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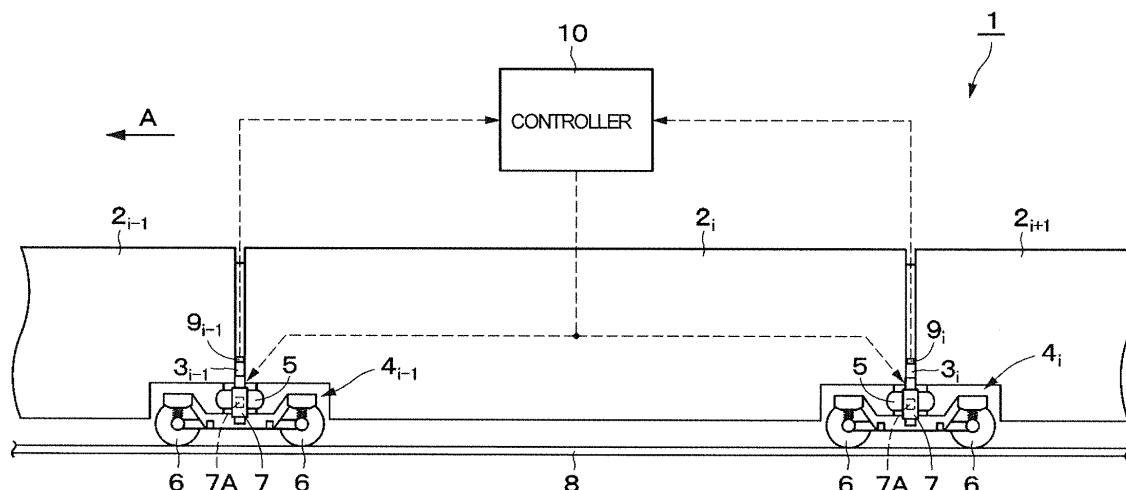
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(54) **Suspension control system**

(57) A vehicle body 2_i and a vehicle body 2_{i+1} are coupled to each other via a coupling portion 3_i . A bogie 4_i is disposed under the coupling portion 3_i , and a vertically movable damper 7 coupled to the bogie 4_i and the coupling portion 3_i is mounted on each of both lateral sides of the bogie 4_i . A damping force of the vertically movable damper 7 is controlled by an actuator 7A. An acceleration sensor 9_i for detecting a vertical vibration is

mounted at a position directly above the bogie 4_i . A controller 10 detects vibrations of the vehicle bodies 2_i and 2_{i+1} with use of detection signals from the acceleration sensors 9_{i-1} , 9_i , and 9_{i+1} , and calculates a number i bogie control force instruction u_i for the vertically movable damper 7 of the bogie 4_i in consideration of vibrations of all of the vehicle bodies 2_1 to 2_n .

Fig. 1



Description

[0001] The present invention relates to a suspension control system preferably used to reduce a vibration or the like of a railway train.

[0002] Railway trains that run on railway tracks less requiring a change in the number of connected vehicles may employ a method in which a bogie is disposed at a portion coupling vehicles to each other, and the adjacent two vehicle bodies are supported by the single bogie. Such a bogie is referred to as a coupling bogie (Jacobs bogie), and a railway train employing the coupling bogie is referred to as a coupling bogie train. The coupling bogie train has an advantage of facilitating a favorable design in terms of a vehicle's movement such as reducing a noise in a passenger vehicle because the bogie is located away from the passenger vehicle, lowering the vehicle's center of gravity, and raising the position where a secondary suspension is supported, compared to a railway train that is not the coupling bogie train.

[0003] Further, for example, Japanese Patent Application Public Disclosure No. 2012-76553 discusses an invention configured in such a manner that a cylinder apparatus such as a damping force adjustable shock absorber is provided between a vehicle body and a bogie of a railway train, and a damping force characteristic of the cylinder apparatus is variably controlled according to a control signal (a control current).

[0004] The configuration discussed in Japanese Patent Application Public Disclosure No. 2012-76553 is applied to the railway train that is not the coupling bogie train. In the railway train that is not the coupling bogie train, vehicle bodies are flexibly coupled to each other so as to be vertically displaceable relative to each other therebetween. Therefore, a vertical vibration of the vehicle body is less affected by a vertical vibration of the adjacent vehicle body. Further, vertically movable dampers of bogies disposed at front and rear sides are connected to only their own vehicle body. Therefore, the vibration of the vehicle body can be reduced by controlling the vertically movable dampers to generate damping forces for damping the vibration of only their own vehicle body.

[0005] On the other hand, in the coupling bogie train, the vehicle bodies are inflexibly coupled to each other by a connection portion (coupling portion) so as to be unable to be vertically displaced relative to each other therebetween, and a vertical vibration of the vehicle body is highly affected by a vertical vibration of the adjacent vehicle body. Therefore, all vehicle bodies coupled by coupling bodies are influentially linked to one another, and vertically movable dampers should be in charge of absorption of vibrations of these vehicle bodies. As a result, there is raised such a problem that only controlling the vertically movable damper to generate a damping force for reducing a vibration of its own vehicle body, like the conventional technique, cannot sufficiently reduce the vibration of the vehicle body actually.

[0006] The present invention has been contrived in consideration of the above-described problem with the conventional technique, and an object thereof is to provide a suspension control system capable of reducing a vibration of the coupling bogie train.

[0007] To achieve the above-described object, according to an aspect of the present invention, a suspension control system includes a coupling portion configured to couple at least two vehicle bodies and connect a first vehicle body and a second vehicle body adjacent to each other in such a manner that a driving force can be transmitted therebetween, a coupling bogie configured to provide a support on at least a second vehicle body side of the first vehicle body via a spring member, a cylinder apparatus disposed between the coupling bogie and the first vehicle body and configured to exert an application force adjustable by an actuator, a controller configured to control the actuator, a first vibration detector configured to detect a vibration of the first vehicle body, and a second vibration detector configured to detect a vibration of the second vehicle body. The controller calculates an instruction value for the actuator based on a detection value of the first vibration detector and a detection value of the second vibration detector.

[0008] According to the present invention, it is possible to reduce a vibration of the coupling bogie train.

Fig. 1 is a front view illustrating a railway train that employs a suspension control system according to a first embodiment of the present invention.

Fig. 2 schematically illustrates the railway train according to the first embodiment.

Fig. 3 illustrates a positional relationship among a coupling portion, a bogie, a vertically movable damper, and the like illustrated in Fig. 1.

Fig. 4 is a block diagram illustrating a controller according to the first embodiment.

Fig. 5 illustrates a pitching mode of vehicle bodies.

Fig. 6 illustrates a bouncing mode of the vehicle bodies.

Fig. 7 illustrates a mode generated by combining the pitching mode and bouncing mode of the vehicle bodies.

Fig. 8 illustrates a model generated to simulate the railway train according to the first embodiment.

Fig. 9 illustrates a coupling force between a bogie corresponding to a bogie number i thereto and the vehicle body.

Fig. 10 illustrates a traction force applied to a rear side of a number i vehicle body.

Fig. 11 illustrates a force applied in a direction for preventing a relative rotation between the i -th vehicle body and an $i+1$ -th vehicle body.

Fig. 12 illustrates a force generated by the relative rotation between the i -th vehicle body and the $i+1$ -th vehicle body.

Fig. 13 schematically illustrates a railway train according to a first modification.

Fig. 14 schematically illustrates a railway train according to a second embodiment.

Fig. 15 is a block diagram illustrating a controller according to the second embodiment.

Fig. 16 illustrates characteristic lines that indicate PSD of bouncing of the vehicle body.

Fig. 17 illustrates characteristic lines that indicate PSD of pitching of the vehicle body.

Fig. 18 is a block diagram illustrating a controller according to a third embodiment.

Fig. 19 is a block diagram illustrating a controller according to a fourth embodiment.

Fig. 20 is a block diagram illustrating a controller according to a fifth embodiment.

Fig. 21 is a block diagram illustrating a controller according to a sixth embodiment.

Fig. 22 illustrates a traction force applied to a passenger vehicle while the railway train is running on an ascending slope track

Fig. 23 schematically illustrates a railway train according to a seventh embodiment.

Fig. 24 schematically illustrates a railway train according to a second modification.

Fig. 25 schematically illustrates a railway train according to a third modification.

Fig. 26 schematically illustrates a railway train according to a fourth modification.

Fig. 27 schematically illustrates a railway train according to an eighth embodiment.

Fig. 28 is a block diagram illustrating a controller according to the eighth embodiment.

Fig. 29 is a block diagram illustrating a controller according to a ninth embodiment.

Fig. 30 illustrates a virtual railway train.

Fig. 31 schematically illustrates a railway train according to a tenth embodiment.

Fig. 32 is a block diagram illustrating a controller according to the tenth embodiment.

Fig. 33 schematically illustrates a railway train according to an eleventh embodiment.

Fig. 34 is a block diagram illustrating a controller according to the eleventh embodiment.

Fig. 35 schematically illustrates a railway train according to a fifth modification.

Fig. 36 is a block diagram illustrating a controller according to a twelfth embodiment.

Fig. 37 schematically illustrates a railway train according to a sixth modification.

[0009] In the following description, suspension control systems according to embodiments of the present invention will be described in detail with reference to the accompanying drawings.

[0010] Figs. 1 to 4 illustrate a first embodiment of the present invention. Referring to Figs. 1 and 2, a railway train 1 includes a vehicle body 2_i , a coupling portion 3_i , a bogie 4_i , vertically movable dampers 7, an acceleration sensor 9_i , a controller 10, and the like. The railway train 1 is a coupling bogie train using coupling bogies by which, for example, n vehicle bodies 2_1 to 2_n are coupled to one another. Such coupling bogies are used for, for example, 50000 series trains provided by Odakyu Electric Railway Co., Ltd., and 300 series trains provided by Enoshima Electric Railway Co., Ltd.

[0011] For example, passages and crews are aboard on the vehicle body 2_i . Further, a vehicle body 2_{i-1} is adjacently disposed in front of the vehicle body 2_i , and a vehicle bogie 2_{i+1} is adjacently disposed behind the vehicle body 2_i . Therefore, a vehicle body 2_1 is the foremost vehicle body and a vehicle body 2_n is the last vehicle body of the railway train 1 (coupling bogie train) having the n vehicles. Hereinafter, the term "vehicle body 2_i " will be used to refer to any one of the vehicle bodies 2_1 to 2_n .

[0012] The coupling portion 3_i couples the vehicle body 2_i and the vehicle body 2_{i+1} in such a manner that a driving force can be transmitted therebetween. The coupling portion 3_i couples the vehicle body 2_i and the vehicle body 2_{i+1} by a not-illustrated rubber bush or mechanical link mechanism. As a result, the coupling portion 3_i allows the vehicle body 2_i and the vehicle body 2_{i+1} to be bent therebetween to the left or right relative to a traveling direction when the railway train 1 is running on a curved track, and to be bent therebetween in a vertical direction of the railway train 1 when the railway train 1 is entering a slope track.

[0013] Further, the coupling portion 3_i is disposed behind the vehicle body 2_i , and a coupling portion 3_{i-1} is disposed in front of the vehicle body 2_i . Therefore, if the railway train 1 has, for example, n vehicles, a coupling portion 3_1 is disposed between the vehicle body 2_1 as a number 1 vehicle body and a vehicle body 2_2 as a number 2 vehicle body, and a coupling portion 3_{n-1} is disposed between a vehicle body 2_{n-1} as a number $n-1$ vehicle body and the number n vehicle body 2_n as the last vehicle body. Hereinafter, the term "coupling portion 3_i " will be used to refer to any one of the coupling portions 3_1 to 3_{n-1} .

[0014] The coupling portion 3_i couples the vehicle body 2_i and the vehicle body 2_{i+1} in such a manner that they are displaced vertically in a same phase by a substantially same amount. In other words, the vehicle body 2_i and the vehicle body 2_{i+1} are vertically inflexibly coupled to each other based on the coupling portion 3_i . Therefore, the vehicle body 2_i and the vehicle body 2_{i+1} are vertically displaced at the position of the coupling portion 3_i together with each other. It is desirable that the vehicle body 2_i and the vehicle body 2_{i+1} are vertically inflexibly coupled to each other by the coupling portion 3_i , i.e., they are coupled to each other so as to be unable to be vertically displaced relative to each other, but they may be allowed to have a slight vertical relative displacement therebetween.

[0015] The bogie 4_i is disposed under the vehicle body 2_i or the coupling portion 3_i . Bogies 4_1 to 4_{n-1} each are a coupling bogie that supports two vehicles such as the vehicle body 2_i and the vehicle bogie 2_{i+1} , and are disposed under the coupling portions 3_1 to 3_{n-1} , respectively. Further, a bogie 4_0 is disposed under the front side of the foremost vehicle body 2_1 , and the bogie 4_n is disposed under the rear side of the last vehicle body 2_n . These bogies 4_0 and 4_n each support only a single vehicle such as the vehicle body 2_1 or 2_n . Hereinafter, the term "bogie 4_i " will be used to refer to any one of the bogies 4_0 to 4_n .

[0016] As illustrated in Figs. 1 to 3, the bogie 4_i includes pneumatic springs 5, vehicle wheels 6, the vertically movable dampers 7, a traction link (not illustrated), and the like. The bogies 4_0 and 4_n are connected to the vehicle bodies 2_1 and 2_n with use of the traction links. The bogies 4_1 to 4_{n-1} are connected to the coupling portions 3_1 to 3_{n-1} with use of the traction links. The bogie 4_i includes, for example, two axles having the vehicle wheels 6 at both left and right ends thereof, thereby including four vehicle wheels 6 in total. The respective vehicle wheels 6 rotate on left and right rails 8 (only one of them is illustrated), by which the railway train 1 is driven to run along the rails 8, for example, in a direction indicated by an arrow A when being traveling forward.

[0017] The pneumatic spring 5 is a spring member of the present invention, and corresponds to a secondary suspension mounted on the bogie 4_i . The pneumatic springs 5 are, for example, disposed on both sides of the bogie 4_i in a lateral direction, and vertically elastically support the coupling portions 3_1 to 3_{n-1} and the vehicle bodies 2_1 and 2_n relative to the bogie 4_i . These pneumatic springs 5 reduce a vertical vibration between the bogie 4_i and the coupling portions 3_1 to 3_{n-1} and the vehicle bodies 2_1 and 2_n .

[0018] Further, the traction link transmits a traction force and a braking force applied in a longitudinal direction between the bogie 4_i and the coupling portions 3_1 to 3_{n-1} and the vehicle bodies 2_1 and 2_n . The traction link is realized with use of a rubber bush or the like so as to allow the coupling portions 3_1 to 3_{n-1} and the vehicle bodies 2_1 and 2_n to be displaced (moved) relative to the bogie 4_i vertically, laterally, in a yawing direction (when the bogie rotates), and in a pitching direction.

[0019] The vertically movable dampers 7 are respectively mounted on the right and left sides of the bogie 4_i between the vehicle bodies 2_i and 2_n and the bogies 4_0 and 4_n or the coupling portions 3_1 to 3_{n-1} and the bogies 4_1 to 4_{n-1} . The vertically movable dampers 7 are connected via, for example, rubber bushes to the coupling portions 3_1 to 3_{n-1} or the vehicle bodies 2_i and 2_n , and the bogie 4_i , respectively. Each of these vertical movable dampers 7 corresponds to a cylinder apparatus configured to exert an individually adjustable damping force serving as an application force (for example, a damping force adjustable hydraulic shock absorber called a semi-active damper), and includes a damping force generation mechanism (not illustrated) that generates the damping force by controlling a flow of hydraulic fluid in the cylinder apparatus.

