



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
13.05.2015 Bulletin 2015/20

(51) Int Cl.:
B61F 5/22^(2006.01)

(21) Application number: **13192003.5**

(22) Date of filing: **07.11.2013**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
 Designated Extension States:
BA ME

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(54) **Crosswind stabilisation method and associated rail vehicle**

(57) A rail vehicle comprises a vehicle body resting on two longitudinally spaced running gears (14, 16), each of the running gears (14, 16) comprising a running gear frame (14.1, 16.1), a primary suspension (14.2, 16.2) between the running gear frame (14.1, 16.1) and a set of wheels (14.3, 16.3), and a secondary suspension comprising at least one lateral actuator (14.4, 14.41, 16.4) between the running gear frame (14.1, 16.1) and the vehicle body (12). A method for controlling the suspension

of the rail vehicle comprises: processing signals from sensors (14.21, 16.21) directly or indirectly measuring a wheel unloading condition to detect crosswind and a windward side; and controlling the at least one lateral actuator (14.4, 14.41, 16.4) of at least one of the running gears (14, 16) to move the vehicle body (12) according to a stability-oriented control strategy towards the windward side in response to the detected crosswind.

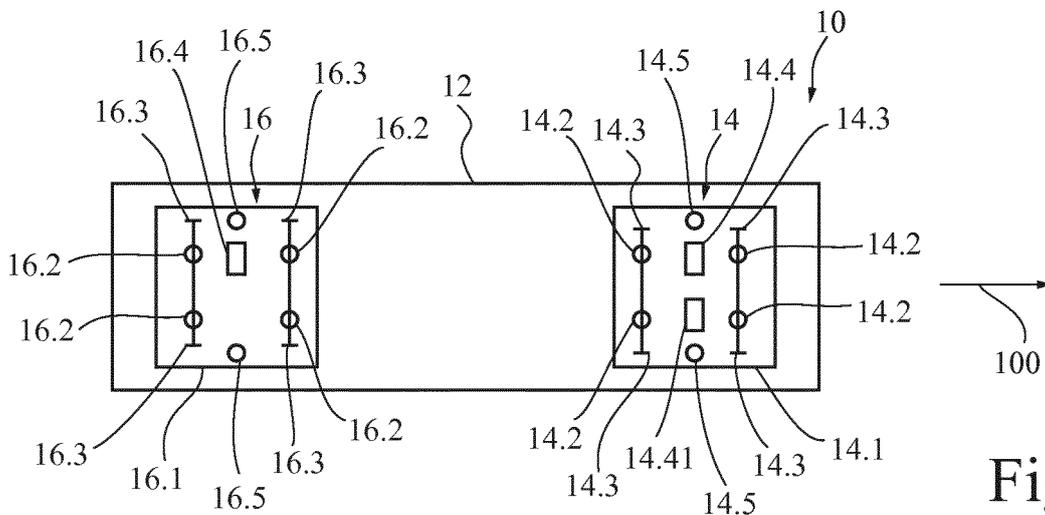


Fig.1

Description

stability-oriented control strategy towards the windward side in response to the detected crosswind.

TECHNICAL FIELD OF THE INVENTION

[0001] This invention relates to the crosswind stability of a rail vehicle, in particular a high-speed rail vehicle, e.g. an intercity rail vehicle, and/or a vehicle subjected to high crosswind loads, e.g. a double-deck rail vehicle.

BACKGROUND ART

[0002] The crosswind stability of rail vehicles is influenced by the shape of the vehicle body, the inertial properties of the vehicle body and the running gear frames, and by the vehicle suspension systems. A rail vehicle provided with a passive suspension system and exposed to a crosswind reacts with a sway motion of the vehicle body. A yaw motion of the vehicle body can also be observed, in particular under the impact of a gust. Measurements of vehicle response to crosswind show that in particular the lateral stiffness of the secondary suspension, and to somewhat less extent the roll stiffness, influence the stability of the vehicle under the induced loads. However, the magnitude of the aerodynamic loads is often so high that it proves impossible to sufficiently adapt the passive suspension system to crosswind without compromising or even deteriorating the ride comfort.

