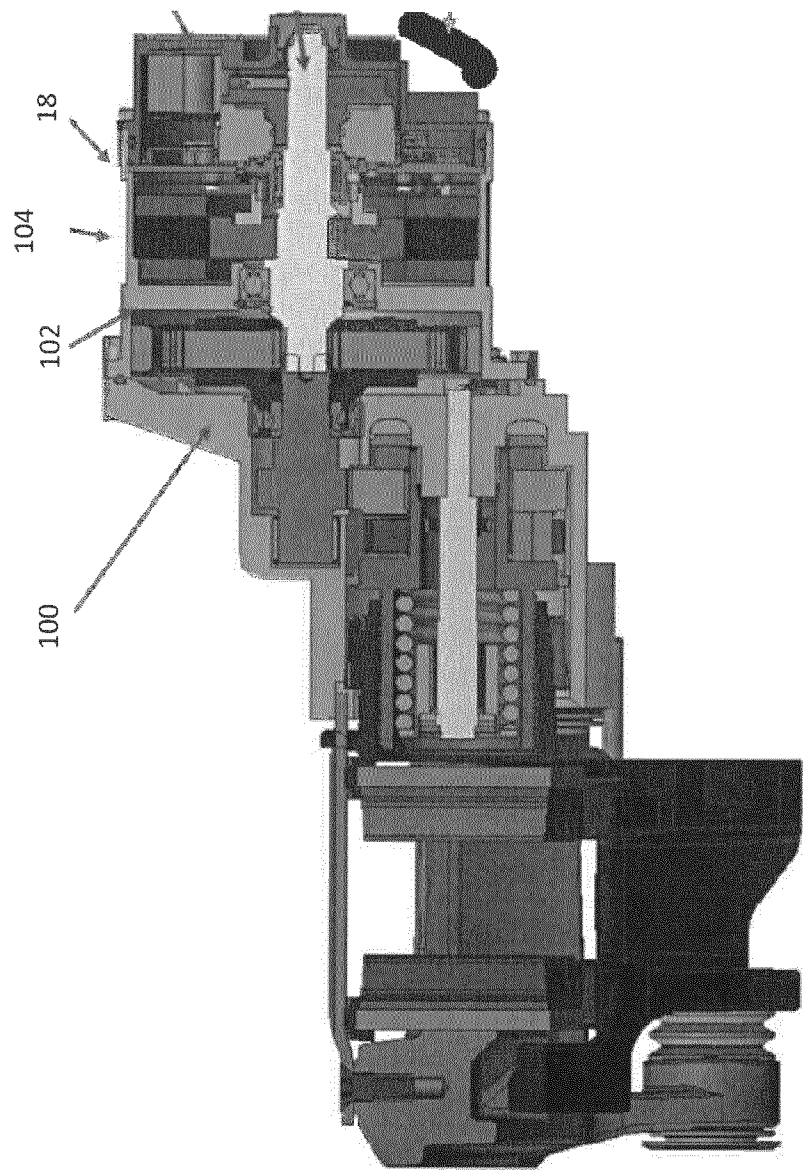


Figure 3 - Loaded- versus effective rolling radius as function of vertical load



INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER
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ADD.

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G01M B60T

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 825 284 A (DUNWOODY ANDREW B [CA] ET AL) 20 October 1998 (1998-10-20) abstract column 7, line 39 - column 8, line 31 figure 4	1-14
X	US 2012/173133 A1 (RANC FABRICE [FR] ET AL) 5 July 2012 (2012-07-05) abstract paragraphs [0005], [0014], [0015]	1-14
X	US 2018/306665 A1 (DORAY JEAN-BAPTISTE [FR] ET AL) 25 October 2018 (2018-10-25) abstract paragraphs [0014] - [0024]	1-14



Further documents are listed in the continuation of Box C.



See patent family annex.

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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