[0020] The damping force generation mechanism includes an actuator 7A that generates the damping force by controlling the flow of the hydraulic fluid in the cylinder apparatus. This actuator 7A includes, for example, a flow amount control valve, and continuously adjusts a characteristic of the generated damping force (a damping force characteristic) from a hard characteristic to a soft characteristic. More specifically, the actuator 7A includes, for example, a current control type proportional solenoid valve. Then, the vertically movable damper 7 can adjust the damping force characteristic according to a current value supplied to the actuator 7A. The actuator 7A for adjusting the damping force does not necessarily have to adjust the damping force characteristic continuously, and may adjust the damping force through two steps or a plurality of steps.

[0021] Then, the vertically movable damper 7 adjusts the damping force characteristic to an arbitrary characteristic between the hard characteristic and the soft characteristic to reduce a vibration of the vehicle body 2_i . More specifically, a control signal (an instruction current) is supplied from the controller 10, which will be described below, to the actuator 7A according to a number i bogie control force instruction u_i to reduce pitching and bouncing of the vehicle body 2_i , and the damping force of the vertically movable damper 7 is variably controlled according to the control signal. As a result, the vertically movable damper 7 generates a control force for reducing a vertical vibration of the vehicle body 2_i .

[0022] The acceleration sensor 9_i is mounted at each of the coupling portions 3_1 to 3_{n-1} and the vehicle bodies 2_1 and 2_n . More specifically, the acceleration sensors 9_1 to 9_{n-1} are disposed at the coupling portions 3_1 to 3_{n-1} at positions corresponding to the bogies 4_1 to 4_{n-1} , when viewing from above, and detect vertical accelerations a_1 to a_{n-1} of the coupling portions 3_1 to 3_{n-1} . The acceleration sensor 9_0 is disposed on the front side of the vehicle body 2_1 as a position corresponding to the bogie 4_0 , and detects a vertical acceleration a_0 of the vehicle body 2_1 at the position of the bogie 4_0 . The acceleration sensor 9_n is disposed on the rear side of the vehicle body 2_n as a position corresponding to the bogie 4_n , and detects a vertical acceleration a_n of the vehicle body 2_n at the position of the bogie 4_n . These acceleration sensors 9_0 to 9_n detect the vertical accelerations a_0 to a_n of the coupling portions 3_1 to 3_{n-1} and the vehicle bodies 2_1 and 2_n directly above the bogies 4_0 to 4_n , and outputs detection signals according to these accelerations a_0 to a_n . Hereinafter, the term "acceleration sensor 9_i " will be used to refer to any one of the acceleration sensors 9_0 to 9_n .

[0023] For example, suppose that the vehicle body 2_i is a first vehicle body, and the vehicle body 2_{i+1} adjacently disposed behind the vehicle body 2_i is a second vehicle body. In this case, the acceleration sensor 9_{i+1} and the acceleration sensor 9_i correspond to a first vibration detector configured to detect a vibration of the vehicle body 2_i together with a number i vehicle body vibration calculation unit 12_i of the controller 10, which will be described below. Further, the

acceleration sensor 9_i and the acceleration sensor 9_{i+1} correspond to a second vibration detector configured to detect a vibration of the vehicle body 2_{i+1} together with a number $i+1$ vehicle body vibration calculation unit 12_{i+1} of the controller 10. In this manner, the acceleration sensor 9_i corresponds to a part of the first and second vibration detectors. The second vehicle body does not necessarily have to be a vehicle body disposed behind the first vehicle body, and may be disposed in front of the first vehicle body.

[0024] The controller 10 includes, for example, a microcomputer, and the acceleration sensor 9_i is connected to an input side of the controller 10. Further, the actuators 7A of the vertically movable dampers 7 of each bogie 4_i are connected to an output side of the controller 10. Then, the controller 10 generates the number i bogie control force instruction u_i , which serves as a damping force instruction signal for the vertically movable dampers 7 of each bogie 4_i based on a detection signal from the acceleration sensor 9_i , thereby variably controlling the damping forces of the vertically movable dampers 7.

[0025] As illustrated in Fig. 4, the controller 10 includes a preprocessing unit (not illustrated) that includes an AD converter, a filter processor, and the like, and acquires the acceleration a_i from the detection signal of the acceleration sensor 9_i . The controller 10 further includes a vibration control unit 11 that outputs the number i bogie control force instruction u_i according to instruction values for the actuators 7A based on the acceleration a_i .

[0026] The vibration control unit 11 includes the number i vehicle body vibration calculation unit 12_i that calculates the vibration of the vehicle body 2_i based on the acceleration a_i , which is the detection value of the acceleration sensor 9_i , and a control force instruction calculation unit 13 that calculates the number i bogie control force instruction u_i for the vertically movable dampers 7 of each bogie 4_i based on the vibration of the vehicle body 2_i calculated by the number i vehicle body vibration calculation unit 12_i . In this case, the number i vehicle body vibration calculation unit 12_i calculates the vibration of the vehicle body 2_i based on the detection signal from the acceleration sensor 9_{i-1} and the detection signal from the acceleration sensor 9_i . Therefore, the vibration control unit 11 includes a number 1 vehicle body vibration calculation unit 12_1 to a number n vehicle body vibration calculation unit 12_n corresponding to the n vehicle bodies 2_1 to 2_n . Hereinafter, the term "number i vehicle body vibration calculation unit 12_i " will be used to refer to any one of the number 1 vehicle body vibration calculation unit 12_1 to the number n vehicle body vibration calculation unit 12_n .

[0027] The control force instruction calculation unit 13 calculates the number i bogie control force instruction u_i according to a control law, which will be described below. Then, the number i bogie control force instruction u_i calculated by the control force instruction calculation unit 13 is input into a number i bogie current output unit 14_i , and the number i bogie current output unit 14_i supplies instruction currents according to the number i bogie control force instruction u_i to the actuators 7A of the vertically movable dampers 7 of the bogie 4_i . This results in a reduction in a vibration of the vehicle body 2_i due to pitching and bouncing, thereby succeeding in improving the ride comfort of the vehicle body 2_i . Hereinafter, the term "number i bogie current output unit 14_i " will be used to refer to any of a number 0 bogie current output unit 14_0 to a number n bogie current output unit 14_n . A possible simplest configuration to realize this control is such a configuration that the acceleration sensor is disposed directly above the coupling portion of the vehicle body side to acquire a vertical acceleration of the vehicle body directly above the coupling portion, and the vertically movable damper directly below the coupling portion is controlled so as to reduce a change in the acceleration. However, this configuration can provide only a small effect of improving the ride comfort, because a motion mode such as pitching and bouncing of the vehicle body is not taken into consideration in this configuration.

[0028] A concept of a vibration mode of the vehicle body 2_i in the railway train 1 will be described. Fig. 5 illustrates a concept of a pitching mode of the vehicle body 2_i . Further, Fig. 6 illustrates a concept of a bouncing mode of the vehicle body 2_i . Fig. 7 illustrates a concept of a mode of the vehicle body 2_i , which is generated by combining the bouncing vehicle bodies 2_{i-1} and 2_{i+1} and the pitching vehicle body 2_i . Figs. 5 to 7 illustrate the bouncing mode and the pitching mode respectively independently, but these modes are combined in the vehicle body 2_i in actual use.

[0029] The railway train 1 configured in the above-described manner controls the damping forces of the vertically movable dampers 7 of each bogie 4_i based on the output of the acceleration sensor 9_i according to the control law that will be described next.

[0030] To calculate the damping force instruction (the number i bogie control force instruction u_i) by the controller 10, a model of the single vehicle body 2_i is formulated with the bouncing mode and the pitching mode set as two degrees of freedom, and the control law for the train having n vehicles is developed with use of a $4 \times n$ -degree state equation with $2 \times n$ degrees of freedom set thereto.

[0031] A method for calculating the state equation will be described. Fig. 8 illustrates a model generated to simulate the railway train 1 according to the present embodiment. The left side in Fig. 8 corresponds to the traveling direction A of the present model. An X axis, a Z axis, and a Y axis are set so as to represent the traveling direction A (a forward direction), the vertical direction of the vehicle body 2_i , and the lateral direction of the vehicle body 2_i , respectively (refer to Fig. 3). The present model is established ignoring an elastic vibration of the vehicle body 2_i and assuming that both the vehicle body 2_i and the bogie 4_i are rigid bodies.

[0032] Main symbols used in this model will be described in a table 1. Unless otherwise indicated, i represents a number of a vehicle body, and the bogie number i is assigned to the bogie 4_i disposed behind the number i vehicle body.

Therefore, the bogie 4₁ disposed behind the number 1 vehicle body has a bogie number 1, and the bogie 4₀ disposed in front of the number 1 vehicle body has a bogie number 0.

[0033] Further, a dot in equations represents first-order differentiation (d/dt) by time t. Two dots represent second-order differentiation (d²/dt²). Further, suppose that all of the vehicle bodies 2₁ to 2_n have equal lengths ($L_1 = L_2 = \dots = L_n = L$), and the pneumatic springs 5 have equal stiffnesses on all of the bogies 4₁ to 4_n ($k_1 = k_2 = \dots = k_n = k$).

[Table 1]

SYMBOL	QUANTITY REPRESENTED BY SYMBOL
m _i	Mass of Number i Vehicle Body(kg)
n	Number of Vehicles (vehicles)
L _i	Length of Vehicle Body (m)
u _i	Force to be Generated by Vertically Movable Dampers of Number i Bogie (N) (Sum of Control Forces for Vertically Movable Dampers on Left and Right Sides of Bogie)
k _i	Stiffness of Pneumatic Springs (Secondary Suspensions) of Number i Bogie (N/m) (Sum of Stiffnesses of Pneumatic Springs on Left and Right Sides of Bogie)
c _r	Damping Force against Relative Rotation between Vehicle Bodies ((N•m)/(rad/s))
k _r	Stiffness against Relative Rotation between Vehicle Bodies ((N•m)/rad)
z _{Bi}	Vertical Displacement of Center of Number i Vehicle Body (m); Positive in Upward Direction
x _{Bi}	Longitudinal Displacement of Center of Number i Vehicle Body (m); Positive in Forward Direction
θ _i	Pitching Angle of Number i Vehicle Body (rad); Positive When Vehicle Body is Plunging Forward
z _{Ti}	Vertical Displacement of Number i Bogie (m); Positive in Upward Direction
F _i	Coupling Force between Number i Bogie and Vehicle Body (N); Positive in Upward Direction
T _i	Traction Force Applied to Rear Side of Number i Vehicle Body (Directly Above Number i Bogie) (N); Positive in Backward Direction
F _{ri}	Force Generated by Relative Rotation between Vehicle Bodies (N); Positive in Upward Direction
I	Inertia Moment in Pitching Direction of Number i Vehicle Body

[0034] Further, the number i vehicle body vibration calculation unit 12_i calculates a vertical acceleration (d²z_{Bi}/dt²) at a central position of the vehicle body 2_i as the vibration of the vehicle body 2_i based on an equation 1, and a pitching angular acceleration (d²θ_i/dt²) based on an equation 2. The equations 1 and 2 are expressed as follows.

[Equation 1]

$$\ddot{z}_{Bi} = \frac{a_i + a_{i-1}}{2}$$

[Equation 2]

$$\ddot{\theta}_i = \frac{a_i - a_{i-1}}{L_i} = \frac{a_i - a_{i-1}}{L}$$

[0035] All of the number 1 vehicle body vibration calculation unit 12₁ to the number n vehicle body vibration calculation unit 12_n perform similar calculations. For example, if the vehicle body 2_i is the first vehicle body, and the vehicle body 2_{i+1} is the second vehicle body, the acceleration (d²z_{Bi}/dt²) and the pitching angular acceleration (d²θ_i/dt²) correspond to a vibration of the first vehicle body (the vehicle body 2_i), and the acceleration (d²z_{Bi+1}/dt²) and the pitching angular acceleration (d²θ_{i+1}/dt²) correspond to a vibration of the second vehicle body (the vehicle body 2_{i+1}).

[0036] The number i vehicle body vibration calculation unit 12_i can calculate a vertical speed (dz_{Bi}/dt) and the vertical displacement z_{Bi} at the central position of the vehicle body 2_i based on the acceleration (d²z_{Bi}/dt²), and calculate a

pitching angular speed ($d\theta_i/dt$) and the pitching angle θ_i at the central position of the vehicle body 2_i based on the pitching angular acceleration ($d^2\theta_i/dt^2$) by performing an integral calculation or the like.

[0037] Next, the coupling force F_i , the traction force T_i , and the force F_{ri} generated by a relative rotation of the number i vehicle body are expressed as equations in the following manner. The coupling force F_i is a coupling force between the bogie 4_i corresponding to the bogie number i (the number i bogie) and the vehicle body 2_i . The traction force T_i is a traction force applied to the rear side of the number i vehicle body (directly above the bogie 4_i corresponding to the bogie number i). The force F_{ri} generated by a relative rotation is a force generated by a relative rotation between the vehicle body 2_i and the vehicle body 2_{i+1} .

[0038] The coupling force F_i between the bogie 4_i corresponding to the bogie number i and the vehicle body 2_i is expressed as illustrated in Fig. 9. In this case, the vertical coupling force F_i between the vehicle body 2_i and the bogie 4_i is calculated by the following equation as a sum of tensional forces of the pneumatic springs 5 and the damping forces of the vertically movable dampers 7.

[Equation 3]

$$F_i = -k \left\{ \left(z_{Bi} + \frac{L}{2} \sin \theta_i \right) - z_{Ti} \right\} - u_i$$

[0039] The coupling force F_i applied to the coupling portion 3_i (connection portion) between the number i vehicle body and the number $i+1$ vehicle body can be expressed in the following manner with use of a force $f_i(i)$ applied to the rear end of the number i vehicle body 2_i and a force $f_i(i+1)$ applied to the front end of the number $i+1$ vehicle body 2_{i+1} . In the following equation, $f_a(b)$ represents a component force of a force applied to a coupling portion 3_a corresponding to a bogie number a that is applied to a b -th vehicle body 2_b .

[Equation 4]

$$F_i = f_i(i) + f_i(i+1)$$

[0040] In this equation, $f_0(0) = 0$, $f_n(n+1) = 0$

[0041] Next, the traction force T_i applied to the rear side of the number i vehicle body (directly above the bogie 4_i corresponding to the bogie number i) is expressed as illustrated in Fig. 10. In this case, the traction force T_i applied to the number i vehicle body 2_i (directly above the bogie 4_i corresponding to the bogie number i) is calculated by an equation 5 from a longitudinal inertia force of the vehicle body 2_{i+1} when the vehicle body 2_i is accelerating forward. The equation 5 is formulated ignoring a rolling friction.

[Equation 5]

$$T_i = - \left(\sum_{k=i+1}^n m_k \right) \ddot{x}_{Bi}$$

[0042] In this equation, $T_n = 0$

[0043] In this case, assuming that T_{zi} represents a Z-direction component of the traction force T_i , the Z-direction component T_{zi} can be expressed by the following equation, an equation 6.