[0003] Rail vehicles are today increasingly equipped with active suspension systems for ride comfort purposes. When such a vehicle is exposed to high crosswind loads, the active secondary suspension may somewhat reduce the impact of crosswind on the vehicle. The magnitude and suddenness of the aerodynamic loads on the vehicle, however, are often such that the response of the active secondary suspension is insufficient or inappropriate.

[0004] There is therefore a need for a more specific response to crosswind on rail vehicles.

SUMMARY OF THE INVENTION

[0005] According to one aspect of the invention, there is provided a method for stabilising a rail vehicle comprising a vehicle body resting on two longitudinally spaced running gears, each of the running gears comprising a running gear frame, a primary suspension between the running gear frame and a set of wheels, and a secondary suspension comprising one or more lateral actuators between the running gear frame and the vehicle body, the method comprising:

- processing signals from sensors directly or indirectly measuring a wheel unloading condition to detect crosswind and a windward side; and
- controlling at least one of the one or more lateral actuators of at least one, or both of the running gears to move the vehicle body according to a crosswind

[0006] The sideward movement imparted to the vehicle body reduces the wheel unloading on the windward side, which minimises overturning risks and increases the stability of the vehicle. The proposed method may take advantage of an existing active suspension system or use dedicated actuators, in particular one or more dedicated lateral actuators, which are not used in the absence of crosswind.

[0007] The wheel unloading can be assessed as a normalised deviation $(Q-Q_0)/Q_0$ of the actual vertical wheel-rail force Q from a corresponding static force Q_0 on a horizontal track. However, directly measuring the wheel-rail force requires instrumented wheelsets, which is costly and impractical in daily operation. Hence, the sensors preferably measure a vertical deflection and/or force of the primary suspension. Directly measuring the vertical deflection of the primary suspension, in particular, proves particularly easy and appropriate.

[0008] While the wheel unloading can be measured or assessed on a single wheel, it is preferred to compute a left-side loading value and a right-side loading value for each running gear or for the two running gears of the rail vehicle.

[0009] The signal processing may further include comparing at least one of the left-side loading value and right-side loading value to an unloading threshold to decide an occurrence of crosswind. The unloading threshold is preferably determined as a result of a previous processing of signals from the sensors in a static situation, i.e. at standstill on a horizontal track or at constant speed on a straight horizontal track.

[0010] Preferably, the signal processing further includes comparing the left-side loading value to a right-side loading value to determine a windward direction.

[0011] The signals are preferably filtered with a low-pass filter, preferably a 1st order low-pass filter, preferably with a cut-off frequency between 0,1 and 4 Hz, to avoid unnecessary time delays in the response.

[0012] The crosswind stability-oriented control strategy preferably includes controlling at least one of the lateral actuators with a predetermined crosswind stability-oriented constant set value upon detection of the crosswind. This strategy is particularly simple to implement. The predetermined constant crosswind stability-oriented set value can be the maximum force or deflection value achievable with the lateral actuator.

[0013] Alternatively, if the lateral actuator is sufficiently powerful, it can be controlled with a set force value or deflection value which is the sum of a predetermined crosswind stability-oriented constant mean value and of a superimposed dynamic value. In particular, the superimposed dynamic value can be determined according to a known comfort-oriented control strategy. The dynamic value should not interfere with the constant mean value and should therefore have no frequency component un-

der a given split frequency. If the known comfort-oriented control strategy generates low frequency signals, it may be necessary to process the set value computed according to the comfort-oriented control strategy through a high-pass filter with a cut-off frequency at the split frequency, which is preferably more than 0,1 Hz and less than 3Hz.

[0014] If one of the running gears is provided with more than one lateral actuator, one of the lateral actuators can be dedicated to the crosswind stability-oriented control strategy while another can be controlled according to the comfort-oriented control strategy, after processing through a high-pass filter if necessary in order not to interfere with the first actuator.

[0015] The secondary suspension may be provided with left and right vertical actuators. In such a case, the crosswind stability-oriented control strategy may include controlling at least one vertical actuator of the secondary suspension to tilt the vehicle body towards the windward side in response to the detected crosswind. In particular, it may include lifting the vehicle body on a leeward side of the vehicle and lowering the vehicle body on the windward side of the vehicle.

[0016] At least one of the vertical actuators can be controlled with a predetermined constant set value upon detection of the crosswind. This predetermined constant set value can be a maximum force or deflection value of the vertical actuator.

[0017] At least one, and preferably all, of the vertical actuators can be controlled with a set force or deflection value, which is the sum of a predetermined constant mean value and of a superimposed dynamic value. In particular, the superimposed dynamic value can be determined according to a known comfort-oriented control strategy. As discussed above in connection with the lateral actuator, the dynamic value for controlling the vertical actuators should not interfere with the constant mean value and should therefore have no frequency component under a given split frequency. If the known comfort-oriented control strategy generates low frequency signals, it may be necessary to process the set value computed according to the comfort-oriented control strategy through a high-pass filter with a cut-off frequency at the split frequency, which is preferably more than 0,1 Hz and less than 3Hz.

[0018] Preferably, the method includes phasing in the crosswind stability-oriented control strategy and simultaneously phasing out a comfort-oriented control strategy in a transition phase at detection of the crosswind. The transition phase should be short enough to react quickly to the crosswind, but also to ensure a relatively smooth transition between the two control approaches.

[0019] The method preferably also includes processing the signals from sensors measuring a vertical deflection and/or force of the primary suspension to detect an end of the crosswind. In particular, it may include comparing at least one of the left-side loading value and right-side loading value to an end-of-unloading threshold to

detect the end of the crosswind. The end-of-unloading threshold may be equal to the unloading threshold. The method preferably also includes phasing out the crosswind stability-oriented control strategy and simultaneously phasing in a comfort-oriented control strategy in an end-of-crosswind transition phase. This transition phase can be longer than the previous one as returning to the comfort-oriented control strategy is not safety-related.

[0020] The method may further include processing stored data in combination with a positioning system and with the signals from sensors to improve the capability to differentiate crosswind from track layout, i.e. curve transitions.

[0021] If the rail vehicle is part of a set of rail vehicles, e.g. a multiple unit or a train, the method can include processing data from another rail vehicle of the set of rail vehicles in combination with the signals from sensors to detect crosswind.

[0022] According to another aspect of the invention, there is provided a method of controlling a rail vehicle comprising a vehicle body resting on two longitudinally spaced running gears, each of the running gears comprising a running gear frame, a primary suspension between the running gear frame and a set of wheels, and a secondary suspension comprising one or more lateral actuators between the running gear frame and the vehicle body, the method being **characterised in that** it comprises:

- processing signals from sensors directly or indirectly measuring a wheel unloading condition to detect a crosswind and a windward side;
- controlling at least one of the one or more lateral actuators of at least one or both of the running gears to move the vehicle body according to a crosswind stability-oriented control strategy towards the windward side in response to the detected crosswind..
- controlling at least one of the lateral actuators of at least one or both of the running gears according to a comfort-oriented control strategy to maximise ride comfort in the absence of crosswind

[0023] The comfort-oriented control strategy preferably includes a dynamic component to reduce the vibrations of the vehicle body in the lateral and vertical directions, and in particular the vibration in a frequency spectrum considered as most uncomfortable for the passengers, and a quasi-static component for curving purposes, e.g. to reduce lateral quasi-static suspension deflections during curve negotiation, or to tilt the vehicle body to reduce the impact of unbalanced lateral accelerations in horizontal curves. The vehicle body is therefore preferably provided with lateral and/or vertical accelerometers, which deliver input signals for the comfort-oriented control strategy.

[0024] The crosswind stability-oriented control strate-

gy may include switching off or fading away the comfort-oriented control strategy. It may also be combined with the dynamic component of the comfort-oriented control strategy.