[Equation 6]

$$T_{zi} = -T_i \sin \theta_{i+1}$$

[0044] In a multiple-unit system railway train, each vehicle body 2_i has a power source, and the traction force T_i is not generated between the vehicle bodies 2_i and 2_{i+1} so that T_{zi} is zero regardless of whether the train is running on an ascending slope track or is accelerating. Further, if a brake is mounted in each bogie 4_i , it is possible to assume that T_{zi}

is zero when the railway train is slowing down regardless of the railway train is a push-pull system or a multiple-unit system. In other words, T_{zi} is not zero only when a push-pull system railway train is running on an ascending slope track or is accelerating.

[0045] Next, the force F_{ri} generated by a relative rotation between the vehicle body 2_i and the vehicle body 2_{i+1} is expressed as illustrated in Fig. 12. As illustrated in Fig. 11, when the number i vehicle body is moving in the pitching mode, a force working in a direction for reducing the relative rotation between the number i vehicle body 2_i and the number $i+1$ vehicle body 2_{i+1} by a spring component k_r and a damping component C_r is expressed as a sum of a force $f_{ri-1}(i)$ applied to the front end of the number i vehicle body (the coupling portion 3_{i-1} of the bogie 4_{i-1} corresponding to the bogie number $i-1$) perpendicularly to the vehicle body 2_i , and a force $f_{ri+1}(i+1)$ applied to the rear end of the number $i+1$ vehicle body (the coupling portion 3_{i+1} of the bogie 4_{i+1} corresponding to the bogie number $i+1$) perpendicularly to the vehicle body 2_{i+1} , around the coupling portion 3_i between the number i vehicle body and the number $i+1$ vehicle body. Then, $f_{ra}(b)$ represents a component force of the force applied to the coupling portion 3_a corresponding to the bogie number a that is applied to the b -th vehicle body 2_b . In this case, the forces $f_{ri-1}(i)$ and $f_{ri+1}(i+1)$ are expressed by the following equation.

[Equation 7]

$$f_{ri-1}(i) = f_{ri+1}(i+1) = \frac{1}{L} \left[-k_r(\theta_{i+1} - \theta_i) - c_r(\dot{\theta}_{i+1} - \dot{\theta}_i) \right]$$

[0046] Therefore, the force F_{ri} generated by a relative rotation between the vehicle bodies is calculated by an equation 8.

[Equation 8]

$$F_{ri} = \cos\left(\frac{\theta_{i+1} - \theta_i}{2}\right) f_{ri}(i) + \cos\left(\frac{\theta_{i+1} - \theta_i}{2}\right) f_{ri}(i+1)$$

$$f_{ri}(i) = -k_{rr}(\theta_i - \theta_{i-1}) - c_{rr}(\dot{\theta}_i - \dot{\theta}_{i-1})$$

$$f_{ri}(i+1) = -k_{rr}(\theta_{i+2} - \theta_{i+1}) - c_{rr}(\dot{\theta}_{i+2} - \dot{\theta}_{i+1})$$

[0047] In this equation, $k_{rr} = \frac{1}{L} k_r$, $c_{rr} = \frac{1}{L} c_r$

[0048] The pitching angle θ_i is sufficiently small at the vehicle body 2_i of the railway train 1 so that this is approximated in the following manner.

[Equation 9]

$$\sin \theta_i \doteq \theta_i, \quad \cos\left(\frac{\theta_{i+1} - \theta_i}{2}\right) \doteq 1$$

[0049] Further, suppose that the railway train 1 runs on a flat land at a constant speed. Therefore, assume that an acceleration in the longitudinal direction is not generated ($d^2x_{B1}/dt^2=0$), and the Z-direction component T_{zi} is also not generated ($T_{zi} = 0$) at the center of the vehicle body 2_i . In this case, a vertical motion equation of the vehicle body 2_i is expressed by an equation 10. Further, a rotational motion equation of the vehicle body 2_i is expressed by an equation 11.

[Equation 10]

$$\begin{aligned}
mi\ddot{z}_{Bi} &= \frac{1}{2}(F_i + F_{i-1} + T_{zi} + T_{zi-1} + F_{ri} + F_{ri-1}) \\
&= \frac{1}{2} \left\{ -k \left\{ \left(z_{Bi} + \frac{L}{2} \theta_i \right) - z_{Ti} \right\} - u_i - k \left\{ \left(z_{Bi-1} + \frac{L}{2} \theta_{i-1} \right) - z_{Ti-1} \right\} - u_{i-1} + 0 + 0 + \right. \\
&\quad - k_{\pi} (\theta_i - \theta_{i-1}) - c_{\pi} (\dot{\theta}_i - \dot{\theta}_{i-1}) - k_{\pi} (\theta_{i+2} - \theta_{i+1}) - c_{\pi} (\dot{\theta}_{i+2} - \dot{\theta}_{i+1}) \\
&\quad \left. - k_{\pi} (\theta_{i-1} - \theta_{i-2}) - c_{\pi} (\dot{\theta}_{i-1} - \dot{\theta}_{i-2}) - k_{\pi} (\theta_{i+1} - \theta_i) - c_{\pi} (\dot{\theta}_{i+1} - \dot{\theta}_i) \right\} \\
&= \frac{1}{2} \left\{ -k \left\{ \left(z_{Bi} + \frac{L}{2} \theta_i \right) - z_{Ti} \right\} - u_i - k \left\{ \left(z_{Bi-1} + \frac{L}{2} \theta_{i-1} \right) - z_{Ti-1} \right\} - u_{i-1} \right. \\
&\quad \left. - k_{\pi} (\theta_{i+2} - \theta_{i-2}) - c_{\pi} (\dot{\theta}_{i+2} - \dot{\theta}_{i-2}) \right\}
\end{aligned}$$

[Equation 11]

$$\begin{aligned}
I_i \ddot{\theta}_i &= -\frac{L}{2} \left[\frac{1}{2} (F_{i-1} + T_{zi-1} + F_{ri-1}) \right] + \frac{L}{2} \left[\frac{1}{2} (F_i + T_{zi} + F_{ri}) \right] \\
&= -\frac{L}{2} \left[\frac{1}{2} \left\{ -k \left\{ \left(z_{Bi-1} + \frac{L}{2} \theta_{i-1} \right) - z_{Ti-1} \right\} - u_{i-1} + 0 - k_{\pi} (\theta_{i-1} - \theta_{i-2}) \right. \right. \\
&\quad \left. \left. - c_{\pi} (\dot{\theta}_{i-1} - \dot{\theta}_{i-2}) - k_{\pi} (\theta_{i+1} - \theta_i) - c_{\pi} (\dot{\theta}_{i+1} - \dot{\theta}_i) \right\} \right] \\
&\quad + \frac{L}{2} \left[\frac{1}{2} \left\{ -k \left\{ \left(z_{Bi} + \frac{L}{2} \theta_i \right) - z_{Ti} \right\} - u_i + 0 - k_{\pi} (\theta_i - \theta_{i-1}) \right. \right. \\
&\quad \left. \left. - c_{\pi} (\dot{\theta}_i - \dot{\theta}_{i-1}) - k_{\pi} (\theta_{i+2} - \theta_{i+1}) - c_{\pi} (\dot{\theta}_{i+2} - \dot{\theta}_{i+1}) \right\} \right] \\
&= \frac{L}{4} \left[k \left\{ \left(z_{Bi-1} + \frac{L}{2} \theta_{i-1} \right) - z_{Ti-1} \right\} + u_{i-1} - k \left\{ \left(z_{Bi} + \frac{L}{2} \theta_i \right) - z_{Ti} \right\} - u_i \right. \\
&\quad \left. - k_{\pi} (\theta_{i+2} - 2\theta_{i+1} + 2\theta_i - 2\theta_{i-1} + \theta_{i+2}) \right. \\
&\quad \left. - c_{\pi} (\dot{\theta}_{i+2} - 2\dot{\theta}_{i+1} + 2\dot{\theta}_i - 2\dot{\theta}_{i-1} + \dot{\theta}_{i+2}) \right]
\end{aligned}$$

[0050] Then, the following state equation, which has $4 \times n$ state amounts, $n+1$ disturbance inputs, and $n+1$ control inputs, can be derived from these motion equations.

[Equation 12]

$$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{B}_1\mathbf{w} + \mathbf{B}_2\mathbf{u}$$

[0051] In this equation, a state vector $\mathbf{x}$, a disturbance input $\mathbf{w}$, and a control input $\mathbf{u}$ (the number i bogie control force instruction u_i) have the following contents, respectively.

[Equation 13]

<STATE VECTOR>

$$\mathbf{x} = [\dot{z}_{B1} \ \dot{z}_{B2} \ \cdots \ \dot{z}_{Bn} \ z_{B1} \ z_{B2} \ \cdots \ z_{Bn} \ \dot{\theta}_1 \ \dot{\theta}_2 \ \cdots \ \dot{\theta}_n \ \theta_1 \ \theta_2 \ \cdots \ \theta_n]^T$$

[Equation 14]

<DISTURBANCE INPUT>

$$\mathbf{w} = [z_{T0} \ z_{T1} \ \cdots \ z_{Tn}]^T$$

[Equation 15]

<CONTROL INPUT>

$$\mathbf{u} = [u_0 \ u_1 \ \cdots \ u_n]^T$$

[0052] Subsequently, the control law is developed with use of this state equation based on LG control by way of example. In this case, for example, the control law can be developed by providing a state feedback $\mathbf{K}$ to the state equation so as to minimize an evaluation function J expressed by the following equation.

[Equation 16]

$$J = \int_0^\infty (\mathbf{x}^T \mathbf{Q} \mathbf{x} + \mathbf{u}^T \mathbf{R} \mathbf{u}) dt$$

[Equation 17]

$$\mathbf{u} = -\mathbf{K}\mathbf{x}$$

[0053] The state feedback $\mathbf{K}$ acquired at this time is expressed by the following matrix constituted by n rows and $4 \times n$ columns. In this case, G_A represents a control gain matrix for the vertical speed (dz_B/dt), and G_B represents a control gain matrix for the vertical displacement z_{Bi} . Further, G_C represents a control gain matrix for the pitching angular speed ($d\theta/dt$), and G_D represents a control gain matrix for the pitching angle θ_1 .

[Equation 18]

$$\mathbf{K} = [G_A \ G_B \ G_C \ G_D]$$

[Equation 19]

$$G_A = \begin{bmatrix} G_{A0,1} & G_{A0,2} & G_{A0,3} & G_{A0,4} & G_{A0,5} & \cdots & G_{A0,n-3} & G_{A0,n-2} & G_{A0,n-1} & G_{A0,n} \\ G_{A1,1} & G_{A1,2} & G_{A1,3} & G_{A1,4} & G_{A1,5} & \cdots & G_{A1,n-3} & G_{A1,n-2} & G_{A1,n-1} & G_{A1,n} \\ G_{A2,1} & G_{A2,2} & G_{A2,3} & G_{A2,4} & G_{A2,5} & \cdots & G_{A2,n-3} & G_{A2,n-2} & G_{A2,n-1} & G_{A2,n} \\ G_{A3,1} & G_{A3,2} & G_{A3,3} & G_{A3,4} & G_{A3,5} & \cdots & G_{A3,n-3} & G_{A3,n-2} & G_{A3,n-1} & G_{A3,n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ G_{A_{n-1},1} & G_{A_{n-1},2} & G_{A_{n-1},3} & G_{A_{n-1},4} & G_{A_{n-1},5} & \cdots & G_{A_{n-1},n-3} & G_{A_{n-1},n-2} & G_{A_{n-1},n-1} & G_{A_{n-1},n} \\ G_{A_n,1} & G_{A_n,2} & G_{A_n,3} & G_{A_n,4} & G_{A_n,5} & \cdots & G_{A_n,n-3} & G_{A_n,n-2} & G_{A_n,n-1} & G_{A_n,n} \end{bmatrix}$$

[Equation 20]

$$G_B = \begin{bmatrix} G_{B0,1} & G_{B0,2} & G_{B0,3} & G_{B0,4} & G_{B0,5} & \cdots & G_{B0,n-3} & G_{B0,n-2} & G_{B0,n-1} & G_{B0,n} \\ G_{B1,1} & G_{B1,2} & G_{B1,3} & G_{B1,4} & G_{B1,5} & \cdots & G_{B1,n-3} & G_{B1,n-2} & G_{B1,n-1} & G_{B1,n} \\ G_{B2,1} & G_{B2,2} & G_{B2,3} & G_{B2,4} & G_{B2,5} & \cdots & G_{B2,n-3} & G_{B2,n-2} & G_{B2,n-1} & G_{B2,n} \\ G_{B3,1} & G_{B3,2} & G_{B3,3} & G_{B3,4} & G_{B3,5} & \cdots & G_{B3,n-3} & G_{B3,n-2} & G_{B3,n-1} & G_{B3,n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ G_{B_{n-1},1} & G_{B_{n-1},2} & G_{B_{n-1},3} & G_{B_{n-1},4} & G_{B_{n-1},5} & \cdots & G_{B_{n-1},n-3} & G_{B_{n-1},n-2} & G_{B_{n-1},n-1} & G_{B_{n-1},n} \\ G_{B_n,1} & G_{B_n,2} & G_{B_n,3} & G_{B_n,4} & G_{B_n,5} & \cdots & G_{B_n,n-3} & G_{B_n,n-2} & G_{B_n,n-1} & G_{B_n,n} \end{bmatrix}$$

[Equation 21]

$$G_C = \begin{bmatrix} G_{C0,1} & G_{C0,2} & G_{C0,3} & G_{C0,4} & G_{C0,5} & \cdots & G_{C0,n-3} & G_{C0,n-2} & G_{C0,n-1} & G_{C0,n} \\ G_{C1,1} & G_{C1,2} & G_{C1,3} & G_{C1,4} & G_{C1,5} & \cdots & G_{C1,n-3} & G_{C1,n-2} & G_{C1,n-1} & G_{C1,n} \\ G_{C2,1} & G_{C2,2} & G_{C2,3} & G_{C2,4} & G_{C2,5} & \cdots & G_{C2,n-3} & G_{C2,n-2} & G_{C2,n-1} & G_{C2,n} \\ G_{C3,1} & G_{C3,2} & G_{C3,3} & G_{C3,4} & G_{C3,5} & \cdots & G_{C3,n-3} & G_{C3,n-2} & G_{C3,n-1} & G_{C3,n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ G_{C_{n-1},1} & G_{C_{n-1},2} & G_{C_{n-1},3} & G_{C_{n-1},4} & G_{C_{n-1},5} & \cdots & G_{C_{n-1},n-3} & G_{C_{n-1},n-2} & G_{C_{n-1},n-1} & G_{C_{n-1},n} \\ G_{C_n,1} & G_{C_n,2} & G_{C_n,3} & G_{C_n,4} & G_{C_n,5} & \cdots & G_{C_n,n-3} & G_{C_n,n-2} & G_{C_n,n-1} & G_{C_n,n} \end{bmatrix}$$

[Equation 22]

$$G_D = \begin{bmatrix} G_{D0,1} & G_{D0,2} & G_{D0,3} & G_{D0,4} & G_{D0,5} & \cdots & G_{D0,n-3} & G_{D0,n-2} & G_{D0,n-1} & G_{D0,n} \\ G_{D1,1} & G_{D1,2} & G_{D1,3} & G_{D1,4} & G_{D1,5} & \cdots & G_{D1,n-3} & G_{D1,n-2} & G_{D1,n-1} & G_{D1,n} \\ G_{D2,1} & G_{D2,2} & G_{D2,3} & G_{D2,4} & G_{D2,5} & \cdots & G_{D2,n-3} & G_{D2,n-2} & G_{D2,n-1} & G_{D2,n} \\ G_{D3,1} & G_{D3,2} & G_{D3,3} & G_{D3,4} & G_{D3,5} & \cdots & G_{D3,n-3} & G_{D3,n-2} & G_{D3,n-1} & G_{D3,n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ G_{Dn-1,1} & G_{Dn-1,2} & G_{Dn-1,3} & G_{Dn-1,4} & G_{Dn-1,5} & \cdots & G_{Dn-1,n-3} & G_{Dn-1,n-2} & G_{Dn-1,n-1} & G_{Dn-1,n} \\ G_{Dn,1} & G_{Dn,2} & G_{Dn,3} & G_{Dn,4} & G_{Dn,5} & \cdots & G_{Dn,n-3} & G_{Dn,n-2} & G_{Dn,n-1} & G_{Dn,n} \end{bmatrix}$$

[0054] According to the above-described control law, a multi-degree-of-freedom vibration of the entire railway train is set as a control target, and the control force for each vertically movable damper 7 is determined in consideration of an interference between the vehicle bodies 2_i and 2_{i+1} , whereby it is possible to improve the ride comfort of the entire railway train 1. The state feedback K does not necessarily have to be acquired from the above-described LQ control, and may be acquired from any of various kinds of control theories such as LQG control and H_∞ .