[0025] According to another aspect of the invention, there is provided a rail vehicle comprising a vehicle body resting on two longitudinally spaced running gears, each of the running gears comprising a running gear frame, a primary suspension between the running gear frame and a set of wheels, and a secondary suspension comprising one or more lateral actuators between the running gear frame and the vehicle body. The rail vehicle is also provided with sensors for directly or indirectly measuring a wheel loading and a controller connected to the sensors and the one or more lateral actuators for stabilising a rail vehicle according to the control method of any one of the preceding claims.

[0026] According to one embodiment the running gears include at least one running gear, preferably a leading running gear, with two lateral actuators. This can be a convenient way of retrofitting an existing active suspension to increase its maximum lateral force.

[0027] The secondary suspension may include left and right vertical actuators connected to the controller.

[0028] The various embodiments of the invention can be combined at will.

DESCRIPTION OF THE FIGURES

[0029] Other advantages and features of the invention will become more clearly apparent from the following description of specific embodiments of the invention given as non-restrictive example only and represented in the accompanying drawings, in which:

- Fig. 1 is a top view of a rail vehicle according to an embodiment of the invention;
- Fig.2 is a schematic view of a control circuit for the rail vehicle of Fig.1;
- Fig.3 is a flow chart of a crosswind stability-oriented control strategy according to an embodiment of the invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0030] Referring to Fig 1, a rail vehicle 10 comprises a vehicle body 12 on two longitudinally spaced running gears 14, 16, each of the running gears 14, 16 comprising a running gear frame 14.1, 16.1, a primary suspension 14.2, 16.2 between the running gear frame and two sets of wheels 14.3, 16.3, and a secondary suspension comprising lateral actuators 14.4, 14.41, 16.4 and vertical actuators 14.5, 16.5 between the running gear frame 14.1, 16.1 and the vehicle body 12. More specifically, the leading running gear 14 in the travel direction 100 is pro-

vided with two lateral actuators 14.4, 14.41, whereas the other running gear 16 is provided with one lateral actuator 16.4 only.

[0031] The primary suspension 14.2, 16.2 is provided with sensors 14.21, 16.21 for measuring a deflection of the primary suspension. The rail vehicle 10 is further provided with a controller 20, which is connected to the sensors 14.21, 16.21 and to the lateral and vertical actuators 14.4, 14.41, 14.5, 16.4, 16.5 of the secondary suspensions of the two running gears 14, 16. The actuators can be hydraulic actuators, in particular electrically controlled hydraulic actuators, or any other type of suitable actuators with a short response time.

[0032] The controller 20 operates as illustrated in Figure 2. In the absence of strong crosswind, the controller follows a comfort-oriented control strategy e.g. to minimise the vertical and lateral accelerations of the vehicle body and/or to minimize the relative displacement between running gear frame and the vehicle body.

[0033] The input signals from the sensors 14.21, 16.21 are continuously processed through a low-pass filter at step 101, and compared to stored values at step 102 to determine whether crosswind has occurred.

[0034] More specifically, the comparison may include the computation of a normalised deflection value $(D-D_0)/(D_M-D_0)$, where D is the measured and filtered deflection, D_M is a stored value of the maximum admissible deflection for the primary suspension and D_0 is a predetermined value of the input signal measured at standstill or at constant speed on a straight track without crosswind. If the normalised deflection of the two wheels on the same side (windward side) of one of the running gears is more than a first given threshold, e.g. 80% or 90%, and if the normalised deflection of the two wheels on the other side of the same running gear is negative, and if the same conditions are met on the second running gear with a second given threshold, which may be the same as the first threshold or slightly less, e.g. 75% or 85%, the controller determines that crosswind has occurred and proceeds to step 103. Otherwise, the controller goes back to the monitoring step 101.