[0055] Further, the above-described system is realized while the acceleration components (d^2z_{Bi}/dt^2 and $d^2\theta_i/dt^2$) of the state vector x are acquired with use of the acceleration a_i directly above the number i bogie 4_i detected by the acceleration sensor 9_i . However, the present invention is not limited thereto, and the state amount may be acquired from a detection result (information) of the acceleration sensor 9_i or may be estimated by designing an appropriate state observer.

[0056] Next, an effect of improving the ride comfort according to the present embodiment will be described. The ride comfort of the railway train 1 is affected by an acceleration of a lateral vibration of the vehicle body 2_i such as yawing and swaying, an acceleration of a vertical vibration of the vehicle body 2_i such as rolling, pitching, and bouncing, and a relatively low-frequency acceleration such as a lateral stable acceleration generated when the railway train is running on a curved track and a longitudinal acceleration generated when the railway train is accelerating or decelerating.

[0057] The ride comfort against a lateral movement is especially important for vehicles entering a narrow tunnel at a high speed or vehicles running in a section frequently having alignment irregularity of a track. However, active suspensions working laterally have been in widespread use for such vehicles, and in recent years, the ride comfort has been improved. Further, the ride comfort in the lateral direction is also affected by a combination of rolling, lateral translation, and yawing, but the ride comfort has been also improved against them by using both the lateral active suspension and a vehicle body tilting apparatus (including a pendulum device). The improvement of the ride comfort in the lateral direction in this manner resultingly makes the discomfort in the vertical direction in riding, which relates to track irregularity in the vertical direction, relatively conspicuous.

[0058] Further, conventionally, the discomfort in riding in the vertical direction has been conspicuous for vehicles running in a section having a wide tunnel, a section having less tunnels, a section having many straight tracks, a section having less tracks with alignment irregularity, or a section having a track with a large degree of longitudinal level irregularity.

[0059] In the railway vehicle 1, which is the coupling bogie train, the vehicle bodies 2_i and 2_{i+1} are vertically inflexibly coupled to each other by the coupling portion 3_i so that the vertical vibration of the vehicle body 2_i is strongly affected by the vertical vibrations of the adjacent vehicle bodies 2_{i-1} and 2_{i+1} . Therefore, all of the vehicle bodies 2_1 to 2_n coupled by the coupling bogies 4_1 to 4_{n-1} are influentially linked to one another. The vertically movable dampers 7 are in charge of absorbing vibrations of these vehicle bodies 2_1 to 2_n , whereby only controlling the vertically movable dampers 7 to generate the damping forces for damping the vibration of their own vehicle body 2_i cannot be sufficiently effective to reduce the vibration of the vehicle body 2_i .

[0060] On the other hand, according to the present embodiment, the controller 10 calculates the number i bogie control force instruction u_i , which is the instruction values for the actuators 7A of the bogie 4_i , based on the detection values of the vibrations at all of the vehicle bodies 2_1 to 2_n . Therefore, even if all of the vehicle bodies 2_1 to 2_n coupled by the coupling bogies 4_1 to 4_{n-1} are influentially linked to one another, it is possible to control the vertically movable dampers 7 of the bogie 4_i in consideration of the influence of the vibrations of the vehicle bodies 2_1 to 2_n among one another. As a result, it is possible to reduce the vibration of the vehicle body 2_i in the entire railway train 1, which is the coupling bogie train having the n vehicle bodies 2_1 to 2_n , thereby improving the ride comfort.

[0061] Further, the railway train 1 detects the acceleration a_{i-1} of the vehicle body 2_{i-1} with use of the acceleration sensor 9_{i-1} mounted at the coupling portion 3_{i-1} , detects the acceleration a_{i+1} of the vehicle body 2_{i+1} with use of the acceleration sensor 9_{i+1} mounted at the coupling portion 3_{i+1} , and detects the acceleration a_i of the coupling portion 3_i .

with use of the acceleration sensor 9_i mounted at the coupling portion 3_i . Therefore, the railway train 1 can calculate the vibration of the vehicle body 2_i based on the detection value of the acceleration a_{i-1} by the acceleration sensor 9_{i-1} and the detection value of the acceleration a_i by the acceleration sensor 9_i , and calculate the vibration of the vehicle body 2_{i+1} based on the detection value of the acceleration a_{i+1} by the acceleration sensor 9_{i+1} and the detection value of the acceleration a_i by the acceleration sensor 9_i .

[0062] According to the first embodiment, all of the acceleration sensors 9_0 to 9_n , and the vertically movable dampers 7 of all of the bogies 4_0 to 4_n are connected to the single controller 10. However, the present invention is not limited thereto, and may share the acceleration information and the control instructions for the vertically movable dampers 7 among the vehicle bodies via a digital signal such as communication, like, for example, a railway train 21 according to a first modification illustrated in Fig. 13. In this case, a controller 22 includes $n+1$ child devices 23_0 to 23_n and a single parent device 24. The child devices 23_0 to 23_n are located, for example, very close to the respective vertically movable dampers 7, and respectively acquire the detection signals of the acceleration sensors 9_0 to 9_n to output this information to a communication line 25. Further, the child devices 23_0 to 23_n output instruction currents to the actuators 7A of the vertically movable dampers 7 as damping force instructions according to control force information (the number i bogie control force instruction u_i) in the communication line 25. The parent device 24 acquires the acceleration information of the n vehicle bodies from the communication line 25, and calculates control forces (the number i bogie control force instruction u_i) required for the respective vertically movable dampers 7 according to the above-described control law. The parent device 24 transmits a result of this calculation to the child devices bogies 23_0 to 23_n via the communication line 25.

[0063] Next, Figs. 14 and 15 illustrate a second embodiment of the present invention. The second embodiment is characterized in that the controller calculates the control force of the coupling bogie based on vibrations of two vehicle bodies. Similar elements of the second embodiment to the above-described first embodiment will be identified by the same reference numerals as the first embodiment, and will not be described especially.

[0064] A railway train 31 according to the second embodiment includes the vehicle body 2_i , the coupling portion 3_i , the bogie 4_i , the vertically movable dampers 7, the acceleration sensor 9_i , a controller 32_i , and the like, in a substantially similar manner to the railway train 1 according to the first embodiment.

[0065] The controller 32_i is configured in a similar manner to the controller 10 according to the first embodiment with use of, for example, a microcomputer. However, the railway train 31 includes total $n+1$ controllers 32_0 to 32_n corresponding to the number of bogies 4_0 to 4_n . These controllers 32_0 to 32_n control the vertically movable dampers 7 of the bogies 4_0 to 4_n respectively independently. Hereinafter, the term "controller 32_i " will be used to refer to any of the controllers 32_0 to 32_n .

[0066] The actuators 7A of the vertically movable dampers 7 of the bogie 4_i are connected to an output side of the controller 32_i . The acceleration sensors 9_{i-1} , 9_i , and 9_{i+1} are connected to an input side of the controller 32_i . Then, the controller 32_i generates the number i bogie control force instruction u_i , which is the damping force instruction signals for the vertically movable dampers 7 of the bogie 4_i , based on the detection signals from the three acceleration sensors 9_{i-1} , 9_i , and 9_{i+1} , and variably controls the damping forces of these vertically movable dampers 7.

[0067] As illustrated in Fig. 15, the controller 32_i includes a preprocessing unit (not illustrated) that includes the AD converter, the filter processing unit, and the like, and acquires the accelerations a_{i-1} , a_i , and a_{i+1} from the detection signals of the acceleration sensors 9_{i-1} , 9_i , and 9_{i+1} . The controller 32 further includes a vibration control unit 33 that outputs the number i bogie control force instruction u_i according to the instruction values for the actuators 7A based on the accelerations a_{i-1} , a_i , and a_{i+1} .

[0068] The vibration control unit 33 includes a number i vehicle body vibration calculation unit 34_i that calculates the vibration of the vehicle body 2_i based on the accelerations a_{i-1} and a_i as the detection values of the acceleration sensors 9_{i-1} and 9_i , a number $i+1$ vehicle body vibration calculation unit 34_{i+1} that calculates the vibration of the vehicle body 2_{i+1} based on the accelerations a_i and a_{i+1} as the detection values of the acceleration sensors 9_i and 9_{i+1} , and a control force instruction calculation unit 35 that calculates the number i bogie control force instruction u_i for the vertically movable dampers 7 of the bogie 4_i based on the vibrations of the vehicle bodies 2_i and 2_{i+1} calculated by these vehicle body vibration calculation units 34_i and 34_{i+1} .

[0069] The vehicle body vibration calculation units 34_i and 34_{i+1} are configured in a substantially similar manner to the number i vehicle body vibration calculation unit 12_i according to the first embodiment. Therefore, the vehicle body vibration calculation units 34_i and 34_{i+1} calculate the vibrations of the vehicle bodies 2_i and 2_{i+1} based on the equations 1 and 2. Further, the control force instruction calculation unit 35 calculates the number i bogie control force instruction u_i according to a control law, which will be described below.

[0070] Then, the number i bogie control force instruction u_i calculated by the control force instruction calculation unit 35 is input into the number i bogie current output unit 14_i , and the number i bogie current output unit 14_i supplies instruction currents according to the number i bogie control force instruction U_i to the actuators 7A of the vertically movable dampers 7 of the bogie 4_i . As a result, the vibration of the vehicle body 2_i due to pitching and bouncing is damped so that the ride comfort of the vehicle body 2_i can be improved.

[0071] The railway train 31 configured in the above-described manner controls the damping forces of the vertically movable dampers 7 of each bogie 4_i based on the outputs of the acceleration sensors 9_{i-1} , 9_i , and 9_{i+1} according to a control law that will be described next.

[0072] The control law according to the second embodiment is basically similar to the first embodiment. However, a difference from the first embodiment is that the state feedback K is approximated in the following manner.

[0073] Now, the control according to the second embodiment will be described especially focusing on the state feedback K acquired from the various kinds of control theories indicated by the equations 18 to 22 according to the first embodiment. In the state feedback K acquired from the control law such as optimum feedback, a gain is large mainly around diagonal elements in the matrix, and a gain of a non-diagonal element is getting smaller as it is located farther away from the diagonal elements. Focusing on this tendency, gains away from the diagonal elements among the non-diagonal elements are approximated to zero, and the state feedback K is approximated, for example, in the following manner.

[Equation 23]

$$K = [G_A \ G_B \ G_C \ G_D]$$

[Equation 24]

$$G_A = \begin{bmatrix} G_{A0,1} & 0 & 0 & 0 & 0 \cdots & 0 & 0 & 0 & 0 \\ G_{A1,1} & G_{A1,2} & 0 & 0 & 0 \cdots & 0 & 0 & 0 & 0 \\ 0 & G_{A2,2} & G_{A2,3} & 0 & 0 \cdots & 0 & 0 & 0 & 0 \\ 0 & 0 & G_{A3,3} & G_{A3,4} & 0 \cdots & 0 & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 0 \cdots & G_{An-3,n-3} & G_{An-3,n-2} & & \\ 0 & 0 & 0 & 0 & 0 \cdots & 0 & G_{An-2,n-2} & G_{An-2,n-1} & \\ 0 & 0 & 0 & 0 & 0 \cdots & 0 & 0 & G_{An-1,n-1} & G_{An-1,n} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & G_{An,n} \end{bmatrix}$$

[Equation 25]

$$G_B = \begin{bmatrix} G_{B0,1} & 0 & 0 & 0 & 0 \cdots & 0 & 0 & 0 & 0 \\ G_{B1,1} & G_{B1,2} & 0 & 0 & 0 \cdots & 0 & 0 & 0 & 0 \\ 0 & G_{B2,2} & G_{B2,3} & 0 & 0 \cdots & 0 & 0 & 0 & 0 \\ 0 & 0 & G_{B3,3} & G_{B3,4} & 0 \cdots & 0 & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 0 \cdots & G_{Bn-3,n-3} & G_{Bn-3,n-2} & & \\ 0 & 0 & 0 & 0 & 0 \cdots & 0 & G_{Bn-2,n-2} & G_{Bn-2,n-1} & \\ 0 & 0 & 0 & 0 & 0 \cdots & 0 & 0 & G_{Bn-1,n-1} & G_{Bn-1,n} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & G_{Bn,n} \end{bmatrix}$$

[Equation 26]

$$G_C = \begin{bmatrix} G_{C0,1} & 0 & 0 & 0 & 0 \cdots & 0 & 0 & 0 & 0 \\ G_{C1,1} & G_{C1,2} & 0 & 0 & 0 \cdots & 0 & 0 & 0 & 0 \\ 0 & G_{C2,2} & G_{C2,3} & 0 & 0 \cdots & 0 & 0 & 0 & 0 \\ 0 & 0 & G_{C3,3} & G_{C3,4} & 0 \cdots & 0 & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 0 \cdots & G_{Cn-3,n-3} & G_{Cn-3,n-2} & & \\ 0 & 0 & 0 & 0 & 0 \cdots & 0 & G_{Cn-2,n-2} & G_{Cn-2,n-1} & \\ 0 & 0 & 0 & 0 & 0 \cdots & 0 & 0 & G_{Cn-1,n-1} & G_{Cn-1,n} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & G_{Cn,n} \end{bmatrix}$$

[Equation 27]

$$G_D = \begin{bmatrix} G_{D0,1} & 0 & 0 & 0 & 0 \cdots & 0 & 0 & 0 & 0 \\ G_{D1,1} & G_{D1,2} & 0 & 0 & 0 \cdots & 0 & 0 & 0 & 0 \\ 0 & G_{D2,2} & G_{D2,3} & 0 & 0 \cdots & 0 & 0 & 0 & 0 \\ 0 & 0 & G_{D3,3} & G_{D3,4} & 0 \cdots & 0 & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 0 \cdots & G_{Dn-3,n-3} & G_{Dn-3,n-2} & & \\ 0 & 0 & 0 & 0 & 0 \cdots & 0 & G_{Dn-2,n-2} & G_{Dn-2,n-1} & \\ 0 & 0 & 0 & 0 & 0 \cdots & 0 & 0 & G_{Dn-1,n-1} & G_{Dn-1,n} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & G_{Dn,n} \end{bmatrix}$$

[0074] In this case, the control force to be generated at the vertically movable dampers 7 of the number i bogie 4_i is expressed by the following recurrence relation.

[Equation 28]

$$u_i = G_{Ai,i} \dot{z}_{Bi} + G_{Ai,i+1} \dot{z}_{Bi+1} + G_{Bi,i} z_{Bi} + G_{Bi,i+1} z_{Bi+1} \\ + G_{Ci,i} \dot{\theta}_i + G_{Ci,i+1} \dot{\theta}_{i+1} + G_{Di,i} \theta_i + G_{Di,i+1} \theta_{i+1}$$

[0075] In this equation, $G_{A0,0}, G_{B0,0}, G_{C0,0}, G_{D0,0} = 0$

$$G_{An,n+1}, G_{Bn,n+1}, G_{Cn,n+1}, G_{Dn,n+1} = 0$$

$$\dot{z}_{B0}, \dot{z}_{Bn+1}, z_{B0}, z_{Bn+1} = 0$$

$$\theta_0, \theta_{n+1}, \dot{\theta}_0, \dot{\theta}_{n+1} = 0$$

[0076] Focusing on the above-described recurrence relation, the control force to be generated at the vertically movable dampers 7 of the number i bogie 4 _{i} is determined only by motions of the number i vehicle body (the vehicle body 2 _{i}) and the number $i+1$ vehicle body (the vehicle body 2 _{$i+1$}). In other words, the controller 32 _{i} is disposed very close to the dampers 7, and the controller 32 _{i} determines the control force only from the acceleration information of its own vehicle body (the vehicle body 2 _{i}) and the adjacent vehicle body (the vehicle body 2 _{$i+1$}) according to the above-described recurrence relation. In this case, the length of the signal line laid between the acceleration sensor 9 _{i} and the vertically movable dampers 7, and the controller 32 _{i} can be reduced to, for example, approximately a length only for two vehicle bodies. Further, the calculation amount of the controller 32 _{i} can be also reduced. Therefore, the present embodiment can acquire a similar performance to the first embodiment with a simple configuration.

[0077] Next, a simulation result of PSD of bouncing of the vehicle body 2 _{i} is illustrated in Fig. 16, and a simulation result of PSD of pitching of the vehicle body 2 _{i} is illustrated in Fig. 17, as a vibration control effect by the above-described control law. In each of Figs. 16 and 17, a solid line indicates PSD when the second embodiment is employed. A broken line indicates PSD when a passive hydraulic damper that does not perform active control is employed as a first comparative example. A long dashed short dashed line indicates PSD when the vertical acceleration of the vehicle body 2 _{i} directly above the coupling portion 3 _{i} is acquired, and the vertically movable dampers 7 directly below the coupling portion 3 _{i} are controlled so as to reduce a change in this acceleration, as a second comparative example. As illustrated in Figs. 16 and 17, for example, in a frequency range around 1 to 2 Hz to which humans are sensitive, the second embodiment can reduce both bouncing and pitching compared to use of the passive damper and control of the vertically movable dampers 7 based on only the vibration directly above the coupling portion 3 _{i} .

[0078] In this manner, the second embodiment can also acquire a similar result and effect to the first embodiment.

[0079] Further, according to the first embodiment, cables of the $n+1$ acceleration sensors 9₀ to 9 _{n} mounted at the n vehicle bodies 2₁ to 2 _{n} , and control lines of the $(n+1) \times 2$ vertically movable dampers 7 are laid toward the single controller 10. As a result, there are raised various kinds of problems, such as complication of the wiring layout, an easy entry of a noise into the cables, and a failure in keeping the accuracy of an analog signal.

[0080] On the other hand, according to the first modification illustrated in Fig. 13, the acceleration information and the control instructions for the vertically movable dampers 7 are shared among the vehicle bodies via a digital signal such as communication. However, according to this configuration, a delay is generated in each of acquisition of the accelerations and transmission of the acceleration information through communication by the child devices 23₀ to 23 _{n} , reception of the acceleration information and transmission of the control calculations and the control force instructions by the parent device 24, and reception of the control force instructions and outputs of currents to the vertically movable dampers 7 by the child devices 23₀ to 23 _{n} . The communication cable (the communication line 25) is required to transmit data in a noise-prone environment over more than 100 m, thereby being difficult to be configured to handle high-speed communication.

[0081] Further, setting the entire train as the control target, like the first embodiment, results in an extreme increase in the control amount due to a large number of state amounts of the control target, thereby requiring a high-performance microcomputer for the state calculation that processes the $4 \times n$ state amounts. A system that realizes the ride comfort control calculation without delay under this limitation must be an expensive system.

[0082] On the other hand, according to the second embodiment, the controller 32 _{i} calculates the number i bogie control force instruction u_i , which is the instruction values for the actuators 7A of the vertically movable dampers 7 of the bogie 4 _{i} , based on the vibrations of the vehicle body 2 _{i} and the vehicle body 2 _{$i+1$} disposed on the opposite front side and rear side of the bogie 4 _{i} . Therefore, only a length for two vehicle bodies is enough as the length of the cable connecting the acceleration sensors 9 _{$i-1$} , 9 _{i} , and 9 _{$i+1$} and the vertically movable dampers 7 to the controller 32 _{i} , whereby the wiring layout can be simplified and the noise can be reduced. In addition thereto, the ride comfort control calculation can be simplified, whereby the manufacturing cost can be reduced.

[0083] Next, Fig. 18 illustrates a third embodiment of the present invention. The third embodiment is characterized in that the controller calculates the instruction values for the actuators after removing a component of a gradual acceleration change like a change in a slope of a road surface. Similar elements of the third embodiment to the above-described second embodiment will be identified by the same reference numerals as the second embodiment, and will not be described especially.

[0084] A controller 41 _{i} according to the third embodiment is configured in a substantially similar manner to the controller 32 _{i} according to the second embodiment. Therefore, the controller 41 _{i} includes the vibration control unit 33 including the

number i vehicle body vibration calculation unit 34_i , the number $i+1$ vehicle body vibration calculation unit 34_{i+1} , and the control instruction calculation unit 35. Further, the controller 41_i includes a preprocessing unit 42 that acquires the acceleration a_i from the detection signal of the acceleration sensor 9_i . This preprocessing unit 42 includes an acceleration acquisition unit 42A, a low-pass filter 42B (hereinafter referred to as the LPF 42B), a high-pass filter 42C (hereinafter referred to as the HPF 42C), and a phase compensator 42D.

[0085] The acceleration acquisition unit 42A includes the AD converter and the like, and acquires the acceleration a_i by converting the detection signal of the acceleration sensor 9_i into a digital signal. The LPF 42B removes a high-frequency noise superimposed on the input of the acceleration a_i with its cutoff frequency set to, for example, a value equal to or lower than a half of a sampling frequency. The HPF 42C keeps a frequency component of bouncing and pitching while removing a component of a gradual acceleration change according to a change in a situation of a road surface with its cutoff frequency set to a lower value than a low-frequency side of a resonance frequency of bouncing and pitching of the vehicle body 2_i .

[0086] A resonance point of bouncing and pitching of the vehicle body 2_i is generated, for example, at a frequency of about 1 to 2 Hz. On the other hand, an offset component due to an ascending slope or a descending slope is generated at, for example, a frequency of 0.5 Hz or lower. Therefore, the cutoff frequency of the HPF 42C is set to, for example, about 0.5 Hz as a value between the resonance frequency of bouncing and pitching, and the frequency of the offset component. The cutoff frequency of the HPF 42C is not limited to the above-described one, and is determined from an experiment in consideration of, for example, a vibration when the railway train runs actually.

[0087] The phase compensator 42D improves a phase characteristic when a desired phase characteristic cannot be acquired around a control frequency by the LPF 42B and HPF 42C. The LPF 42B, the HPF 42C, and the phase compensator 42D each include a digital filter or the like based on digital signal processing. The vibration control unit 33 calculates the number i bogie control force instruction u_i based on the detection value of the acceleration a_i output from this preprocessing unit 42, and output the calculated instruction to the number i bogie current output unit 14_i .

[0088] In this manner, the third embodiment can also acquire a similar result and effect to the second embodiment.

[0089] Further, during the ride comfort control with use of the acceleration sensor 9_i , the controller 32_i generates the control force instruction so as to reduce a change in the pitching angular speed and a change in the vertical speed of the vehicle body 2_i . Therefore, the control according to the second embodiment leads to generation of a control force instruction to prevent the vehicle body 2_i from moving (a change in the pitching angular speed and a change in the vertical speed) when the railway train 31 is entering an ascending slope track, when the railway train 31 is exiting the ascending slope track, when the railway train 31 is entering a descending slope track, when the railway train 31 is exiting the descending slope track, or when partial vehicles in the railway train 31 are running on an ascending slope track while other vehicles in the railway train 31 are running on a descending slope track.

[0090] This control force instruction is an instruction for extending up the vehicle body 2_i , compressing down the vehicle body 2_i , or inclining the vehicle body 2_i forward or downward, and combining this instruction to the ride comfort control instruction results in deterioration of the ride comfort when the railway train 31 is entering a slope track. Further, an offset is generated in the vertical acceleration a_i of the vehicle body 2_i when the railway train 31 is accelerating or decelerating on an ascending or descending slope track or when the railway train 31 is running along a curved track with the vehicle body 2_i inclined, and this offset affects the ride comfort.

[0091] On the other hand, according to the third embodiment, the controller removes the component of a gradual acceleration change, like a change in a slope of a road surface, with use of the HPF 42C, and therefore can provide control only to the acceleration a_i due to pitching and bouncing to improve the ride comfort on an ascending slope track and a descending slope track.

[0092] The third embodiment has been described based on the example in which this is applied to the second embodiment, but may be applied to the first embodiment.

[0093] Next, Fig. 19 illustrates a fourth embodiment of the present invention. The fourth embodiment is characterized in that the controller switches control gains according to weights of adjacent two vehicle bodies. Similar elements of the fourth embodiment to the above-described second embodiment will be identified by the same reference numerals as the second embodiment, and will not be described especially.

[0094] A controller 51_i according to the fourth embodiment is configured in a substantially similar manner to the controller 32_i according to the second embodiment. The controller 51_i includes a preprocessing unit 52 that acquires the acceleration a_i from the detection signal of the acceleration sensor 9_i . This preprocessing unit 52 includes an acceleration acquisition unit 52A, a low-pass filter 52B (hereinafter referred to as the LPF 52B), a high-pass filter 52C (hereinafter referred to as the HPF 52C), and a phase compensator 52D.

[0095] The acceleration acquisition unit 52A includes the AD converter and the like, and acquires the acceleration a_i by converting the detection signal of the acceleration sensor 9_i into a digital signal. The LPF 52B removes a noise or the like on a higher frequency side than the frequency of bouncing and pitching of the vehicle body 2_i . The HPF 52C removes an unnecessary signal such as a noise on a lower frequency side than the frequency of bouncing and pitching of the vehicle body 2_i . The phase compensator 52D improves the phase characteristic when a desired phase characteristic

cannot be acquired around the control frequency by the LPF 52B and the HPF 52C.

[0096] Further, the controller 51_i includes a tank water level acquisition unit 53, a number i vehicle body weight balance calculation unit 54_i, and a number i+1 vehicle body weight balance calculation unit 54_{i+1}. The tank water level acquisition unit 53 includes an AD converter and the like, and is connected to a number i vehicle body clean water tank water meter 55_i, a number i vehicle body sewage water tank water meter 56_i, a number i+1 vehicle body clean water tank water meter 55_{i+1}, and a number i+1 vehicle body sewage water tank water meter 56_{i+1}. The tank water level acquisition unit 53 acquires a water amount Q_{ai} in a clean water tank and a water amount Q_{bi} in a sewage water tank of the number i vehicle body, and acquires a water amount Q_{ai+1} in a clean water tank and a water amount Q_{bi+1} in a sewage water tank of the number i+1 vehicle body.

[0097] The number i vehicle body weight balance calculation unit 54_i calculates number i vehicle body weight balance based on the water amounts Q_{ai} and Q_{bi} in the tanks of the number i vehicle body, and outputs a signal according to a balance inertia and a weight of the vehicle body 2_i.

[0098] The number i+1 vehicle body weight balance calculation unit 54_{i+1} calculates number i+1 vehicle body weight balance based on the water amounts Q_{ai+1} and Q_{bi+1} in the tanks of the number i+1 vehicle body, and outputs a signal according to a balance inertia and a weight of the vehicle body 2_{i+1}.

[0099] The controller 51_i includes a vibration control unit 57 similar to the vibration control unit 33 according to the second embodiment. Therefore, the vibration control unit 57 includes a number i vehicle body vibration calculation unit 58_i, a number i+1 vehicle body vibration calculation unit 58_{i+1}, and a control force instruction calculation unit 59 substantially similar to the number i vehicle body vibration calculation unit 34_i, the number i+1 vehicle body vibration calculation unit 34_{i+1}, and the control force instruction calculation unit 35 according to the second embodiment. In addition thereto, the vibration control unit 57 includes a memory 60 that stores a plurality of kinds (for example, M kinds) of control gains G_{Ai,i}(1) to G_{Ai,i}(M), G_{Ai,i+1}(1) to G_{Ai,i+1}(M), G_{Ci,i}(1) to G_{Ci,i}(M), and G_{Ci,i+1}(1) to G_{Ci,i+1}(M), and a parameter selection unit 61 that selects one kind of gains from the control gains G_{Ai,i}(1) to G_{Ai,i}(M), G_{Ai,i+1}(1) to G_{Ai,i+1}(M), G_{Ci,i}(1) to G_{Ci,i}(M), and G_{Ci,i+1}(1) to G_{Ci,i+1}(M) stored in the memory 60 based on the signals output from the weight balance calculation units 54_i and 54_{i+1}. Then, the parameter selection unit 61 supplies the selected one kind of gains G_{Ai,i}(m), G_{Ai,i+1}(m), G_{Ci,i}(m), and G_{Ci,i+1}(m) to the control force instruction calculation unit 59 as control gains G_{Ai,i}, G_{Ai,i+1}, G_{Ci,i}, and G_{Ci,i+1}.

[0100] At this time, for example, when the number i vehicle body is heavier than the number i+1 vehicle body, the parameter selection unit 61 increases the control gain G_{Ai,i} of the heavier vehicle body and reduces the control gain G_{Ai,i+1} of the lighter vehicle. Further, when the number i vehicle body has a larger inertia in the pitching direction than the number i+1 vehicle body, the parameter selection unit 61 increases the control gain G_{Ci,i} for the pitching angle θ_i of the vehicle body 2_i having the larger inertia, and reduces the control gain G_{Ci,i+1} for the pitching angle θ_{i+1} of the vehicle body 2_{i+1} having a smaller inertia.

[0101] The relationship of the weight and inertia to the control gains G_{Ai,i}, G_{Ai,i+1}, G_{Ci,i}, and G_{Ci,i+1} is not limited thereto, and an optimum relationship capable of reducing the vibration of the vehicle body 2_i is determined based on the vibration of the vehicle body 2_i when the railway train runs actually. Further, the number of kinds as the control gains G_{Ai,i} and G_{Ai,i+1} for the vertical speed (dz_B/dt) and the number of kinds as the control gains G_{Ci,i} and G_{Ci,i+1} for the pitching angular speed (d θ_i /dt) do not necessarily have to be same numbers, and may be different from each other.

[0102] Then, upon an input of the detection value of the acceleration a_i from the preprocessing unit 52, the control force instruction calculation unit 59 calculates the number i bogie control force instruction u_i with use of the control gains selected by the parameter selection unit 61, and outputs it to the number i bogie current output unit 14_i.