[0035] At step 103 the controller determines the windward side as the side of the vehicle on which the thresholds have been exceeded and proceeds to step 104 to implement the crosswind stability-oriented control strategy. At step 104, the controller starts phasing in the crosswind stability-oriented control strategy and simultaneously phasing out a comfort-oriented control strategy during a transition phase after detection of crosswind. The crosswind stability-oriented control strategy, includes sending control signals to the lateral actuators to move the vehicle body towards the windward side (i.e. the direction opposed to the wind) and to the vertical actuators to tilt the vehicle body towards the windward side.

[0036] According to a first embodiment, a maximum force is demanded from all lateral actuators in order to move the vehicle body towards the windward side (i.e. the direction opposed to the wind) and from the vertical

actuators to tilt the vehicle body towards the windward side.

[0037] According to a second embodiment, one of the lateral actuators on the leading running gear is used for the purpose of producing a maximum force while the control of the other lateral actuators is not changed. The vertical actuators are used in order to produce a maximum tilt.

[0038] According to a third embodiment, only the quasi-static components of the comfort-oriented control strategy is faded out, while the high frequency components of the comfort-oriented control strategy are retained and added to a quasi-static component of the crosswind stability-oriented control strategy, which may be the same as in the first or second embodiment above. As a variant, the lateral quasi-static component of the crosswind stability-oriented control strategy is split equally between the two lateral actuators on the leading running gear, while the dynamic component of the comfort-oriented control strategy is applied on one of the two lateral actuators only.

[0039] The deflection of the primary suspension is continuously monitored at step 105 while the crosswind stability-oriented control strategy is applied, to detect at step 106 whether the crosswind has ended. This will be the case e.g. if the normalised deflection on the windward side decreases below the first threshold mentioned above.

[0040] In such a case, the crosswind stability-oriented control strategy is phased out and the comfort-oriented control strategy is phased in again at step 107 during a transition phase which is preferably longer than the first transition phase.

[0041] The invention is not limited to the embodiments described so far. The number and location of the actuators can vary from one vehicle to another. In particular, there may be only one lateral actuator per running gear, or two lateral actuator per running gear. The running gears can be located at the ends of the vehicle body, or between two vehicle bodies of a multiple unit vehicle.

[0042] The rail vehicle can be equipped with one controller per car body or one controller per running gear.

Claims

1. A method for stabilising a rail vehicle comprising a vehicle body resting on two longitudinally spaced running gears (14, 16), each of the running gears (14, 16) comprising a running gear frame (14.1, 16.1), a primary suspension (14.2, 16.2) between the running gear frame (14.1, 16.1) and a set of wheels (14.3, 16.3), and a secondary suspension comprising one or more lateral actuators (14.4, 14.41, 16.4) between the running gear frame (14.1, 16.1) and the vehicle body (12), the method being **characterised in that** it comprises:

- processing signals from sensors (14.21, 16.21) directly or indirectly measuring a wheel unloading condition to detect a crosswind and a windward side;

- controlling at least one of the one or more lateral actuators (14.4, 14.41, 16.4) of at least one of the running gears (14, 16) to move the vehicle body (12) according to a stability-oriented control strategy towards the windward side in response to the detected crosswind.

2. The method of claim 1, **characterised in that** the sensors measure a vertical deflection and/or force of the primary suspension (14.2, 16.2).

3. The method of claim 1 or claim 2, **characterised in that** the signal processing includes computing a left-side loading value and a right-side loading value.

4. The method of claim 3, **characterised in that** the signal processing further includes comparing at least one of the left-side loading value and right-side loading value to a unloading threshold to decide an occurrence of crosswind.

5. The method of claim 4, wherein the unloading threshold is determined as a result of a previous processing of signals from the sensors (14.21, 16.21) in a static situation.

6. The method of any one of claims 3 to 5, **characterised in that** the signal processing further includes comparing the left-side loading value to a right-side loading value to determine a windward direction.

7. The method of any one of the preceding claims, **characterised in that** the signal processing includes filtering the signals with a low-pass filter, preferably a 1st order low-pass filter, preferably with a cut-off frequency between 0,1 and 4 Hz.

8. The method of any one of the preceding claims, **characterised in that** it includes controlling at least one of the one or more lateral actuators (14.4, 14.41, 16.4) of at least one of the running gears (14, 16) with a predetermined crosswind stability-oriented constant set value upon detection of the crosswind.