[0103] In this manner, the fourth embodiment can also acquire a similar result and effect to the second embodiment.

[0104] Further, according to the second embodiment, the control gains G_{Ai,j}, G_{Bi,j}, G_{Ci,j}, and G_{Di,j} are fixed values tuned in advance, provided that the weight of the vehicle body 2_i and the coupling stiffness between the vehicle bodies 2_i and 2_{i+1} are not changed while the railway train is running. However, the weight balance may be disturbed due to consumption of a loaded fuel by a diesel railcar, a change in the balance between clean water and sewage water in a sleeper train, a difference in vehicle occupancy among the vehicle bodies, and the like.

[0105] On the other hand, the fourth embodiment prepares a plurality of kinds of control gains G_{Ai,j}(1) to G_{Ai,j}(M) and G_{Ci,j}(1) to G_{Ci,j}(M) in consideration of a change in the weight balance of the vehicle body. Then, for example, the fourth embodiment switches the ratio between the control gain G_{Ai,i} and the control gain G_{Ai,i+1} depending on a difference between the weights of the number i vehicle body and the number i+1 vehicle body, and switches the ratio between the control gain G_{Ci,i} and the control gain G_{Ci,i+1} depending on a difference in the inertias of the number i vehicle body and the number i+1 vehicle body.

[0106] More specifically, when the number i vehicle body and the number i+1 vehicle body have different weights, the fourth embodiment increases one of the control gains G_{Ai,i} and G_{Ai,i+1} for bouncing of the vehicle body that corresponds to a heavier vehicle body. Further, when the number i vehicle body and the number i+1 vehicle body have different inertias in the pitching direction, the fourth embodiment increases one of the control gains G_{Ci,i} and G_{Ci,i+1} for the pitching angle θ_i of the vehicle body that corresponds to the pitching angle θ_i of the vehicle body 2_i or 2_{i+1} having a larger inertia. As a result, even when the weight or inertia of the vehicle body 2_i is changed, the fourth embodiment can reduce the

vibration of the vehicle body 2_i by selecting the control gain $G_{Ai,j}$ and $G_{Ci,j}$ according to this change.

[0107] The balance between the control gains for bouncing and pitching, i.e., the balance among the control gains $G_{Ai,j}$ to $G_{Di,j}$ may be changed arbitrarily.

[0108] Further, the fourth embodiment acquires the water amounts Q_{ai} and Q_{ai+1} in the clean water tanks and the water amounts Q_{bi} and Q_{bi+1} in the sewage water tanks respectively measured by the clean water tank water-meters 55_i and 55_{i+1} and the sewage water tank water-meters 56_i and 56_{i+1}, and detects changes in the weight and inertia as a change in the weight balance of the vehicle body 2_i based on the balance between these clean water and sewage water. However, the present invention is not limited thereto. As a change in the weight balance, for example, a weight change due to fuel consumption may be detected based on a driving time or a fuel meter, and a difference in vehicle occupancy may be detected based on an initial displacement of the secondary suspension or the like. Further, the weight and inertia of the vehicle body 2_i may be measured directly.

[0109] Further, the fourth embodiment is configured to include the vibration control unit 57 similar to the vibration control unit 33 according to the second embodiment, but may be configured to include the vibration control unit 11 according to the first embodiment. Further, the fourth embodiment may be combined with the third embodiment.

[0110] Next, Fig. 20 illustrates a fifth embodiment of the present invention. The fifth embodiment is characterized in that the controller switches the control gains according to a vehicle speed. Similar elements of the fifth embodiment to the above-described fourth embodiment will be identified by the same reference numerals as the fourth embodiment, and will not be described especially.

[0111] A controller 71_i according to the fifth embodiment includes the preprocessing unit 52 according to the fourth embodiment. In addition thereto, the controller 71_i includes a speed information acquisition unit 72. The speed information acquisition unit 72 is connected to, for example, a communication line 73 within the vehicle body, and acquires a vehicle speed from the communication line 73. The speed information acquisition unit 72 does not necessarily have to acquire the vehicle speed based on a signal from the communication line 73, and may acquire the vehicle speed based on a signal from, for example, a speed sensor.

[0112] The controller 71_i includes a vibration control unit 74 similar to the vibration control unit 33 according to the second embodiment. Therefore, the vibration control unit 74 includes a number i vehicle body vibration calculation unit 75_i, a number $i+1$ vehicle body vibration calculation unit 75_{i+1}, and a control force instruction calculation unit 76 substantially similar to the number i vehicle body vibration calculation unit 34_i, the number $i+1$ vehicle body vibration calculation unit 34_{i+1}, and the control force instruction calculation unit 35 according to the second embodiment. In addition thereto, the vibration control unit 74 includes a memory 77 and a parameter selection unit 78 substantially similar to the memory 60 and the parameter selection unit 61 according to the fourth embodiment.

[0113] The memory 77 stores the plurality of kinds (for example, M kinds) of control gains $G_{Ai,i}(1)$ to $G_{Ai,i}(M)$, $G_{Ai,i+1}(1)$ to $G_{Ai,i+1}(M)$, $G_{Ci,i}(1)$ to $G_{Ci,i}(M)$, and $G_{Ci,i+1}(1)$ to $G_{Ci,i+1}(M)$. The parameter selection unit 78 selects one kind of control gains from $G_{Ai,i}(1)$ to $G_{Ai,i}(M)$, $G_{Ai,i+1}(1)$ to $G_{Ai,i+1}(M)$, $G_{Ci,i}(1)$ to $G_{Ci,i}(M)$, and $G_{Ci,i+1}(1)$ to $G_{Ci,i+1}(M)$ stored in the memory 77 based on a signal output from the speed information acquisition unit 72. Then, the parameter selection unit 78 supplies the selected one kind of gains $G_{Ai,i}(m)$, $G_{Ai,i+1}(m)$, $G_{Ci,i}(m)$, and $G_{Ci,i+1}(m)$ to the control force instruction calculation unit 76 as the control gains $G_{Ai,i}$, $G_{Ai,i+1}$, $G_{Ci,i}$, and $G_{Ci,i+1}$.

[0114] At this time, for example, the parameter selection unit 78 increases the control gains $G_{Ai,i}$, $G_{Ai,i+1}$, $G_{Ci,i}$, and $G_{Ci,i+1}$ when the vehicle speed is fast, and reduces the control gains $G_{Ai,i}$, $G_{Ai,i+1}$, $G_{Ci,i}$, and $G_{Ci,i+1}$ when the vehicle speed is slow. The number of kinds as the control gains $G_{Ai,i}$ and $G_{Ai,i+1}$ for the vertical speed (dz_B/dt) and the number of kinds as the control gains $G_{Ci,i}$ and $G_{Ci,i+1}$ for the pitching angular speed ($d\theta/dt$) do not necessarily have to be same numbers, and may be different from each other.

[0115] Then, upon an input of the detection value of the acceleration a_i from the preprocessing unit 52, the control force instruction calculation unit 76 calculates the number i bogie control force instruction u_i with use of the control gains selected by the parameter selection unit 78, and outputs the calculated instruction to the number i bogie current output unit 14_i.

[0116] In this manner, the fifth embodiment can also acquire a similar result and effect to the second embodiment. Further, if there is no large peak in a spatial frequency of vertical irregularity of the track, the ride comfort is further deteriorated as the running speed of the vehicle is increasing. Even in this case, the fifth embodiment can prevent the ride comfort from being deteriorated due to a change in the vehicle speed because it changes the control gains $G_{Ai,i}$ and $G_{Ci,i}$ according to the vehicle speed.

[0117] The fifth embodiment is configured to include the vibration control unit 74 similar to the vibration control unit 33 according to the second embodiment, but may be configured to include the vibration control unit 11 according to the first embodiment. Further, the fifth embodiment may be combined with the third or fourth embodiment.

[0118] Next, Fig. 21 illustrates a sixth embodiment of the present invention. The sixth embodiment is characterized in that the controller switches the control gains when the railway train is running on an ascending slope track or is accelerating. Similar elements of the sixth embodiment to the above-described fourth embodiment will be identified by the same reference numerals as the fourth embodiment, and will not be described especially.

[0119] A controller 81_i according to the sixth embodiment includes the preprocessing unit 52 according to the fourth embodiment. In addition thereto, the controller 81_i includes a traveling direction acquisition unit 82, an inclination angle acquisition unit 83, and a longitudinal acceleration acquisition unit 84. The traveling direction acquisition unit 82 is connected to, for example, a communication line 85 within the vehicle body, and acquires a traveling direction of the vehicle body from the communication line 85. The inclination angle acquisition unit 83 is connected to, for example, an angle meter 86 that detects an inclination of the vehicle body, and acquires how much the vehicle body is inclined. The longitudinal acceleration acquisition unit 84 is connected to, for example, a longitudinal acceleration sensor 87, and acquires a longitudinal acceleration.

[0120] The traveling direction acquisition unit 82 may acquire the traveling direction from a speed sensor of the vehicle body. The inclination angle acquisition unit 83 may acquire how much the vehicle body is inclined based on location information of the vehicle body from a GPS, a traffic control sensor, or the like. The longitudinal acceleration acquisition unit 84 may acquire the longitudinal acceleration by differentiating speed information of the vehicle.

[0121] The controller 81_i includes a vibration control unit 88 similar to the vibration control unit 33 according to the second embodiment. Therefore, the vibration control unit 88 includes a number *i* vehicle body vibration calculation unit 89_i, a number *i*+1 vehicle body vibration calculation unit 89_{i+1}, and a control force instruction calculation unit 90 substantially similar to the number *i* vehicle body vibration calculation unit 34_i, the number *i*+1 vehicle body vibration calculation unit 34_{i+1}, and the control force instruction calculation unit 35 according to the second embodiment. In addition thereto, the vibration control unit 88 includes a memory 91 and a parameter selection unit 92 substantially similar to the memory 60 and the parameter selection unit 61 according to the fourth embodiment.

[0122] The memory 91 stores the plurality of kinds (for example, *M* kinds) of control gains $G_{Ai,i}(1)$ to $G_{Ai,i}(M)$, $G_{Ai,i+1}(1)$ to $G_{Ai,i+1}(M)$, $G_{Ci,i}(1)$ to $G_{Ci,i}(M)$, and $G_{Ci,i+1}(1)$ to $G_{Ci,i+1}(M)$. The parameter selection unit 92 selects one kind of control gains from the control gains $G_{Ai,i}(1)$ to $G_{Ai,i}(M)$, $G_{Ai,i+1}(1)$ to $G_{Ai,i+1}(M)$, $G_{Ci,i}(1)$ to $G_{Ci,i}(M)$, and $G_{Ci,i+1}(1)$ to $G_{Ci,i+1}(M)$ stored in the memory 91 based on signals output from the traveling direction acquisition unit 82, the inclination angle acquisition unit 83, and the longitudinal acceleration acquisition unit 84. Then, the parameter selection unit 92 supplies the selected one kind of gains $G_{Ai,i}(m)$, $G_{Ai,i+1}(m)$, $G_{Ci,i}(m)$, and $G_{Ci,i+1}(m)$ to the control force instruction calculation unit 90 as the control gains $G_{Ai,i}$, $G_{Ai,i+1}$, $G_{Ci,i}$, and $G_{Ci,i+1}$.

[0123] According to the first embodiment, the controller solves the motion equation with the acceleration (d^2x_{Bi}/dt^2) set to zero, i.e., T_{zi} set to zero, assuming that the railway train is running on a flat land at a constant speed. However, if the railway train is a train driven only by being pulled by a locomotive disposed on the front side in the traveling direction, like a push-pull system train, the traction force when the railway train is running on an ascending slope track or is accelerating is expressed by the following equation (refer to Fig. 22).

[Equation 29]

$$T_i = -\left(\sum_{k=i+1}^n m_k\right)(\ddot{x}_{Bi} - g \sin \theta_r)$$

[0124] In the equation 29, *g* represents a gravitational acceleration, and θ_r has a positive value when a slope of a road surface is a descending slope. As described in the first embodiment, the *z*-direction component T_{zi} of the traction force T_i is expressed by the above-described equation 6.

[0125] This means that the vertical force T_{zi} , which works at the time of pitching, is increasing as the vehicle body is located closer to the foremost bogie 4₀ when the railway train is running on an ascending slope track or is accelerating. This force works in a direction for preventing pitching of the vehicle body 2_i when the vehicle body 2_i and the vehicle body 2_{i+1} has pitching in opposite phases from each other. Therefore, the pitching vibration is reducing as the vehicle body is located closer to the foremost bogie 4₀ when the railway train is running on an ascending slope track or is accelerating.

[0126] According thereto, for example, when the railway train is running on an ascending slope track or is accelerating, the parameter selection unit 92 more largely reduces the control gains $G_{Ci,i}$ and $G_{Ci,i+1}$ for pitching and sets a higher frequency as a frequency range that the controller 81_i targets, as the coupling bogies 4₁ to 4_{*n*} are located closer to the foremost bogie 4₀. Similarly, the parameter selection unit 92 also switches the control gains $G_{Ai,i}$ and $G_{Ai,i+1}$ for bouncing according to, for example, whether the railway train is running on an ascending slope track or is accelerating.

[0127] The number of kinds as the control gains $G_{Ai,i}$ and $G_{Ai,i+1}$ for the vertical speed (dz_{Bi}/dt) and the number of kinds as the control gains $G_{Ci,i}$ and $G_{Ci,i+1}$ for the pitching angular speed ($d\theta_i/dt$) do not necessarily have to be same numbers, and may be different from each other.

[0128] Then, upon an input of the detection value of the acceleration *a_i* from the preprocessing unit 52, the control force instruction calculation unit 90 calculates the number *i* bogie control force instruction *u_i* with use of the control gains

selected by the parameter selection unit 92, and outputs the calculated instruction to the number i bogie current output unit 14 _{i} .

[0129] In this manner, the sixth embodiment can also acquire a similar result or effect to the second embodiment. Further, when the railway train is running on an ascending slope track or is accelerating, the sixth embodiment switches the control gains $G_{Ai,i}$, $G_{Ai,i+1}$, $G_{Ci,i}$, and $G_{Ci,i+1}$ according to these conditions, and therefore can realize optimum ride comfort control even when the railway train is running on an ascending slope track or is accelerating.

[0130] If the railway train is a multiple-unit system train, each of the vehicle bodies 2₁ to 2 _{n} has a power source, and the traction force T_i is not generated between the vehicle bodies so that T_{zi} is zero regardless of whether the railway train is running on an ascending slope track or is accelerating. Further, if a brake is mounted on each of the bogies 4₀ to 4 _{n} , T_{zi} can be assumed to be zero when the railway train is slowing regardless of whether the railway train is a push-pull system train or a multiple-unit system train. In other words, the sixth embodiment is applicable only when a push-pull system train is running on an ascending slope track or is accelerating.

[0131] Further, the sixth embodiment is configured to include the vibration control unit 88 similar to the vibration control unit 33 according to the second embodiment, but may be configured to include the vibration control unit 11 according to the first embodiment. Further, the sixth embodiment may be combined with any of the third to fifth embodiments.

[0132] Next, Fig. 23 illustrates a seventh embodiment of the present invention. The seventh embodiment is characterized in that the controller sets a control gain for the foremost bogie to a different value from control gains for the other coupling bogies. Similar elements of the seventh embodiment to the above-described second embodiment will be identified by the same reference numerals as the second embodiment, and will not be described especially.

[0133] A railway train 101 according to the seventh embodiment is configured in such a manner that the n vehicle bodies 2₁ to 2 _{n} coupled by the coupling bogies 4₁ to 4 _{$n-1$} are pulled by a locomotive 102. In this case, the locomotive 102 can be separated from the passenger vehicles (the number 1 vehicle body to the number n vehicle body) constituted by the vehicle bodies 2₁ to 2 _{n} . Therefore, the number 1 bogie 4₀ of the number 1 vehicle body does not serve as the coupling bogie, and is not located at an end (the front end) of the vehicle body 2₁.

[0134] The locomotive 102 and the foremost vehicle body are connected to each other longitudinally inflexibly but vertically flexibly so as to be relatively displaceable in this direction. In this case, the number 0 bogie 4₀ supports a half of the vehicle weight of the number 1 vehicle body. On the other hand, the number 1 bogie 4₁ serves as the coupling bogie and therefore supports a sum of a half of the vehicle weight of the number 1 vehicle body and a half of the vehicle weight of the number 2 vehicle body. In other words, a vertical force applied to the number 0 bogie 4₀ is weak compared to the other bogies 4₁ to 4 _{$n-1$} even in consideration of a shorter length between attachment points of the number 0 bogie 4₀ and the number 1 bogie 4₁.

[0135] Therefore, although the railway train 101 includes a controller 103, substantially similar to the controller 32, according to the second embodiment, the controller 103₀ for the foremost bogie 4₀ sets the control gain for the foremost bogie 4₀ to a low value compared to the control gains for the other coupling bogies 4₁ to 4 _{$n-1$} .

[0136] Further, a vertical force applied to the last bogie 4 _{n} at the tail end is also weak compared to the other coupling bogies 4₁ to 4 _{$n-1$} in a similar manner to the foremost bogie 4₀. Therefore, the controller 103 _{n} for the last bogie 4 _{n} at the tail end sets a control gain for the last bogie 4 _{n} at the tail end to a low value compared to the control gains for the other coupling gains 4₁ to 4 _{$n-1$} .

[0137] In this manner, the seventh embodiment can also acquire a similar result and effect to the second embodiment. Further, the control gains for the foremost and last bogies 4₀ and 4 _{n} are set to lower values than the control gains for the other coupling bogies 4₁ to 4 _{$n-1$} , whereby the controllers 103₀ and 103 _{n} can calculate control force instructions u_0 and u_n according to the vertical forces applied to the bogies 4₀ and 4 _{n} , thereby improving the ride comfort of the railway train 101.

[0138] The seventh embodiment has been described based on the example in which the locomotive 102 and the number 1 vehicle body are flexibly connected to each other. However, the present invention is not limited thereto. For example, like a railway train 111 according to a second modification illustrated in Fig. 24, a locomotive 112 and the number 1 vehicle body may be connected vertically inflexibly so as to be unable to be vertically displaced relative to each other.

[0139] In this case, a vertical force of the locomotive 112 is applied on the number 0 bogie 4₀, in addition to the vertical force of the number 1 vehicle body 2₁. Generally, the mass of the locomotive 112 is heavy compared to the passenger vehicle. Therefore, the vertical force applied to the number 0 bogie 4₀ is strong compared to the other bogies 4₁ to 4 _{n} . In consideration thereof, the railway train 111 according to the second modification includes a controller 113, substantially similar to the controller 32, according to the second embodiment. In this case, a controller 113₀ for the foremost bogie 4₀ sets the control gain for the foremost bogie 4₀ to a higher value than the control gains for the other bogies 4₁ to 4 _{n} .

[0140] Further, the seventh embodiment has been described based on the example in which the number 1 passenger vehicle is connected to the locomotive 102. However, the present invention is not limited thereto. For example, like a railway train 121 according to a third modification illustrated in Fig. 25, the seventh embodiment may be applied to a train that is not pulled by the locomotive.

[0141] The railway train 121 is configured in such a manner that power devices 122 including such as motors are distributed to the respective passenger vehicles. In this case, the foremost bogie 4_0 (the number 0 bogie) of the passenger vehicle is the foremost bogie of the entire railway train. In this case, the number 0 bogie 4_0 supports only a half of the weight of the number 1 vehicle body, and the number 1 bogie 4_1 supports a sum of a half of the weight of the number 1 vehicle body and a half of the weight of the number 2 vehicle body. On the other hand, a driver's platform is installed on the foremost vehicle body (the number 1 vehicle body), whereby it is highly likely that the number 1 vehicle body has a different vehicle weight and a different distance to the bogie from the other passenger vehicles. In light thereof, the railway train 121 according to the third modification includes a controller 123_i substantially similar to the controller 32_i according to the second embodiment. In this case, a controller 123_0 for the foremost bogie 4_0 sets the control gain for the foremost bogie 4_0 to a different value from the control gains for the other coupling bogies 4_1 to 4_{n-1} in comprehensive consideration of the influence therefrom.

[0142] For example, the control gain for the foremost bogie 4_0 is set to a low value when the vertical force applied to the number 0 bogie 4_0 is weak compared to the other coupling bogies 4_1 to 4_{n-1} . Conversely, the control gain for the foremost bogie 4_0 is set to a large value when the vertical force applied to the number 0 bogie 4_0 is strong compared to the other coupling bogies 4_1 to 4_{n-1} due to the influence of the driver's platform or the like.

[0143] Further, the seventh embodiment also sets the control gain for the last bogie 4_n to a low value in consideration of the fact that the vertical force applied to the last bogie 4_n is weak compared to the other coupling bogies 4_1 to 4_{n-1} . However, the present invention is not limited thereto. For example, like a railway train 131 according to a fourth modification illustrated in Fig. 26, the control gain for the last bogie 4_n may be set to a different value.

[0144] If the railway train is a train running at a high speed, the ride comfort on the last vehicle body tends to be deteriorated due to the influence of an aerodynamic disturbance. In consideration thereof, the railway train 131 according to the fourth modification may be configured in such a manner that a controller 132_n among controllers 132_0 to 132_n sets the control gain for the last bogie 4_n to a different value (for example, a high value) from the control gains for the other coupling bogies 4_1 to 4_{n-1} . A specific value of the control gain is appropriately set based on a result of detection of the vibration or the like when the railway train runs actually. In this case, the railway train 131 may be configured to be pulled by a locomotive, and may be configured not to be pulled by a locomotive, like the third modification.

[0145] Further, the seventh embodiment and the second to fourth modifications have been described based on the example in which they are applied to the second embodiment, but may be applied to the first embodiment. Further, the seventh embodiment may be combined with any of the third to sixth embodiments.

[0146] Next, Figs. 27 and 28 illustrate an eighth embodiment of the present invention. The eighth embodiment is characterized in that the controller calculates vibrations of adjacent two vehicle bodies based on a detection value of a sensor mounted near one of the vehicle bodies. Similar elements of the eighth embodiment to the above-described second embodiment will be identified by the same reference numerals as the second embodiment, and will not be described especially.

[0147] A railway vehicle 141 according to the eighth embodiment includes the vehicle body 2_i , the coupling portion 3_i , the bogie 4_i , the vertically movable dampers 7, the acceleration sensor 9_i , a controller 143_i , and the like in a substantially similar manner to the railway train 31 according to the second embodiment. In addition thereto, the railway vehicle 141 includes an inter-vehicle body displacement sensor 142_i that detects a relative longitudinal displacement between the adjacent vehicle body 2_i and vehicle body 2_{i+1} .

[0148] The inter-vehicle displacement sensor 142_0 is disposed between the number 1 vehicle body 2_1 and the number 2 vehicle body 2_2 , and detects a relative longitudinal displacement $X_{b1,2}$ therebetween. The inter-vehicle displacement sensor 142_{n-1} is disposed between the number $n-1$ vehicle body 2_{n-1} and the number n vehicle body 2_n (the last vehicle body), and detects a relative longitudinal displacement $X_{bn-1,n}$ therebetween. These inter-vehicle displacement sensors 142_0 to 142_{n-1} each output a detection signal according to the relative longitudinal displacement $X_{bi,i+1}$, which corresponds to a distance between adjacent vehicle bodies. Hereinafter, the term "inter-vehicle displacement sensor 142_i " will be used to refer to any of the inter-vehicle displacement sensor 142_0 to 142_{n-1} . The inter-vehicle displacement sensor 142_i is mounted at a position upward away from the coupling portion 3_i between the number i vehicle body and the number $i+1$ vehicle body by a distance h .

[0149] The controller 143_i includes a preprocessing unit (not illustrated) that acquires the accelerations a_{i-1} and a_i from the detection signals of the acceleration sensors 9_{i-1} and 9_i , and includes a preprocessing unit (not illustrated) that acquires the relative displacement $X_{bi,i+1}$ from the detection signal of the inter-vehicle displacement sensor 142_i . In addition thereto, the controller 143_i includes a vibration control unit 144 that outputs the number i bogie control force instruction u_i according to the instruction values for the actuators 7A based on the accelerations a_{i-1} and a_i and the relative displacement $x_{bi,i+1}$.

[0150] The vibration control unit 144 includes a number i vehicle body vibration calculation unit 145_i that calculates the vibration of the vehicle body 2_i based on the accelerations a_{i-1} and a_i , which are the detection values of the acceleration sensors 9_{i-1} and 9_i , a number $i+1$ vehicle body vibration calculation unit 145_{i+1} that calculates the vibration of the vehicle body 2_{i+1} based on a result of the calculation of the number i vehicle body vibration calculation unit 145_i and the relative

displacement $x_{bi,i+1}$, which is the detection value of the inter-vehicle displacement sensor 142_i, and a control force instruction calculation unit 146 that calculates the number i bogie control force instruction u_i for the vertically movable dampers 7 of the bogie 4_i based on the vibrations of the vehicle bodies 2_i and 2_{i+1} calculated by these vehicle body vibration calculation units 145_i and 145_{i+1}. In this case, the control force instruction calculation unit 146 is configured in

a substantially similar manner to the control force instruction calculation unit 35 according to the second embodiment. **[0151]** Then, the number i bogie control force instruction u_i calculated by the control force instruction calculation unit 146 is input into the number i bogie current output unit 14_i, and the number i bogie current output unit 14_i supplies instruction currents according to the number i bogie control force instruction u_i to the actuators 7A of the vertically movable dampers 7 of the bogie 4_i. As a result, the vibration of the vehicle body 2_i due to pitching and bouncing is damped, whereby the ride comfort of the vehicle body 2_i can be improved.

[0152] Next, the method for calculating the vibrations of the vehicle bodies 2_i and 2_{i+1} by the number i vehicle body vibration calculation unit 145_i and the number i+1 vehicle body vibration calculation unit 145_{i+1} will be described.

[0153] The relative displacement $x_{bi,i+1}$ detected by the inter-vehicle displacement sensor 142_i is defined with use of the distance h between the inter-vehicle displacement sensor 142_i and the coupling portion 3_i in the following manner. In this case, the relative displacement $x_{bi,i+1}$ is zero when the pitching angles θ_i and θ_{i+1} of the number i and i+1 vehicle bodies are equal to each other.

[Equation 30]

$$x_{bi,i+1} = \sin(\theta_i - \theta_{i+1}) \times h$$

[0154] Both the pitching angles θ_i and θ_{i+1} are small, and therefore can be approximated in the following manner.

[Equation 31]

$$\sin(\theta_i - \theta_{i+1}) \approx \theta_i - \theta_{i+1}$$

[0155] Therefore, a relative angle $(\theta_i - \theta_{i+1})$ between the number i vehicle body and the number i+1 vehicle body is calculated from the output (the relative displacement $x_{bi,i+1}$) of the inter-vehicle displacement sensor 142_i according to the following conversion equation.

[Equation 32]

$$\theta_i - \theta_{i+1} \approx \frac{x_{bi,i+1}}{h}$$

[0156] In the present embodiment, the pitching angular acceleration ($d^2\theta/dt^2$) of the number i vehicle body is calculated by an equation 33.

[Equation 33]

$$\ddot{\theta}_i = \frac{a_i - a_{i-1}}{L_i}$$

[0157] Therefore, the pitching angular acceleration ($d^2\theta_{i+1}/dt^2$) of the number i+1 vehicle body is calculated in the following manner.

[Equation 34]

$$\ddot{\theta}_{i+1} \approx \frac{a_i - a_{i-1}}{L_i} - \frac{\ddot{x}_{bi,i+1}}{h}$$

[0158] Further, the vertical accelerations (d^2z_{Bi}/dt^2) and (d^2z_{Bi+1}/dt^2) of the number i and $i+1$ vehicle bodies are calculated based on the acceleration a_{i-1} acquired by the acceleration sensor 9_{i-1} and the acceleration a_i acquired by the acceleration sensor 9_i by the following equation.

[Equation 35]

$$\ddot{z}_{Bi} = \frac{a_i + a_{i-1}}{2}$$

[Equation 36]

$$\ddot{z}_{Bi+1} = a_i + \frac{L_{i+1}}{2} \ddot{\theta}_{i+1}$$

[0159] According to the present embodiment, the above-described calculations allow pitching and bouncing of the number i vehicle body and the number $i+1$ vehicle body to be acquired only from the accelerations a_{i-1} and a_i of the number i vehicle and the displacement $x_{bi,i+1}$ between the vehicle bodies directly above the number i bogie 4_i . In this case, the acceleration a_i can be expressed by the vertical acceleration (d^2z_{Bi}/dt^2) and the pitching angular acceleration ($d^2\theta_i/dt^2$) of the number i vehicle body. Therefore, pitching and bouncing of the number $i+1$ vehicle body can be acquired based on pitching and bouncing of the number i vehicle body and the displacement $x_{bi,i+1}$ between the vehicle bodies.

[0160] In this case, the acceleration sensor 9_{i-1} and the acceleration sensor 9_i correspond to the first vibration detector that detects the vibration of the vehicle body 2_i , together with the number i vehicle body vibration calculation unit 145_i of the controller 143_i . Further, the first vibration detector and the inter-vehicle displacement sensor 142_i correspond to the second vibration detector that detects the vibration of the vehicle body 2_{i+1} , together with the number $i+1$ vehicle body vibration calculation unit 145_{i+1} of the controller 143_i .

[0161] The number $i+1$ vehicle body vibration calculation unit 145_{i+1} may calculate the vibration of the vehicle body 2_{i+1} by substituting the accelerations a_{i-1} and a_i , which are the detection values of the acceleration sensors 9_{i-1} and 9_i , and the displacement $x_{bi,i+1}$ between the vehicle bodies, which is the detection value of the inter-vehicle displacement sensor 142_i into the equations 34 and 36 without using the detection value of the first vibration detector.

[0162] In this manner, the eighth embodiment can also acquire a similar result and effect to the second embodiment. Further, the eighth embodiment realizes control for reducing the vibrations of the vehicle body 2_i and the adjacent vehicle body 2_{i+1} in a similar manner to the second embodiment while using only the wiring for the vehicle body 2_i . Therefore, it is possible to acquire a control effect close to the second embodiment with a smaller calculation amount of the controller 143_i and a simpler configuration.

[0163] Further, according to the eighth embodiment, the inter-vehicle displacement sensor 142_i detects the relative longitudinal displacement $x_{bi,i+1}$, and then calculates the relative angle ($\theta_i - \theta_{i+1}$) between the vehicle bodies. However, the present invention is not limited thereto, and the inter-vehicle displacement sensor may directly detect the relative angle ($\theta_i - \theta_{i+1}$) between the vehicle bodies.