9. The method of claim 8, **characterised in that** the predetermined constant crosswind stability-oriented set value is a maximum force or deflection value of the lateral actuator (14.4, 14.41, 16.4).

10. The method of any one of the preceding claims, **characterised in that** it includes controlling at least one of the one or more lateral actuators (14.4, 14.41, 16.4) of at least one of the running gears (14, 16) with a set force or deflection value which is the sum

- of a predetermined crosswind stability-oriented constant mean value and of a superimposed dynamic value.
11. The method of any one of the preceding claims, wherein the secondary suspension of at least one of the running gears (14, 16) comprises left and right vertical actuators (14.5, 16.5), **characterised in that** the method includes controlling at least one of the vertical actuators (14.5, 16.5) of the secondary suspension to tilt the vehicle body towards the windward side in response to the detected crosswind.
12. The method of the preceding claim, **characterised in that** it includes lifting the vehicle body (12) on a leeward side of the vehicle (10) and lowering the vehicle body (12) on the windward side of the vehicle (10).
13. The method of any one claims 11 or 12, **characterised in that** it includes controlling at least one of the vertical actuators (14.5, 16.5) with a predetermined constant set value upon detection of the crosswind.
14. The method of claim 13, **characterised in that** the predetermined constant set value is a maximum force or deflection value of the vertical actuator (14.5, 16.5).
15. The method of any one claims 11 to 14, **characterised in that** it includes controlling at least one of the vertical actuators (14.5, 16.5) with a set force or deflection value which is the sum of a predetermined constant mean value and of a superimposed dynamic value.
16. The method of any one of the preceding claims, **characterised in that** it includes phasing in the crosswind stability-oriented control strategy and simultaneously phasing out a comfort-oriented control strategy in a first transition phase after detection of the crosswind.
17. The method of any one of the preceding claims, **characterised in that** it includes processing the signals from sensors measuring a vertical deflection and/or force of the primary suspension to detect an end of the crosswind.
18. The method of claim 17 and claim 3, **characterised in that** it includes comparing at least one of the left-side loading value and right-side loading value to a end-of-unloading threshold to detect the end of the crosswind.
19. The method of claim 18 and claim 4, **characterised in that** the end-of-unloading threshold is equal to the unloading threshold.
20. The method of any one of claims 17 to 19, **characterised in that** it includes phasing out the crosswind stability-oriented control strategy and simultaneously phasing in a comfort-oriented control strategy in a end-of-gust transition phase.
21. The method of any one of the preceding claims, **characterised in that** it includes processing stored data in combination with a positioning system and with the signals from sensors to detect the crosswind.
22. The method of any one of the preceding claims, wherein the rail vehicle is part of a set of rail vehicles, **characterised in that** it includes processing data from another rail vehicle of the set of rail vehicles in combination with the signals from sensors to detect the crosswind.
23. A rail vehicle (10) comprising a vehicle body (12) resting on two longitudinally spaced running gears (14, 16), each of the running gears (14, 16) comprising a running gear frame (14.1, 16.1), a primary suspension (14.2, 16.2) between the running gear frame and a set of wheels (14.3, 16.3), and a secondary suspension comprising one or more lateral actuators (14.4, 14.41, 16.4) between the running gear frame (14.1, 16.1) and the vehicle body (12), **characterised in that** it comprises sensors (14.21, 16.21) directly or indirectly measuring a wheel unloading and a controller (20) connected to the sensors (14.21, 16.21) and to the one or more lateral actuators (14.4, 14.41, 16.4) for stabilising the rail vehicle according to the control method of any one of the preceding claims.
24. The vehicle of claim 24, **characterised in that** the secondary suspension of at least one of the running gears (14, 16) includes at least two lateral actuators (14.4, 14.41).
25. The vehicle of claim 23 or claim 24, **characterised in that** the secondary suspension of at least one of the running gears (14, 16) includes left and right vertical actuators (14.5, 16.5).
26. The vehicle of any one of claims 23 to 25, **characterised in that** the sensors (14.21, 16.21) include deflection sensors for measuring a deflection of the primary suspension (14.2, 16.2)

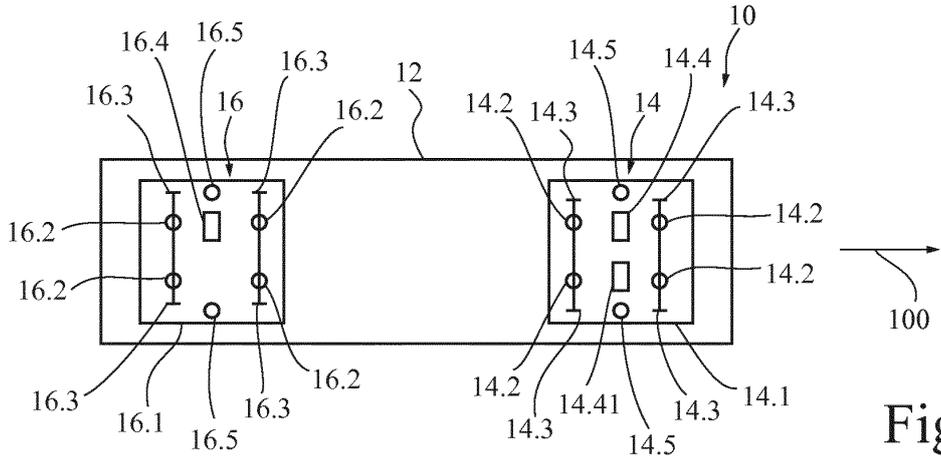


Fig.1

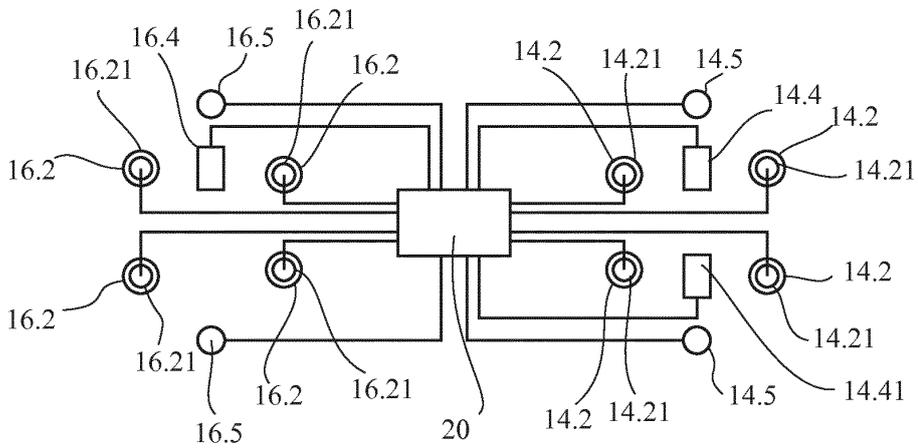


Fig.2

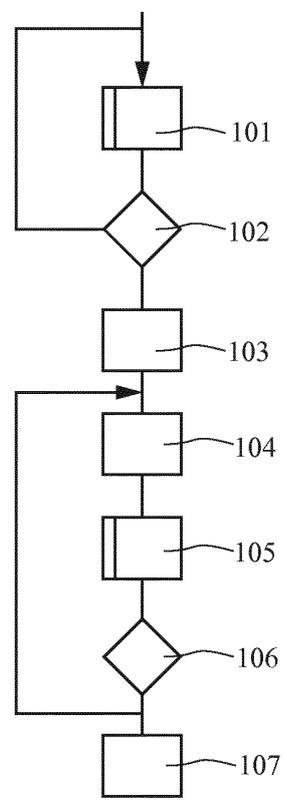


Fig.3



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Application Number
EP 13 19 2003

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The present search report has been drawn up for all claims			
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ANNEX TO THE EUROPEAN SEARCH REPORT
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