[0164] Further, according to the eighth embodiment, the vehicle body 2_i detects the vibration of the vehicle body 2_i such as pitching and bouncing with use of the acceleration sensors 9_{i-1} and 9_i mounted on the front end and the rear end. However, the positions of the acceleration sensors 9_{i-1} and 9_i , and the directions in which the accelerations are detected are not limited thereto, and may be arbitrarily changed.

[0165] In other words, according to the eighth embodiment, with respect to the vehicle bodies 2_i and 2_{i+1} adjacent to each other, detecting the relative angle therebetween and the motion of the vehicle body 2_i , which is only one of them, is enough to calculate the motion of the vehicle body 2_{i+1} , which is the other of them, thereby allowing application of the above-described control.

[0166] Further, the eighth embodiment may be combined with any of the third to seventh embodiments.

[0167] Next, Fig. 29 illustrates a ninth embodiment of the present invention. The ninth embodiment is characterized in that the controller calculates the control force of the coupling bogie based on the control force of the bogie when the vehicle body exits by itself. Similar elements of the ninth embodiment to the above-described second embodiment will be identified by the same reference numerals as the second embodiment, and will not be described especially.

[0168] A controller 151_i according to the ninth embodiment includes a preprocessing unit (not illustrated) that acquires the accelerations a_{i-1} , a_i , and a_{i+1} from the detection signals of the acceleration sensors 9_{i-1} , 9_i , and 9_{i+1} . In addition thereto, the controller 151_i includes a vibration control unit 152 that outputs the number i bogie control force instruction

u_i according to the instruction values for the actuators 7A based on the accelerations a_{i-1} , a_i , and a_{i+1} .

[0169] The vibration control unit 152 includes a number i vehicle body vibration calculation unit 153_i , a number $i+1$ vehicle body vibration calculation unit 153_{i+1} , and a control force instruction calculation unit 154.

[0170] The number i vehicle body vibration calculation unit 153_i is configured in a substantially similar manner to the number i vehicle body vibration calculation unit 34_i according to the second embodiment, and calculates the vibration of the vehicle body 2_i based on the accelerations a_{i-1} and a_i , which are detection values of the acceleration sensors 9_{i-1} and 9_i . The number $i+1$ vehicle body vibration calculation unit 153_{i+1} is configured in a substantially similar manner to the number $i+1$ vehicle body vibration calculation unit 34_{i+1} according to the second embodiment, and calculates the vibration of the vehicle body 2_{i+1} based on the accelerations a_i and a_{i+1} , which are detection values of the acceleration sensors 9_i and 9_{i+1} .

[0171] The control force instruction calculation unit 154 calculates the number i bogie control force instruction u_i based on the vibrations of the vehicle bodies 2_i and 2_{i+1} . This control force instruction calculation unit 154 includes a number i vehicle body control force instruction calculation unit 155_i , a number $i+1$ vehicle body control force instruction calculation unit 155_{i+1} , and an addition unit 156.

[0172] The number i vehicle body control force instruction calculation unit 155_i calculates control force instructions u_{iF} and u_{iR} for reducing the vibration of the vehicle body 2_i by bogies 4_{iF} and 4_{iR} , assuming that the vehicle body 2_i is a non-coupled independent vehicle with the bogies 4_{iF} and 4_{iR} disposed on the front and rear sides thereof. More specifically, the number i vehicle body control force instruction calculation unit 155_i calculates a number i vehicle body front side control force instruction u_{iF} for the vertically movable dampers 7 of the bogie 4_{iF} virtually disposed on the front side of the vehicle body 2_i based on the vibration of the vehicle body 2_i . Similarly, the number i vehicle body control force instruction calculation unit 155_i calculates a number i vehicle body rear side control force instruction u_{iR} for the vertically movable dampers 7 of the bogie 4_{iR} virtually disposed on the rear side of the vehicle body 2_i based on the vibration of the vehicle body 2_i .

[0173] The number $i+1$ vehicle body control force instruction calculation unit 155_{i+1} calculates control force instructions u_{i+1F} and u_{i+1R} for reducing the vibration of the vehicle body 2_{i+1} by bogies 4_{i+1F} and 4_{i+1R} , assuming that the vehicle body 2_{i+1} is a non-coupled independent vehicle with the bogies 4_{i+1F} and 4_{i+1R} disposed on the front and rear sides of the vehicle body 2_{i+1} . More specifically, the number $i+1$ vehicle body control force instruction calculation unit 155_{i+1} calculates a number $i+1$ vehicle body front side control force instruction u_{i+1F} for the vertically movable dampers 7 of the bogie 4_{i+1F} virtually disposed on the front side of the vehicle body 2_{i+1} based on the vibration of the vehicle body 2_{i+1} . Similarly, the number $i+1$ vehicle body control force instruction calculation unit 155_{i+1} calculates a number $i+1$ vehicle body rear side control force instruction u_{i+1R} for the vertically movable dampers 7 of the bogie 4_{i+1R} virtually disposed on the rear side of the vehicle body 2_{i+1} based on the vibration of the vehicle body 2_{i+1} .

[0174] The addition unit 156 adds the number i vehicle body rear side control force instruction u_{iR} calculated by the number i vehicle body control force instruction calculation unit 155_i and the number $i+1$ vehicle body front side control force instruction u_{i+1F} calculated by the $i+1$ vehicle body control force instruction calculation unit 155_{i+1} , and calculates the number i bogie control force instruction u_i for the vertically movable dampers 7 of the coupling bogie 4_i disposed between the number i vehicle body and the number $i+1$ vehicle body.

[0175] Then, the number i control force instruction u_i calculated by the control force instruction calculation unit 154 is input into the number i bogie current output unit 14_i , and the number i bogie current output unit 14_i supplies instruction currents according to the number i bogie control force instruction u_i to the actuator 7As of the vertically movable dampers 7 of the bogie 4_i . As a result, the vibration of the vehicle body 2_i due to pitching and bouncing is damped, whereby the ride comfort of the vehicle body 2_i can be improved.

[0176] Next, a control law used by the control force instruction calculation unit 154 will be described.

[0177] First, control of the ride comfort of the number i vehicle body 2_i will be described. As illustrated in Fig. 30, suppose that the vehicle body 2_i exists by itself with the bogies 4_{iF} and 4_{iR} virtually disposed on the front and rear sides of the vehicle body 2_i , and the vertically movable dampers 7 are disposed on the front bogie 4_{iF} and the rear bogie 4_{iR} , respectively. Assume that u_{iF} and u_{iR} represent control forces for these respective vertically movable dampers 7.

[0178] In this case, the number i vehicle body control force instruction calculation unit 155_i calculates the control force u_{iF} for the vertically movable dampers 7 of the front bogie 4_{iF} of the number i vehicle body and the control force u_{iR} for the vertically movable dampers 7 of the rear bogie 4_{iR} of the number i vehicle body based on the vertical displacement z_{Bi} and the pitching angle θ_i of the number i vehicle body 2_i in the following manner.

[Equation 37]

$$\begin{pmatrix} u_{iF} \\ u_{iR} \end{pmatrix} = \begin{pmatrix} A_{iF} & B_{iF} & C_{iF} & D_{iF} \\ A_{iR} & B_{iR} & C_{iR} & D_{iR} \end{pmatrix} \begin{pmatrix} \dot{z}_{Bi} \\ z_{Bi} \\ \dot{\theta}_i \\ \theta_i \end{pmatrix}$$

[0179] Gains A_{iF} to D_{iF} and A_{iR} to D_{iR} are determined, for example, by the Skyhook control, the LQG control, or the like performed against pitching and bouncing of the number i vehicle body 2.

[0180] Similarly, the number $i+1$ vehicle body control force instruction calculation unit 155_{i+1} calculates the control force u_{i+1F} for the vertically movable dampers 7 of the front bogie 4_{i+1F} of the number $i+1$ vehicle body, and the control force u_{i+1R} for the vertically movable dampers 7 of the rear bogie 4_{i+1R} of the number $i+1$ vehicle body in the following manner.

[Equation 38]

$$\begin{pmatrix} u_{i+1F} \\ u_{i+1R} \end{pmatrix} = \begin{pmatrix} A_{i+1F} & B_{i+1F} & C_{i+1F} & D_{i+1F} \\ A_{i+1R} & B_{i+1R} & C_{i+1R} & D_{i+1R} \end{pmatrix} \begin{pmatrix} \dot{z}_{Bi+1} \\ z_{Bi+1} \\ \dot{\theta}_{i+1} \\ \theta_{i+1} \end{pmatrix}$$

[0181] The coupling bogie 4_i serves as both the rear bogie 4_{iR} of the number i vehicle body and the front bogie 4_{i+1F} of the number $i+1$ vehicle body. Therefore, the addition unit 156 of the control force instruction calculation unit 154 calculates the control force u_i for the number i bogie 4_i from a sum of the control force u_{ip} for the rear bogie 4_i of the number i vehicle body and the control force u_{i+1F} for the front bogie 4_{i+1F} of the number $i+1$ vehicle body, as indicated by the following equation, an equation 39.

[Equation 39]

$$u_i = u_{iR} + u_{i+1F}$$

[0182] The following equation, an equation 40 can be acquired by combining the above-described equations 37 to 39.

[Equation 40]

$$\begin{aligned} u_i = & A_{iR} \dot{z}_{Bi} + A_{i+1F} \dot{z}_{Bi+1} + B_{iR} z_{Bi} + B_{i+1F} z_{Bi+1} \\ & + C_{iR} \dot{\theta}_i + C_{i+1F} \dot{\theta}_{i+1} + D_{iR} \theta_i + D_{i+1F} \theta_{i+1} \end{aligned}$$

[0183] This equation 40 has the same form as the recurrence relation of the equation 28 according to the second embodiment. In other words, the ninth embodiment corresponds to the second embodiment with the control gains $G_{Ai,i}$, $G_{Ai,i+1}$, $G_{Bi,i}$, $G_{Bi,i+1}$, $G_{Ci,i}$, $G_{Ci,i+1}$, $G_{Di,i}$, and $G_{Di,i+1}$ replaced by the following manner.

[Equation 41]

$$G_{Ai,i} = A_{iR} , \quad G_{Ai,i+1} = A_{i+1F}$$

$$G_{Bi,i} = B_{iR} , \quad G_{Bi,i+1} = B_{i+1F}$$

$$G_{Ci,i} = C_{iR} , \quad G_{Ci,i+1} = C_{i+1F}$$

$$G_{Di,i} = D_{iR} , \quad G_{Di,i+1} = D_{i+1F}$$

[0184] Therefore, the ninth embodiment can acquire a vibration reduction effect close to the second embodiment with the control force u_i calculated by the equation 39. In addition thereto, the ninth embodiment can determine the control parameters without calculating the above-described high-order optimum feedback.

[0185] In this manner, the ninth embodiment can also acquire a similar result and effect to the second embodiment. Further, the ninth embodiment can reduce the calculation amount of the control apparatus 151_i because it eliminates the necessity of calculating the high-order optimum feedback.

[0186] The ninth embodiment may be combined with any of the third to eighth embodiments.

[0187] Next, Figs. 31 and 32 illustrate a tenth embodiment of the present invention. The tenth embodiment is characterized in that the controller calculates the control force of the coupling bogie based on vibrations of four vehicle bodies. Similar elements of the tenth embodiment to the above-described second embodiment will be identified by the same reference numerals as the second embodiment, and will not be described especially.

[0188] A railway train 161 according to the tenth embodiment includes the vehicle body 2_i, the coupling portion 3_i, the bogie 4_i, the vertically movable dampers 7, the acceleration sensor 9_i, a controller 162_i, and the like in a substantially similar manner to the railway train 31 according to the second embodiment.

[0189] The controller 162_i include a preprocessing unit (not illustrated) that acquires the accelerations a_{i-2} , a_{i-1} , a_i , a_{i+1} , and a_{i+2} from the detection signals of the acceleration sensors 9_{i-2}, 9_{i-1}, 9_i, 9_{i+1}, and 9_{i+2}. In addition thereto, the controller 162_i includes a vibration control unit 163 that outputs the number i bogie control force instruction u_i according to the instruction values for the actuators 7A based on the accelerations a_{i-2} , a_{i-1} , a_i , a_{i+1} , and a_{i+2} .

[0190] The vibration control unit 163 includes a number $i-1$ vehicle body vibration calculation unit 164_{i-1}, a number i vehicle body vibration calculation unit 164_i, a number $i+1$ vehicle body vibration calculation unit 164_{i+1}, a number $i+2$ vehicle body vibration calculation unit 164_{i+2}, and a control force instruction calculation unit 165.

[0191] In this case, the vehicle body vibration calculation units 164_{i-1}, 164_i, 164_{i+1}, and 164_{i+2} are configured in a substantially similar manner to the number i vehicle body vibration calculation unit 12_i according to the first embodiment. Therefore, the vehicle body vibration calculation units 164_{i-1}, 164_i, 164_{i+1}, and 164_{i+2} calculate the vibrations of the vehicle bodies 2_{i-1}, 2_i, 2_{i+1}, and 2_{i+2} based on the equations 1 and 2. Therefore, the number $i-1$ vehicle body vibration calculation unit 164_{i-1} calculates the vibration of the vehicle body 2_{i-1} based on the accelerations a_{i-2} and a_{i-1} , which are the detection values of the acceleration sensors 9_{i-2} and 9_{i-1}. The number i vehicle body vibration calculation unit 164_i calculates the vibration of the vehicle body 2_i based on the accelerations a_{i-1} and a_i , which are the detection values of the acceleration sensors 9_{i-1} and 9_i. The number $i+1$ vehicle body vibration calculation unit 164_{i+1} calculates the vibration of the vehicle body 2_{i+1} based on the accelerations a_i and a_{i+1} , which are the detection values of the acceleration sensors 9_i and 9_{i+1}. The number $i+2$ vehicle body vibration calculation unit 164_{i+2} calculates the vibration of the vehicle body 2_{i+2} based on the accelerations a_{i+1} and a_{i+2} , which are the detection values of the acceleration sensors 9_{i+1} and 9_{i+2}.

[0192] The control force instruction calculation unit 165 calculates the number i bogie control force instruction u_i for the vertically movable dampers 7 of the bogie 4_i based on the vibrations of the vehicle bodies 2_{i-1}, 2_i, 2_{i+1}, and 2_{i+2} calculated by these vehicle body vibration calculation units 164_{i-1}, 164_i, 164_{i+1}, and 164_{i+2}. Then, the number i bogie control force instruction u_i calculated by the control force instruction calculation unit 165 is input into the number i bogie current output unit 14_i, and the number i bogie current output unit 14_i supplies instruction currents according to the number i bogie control force instruction u_i to the actuators 7A of the vertically movable dampers 7 of the bogie 4_i. As a result, the vibration of the vehicle body 2_i due to pitching and bouncing is damped, whereby the ride comfort of the vehicle body 2_i can be improved.

[0193] The railway train 161 configured in the above-described manner controls the damping forces of the vertically movable dampers 7 of the bogie 4_i based on the outputs of the acceleration sensors 9_{i-2}, 9_{i-1}, 9_i, 9_{i+1}, and 9_{i+2} according to a control law that will be described next.

[0194] The control law according to the tenth embodiment is configured basically in a similar manner to the second embodiment. However, this control law is different from the second embodiment in terms of approximating the state feedback K in the following manner.

[Equation 42]

$$K = [G_A \ G_B \ G_C \ G_D]$$

[Equation 43]

$$G_A = \begin{bmatrix} G_{A0,1} & G_{A0,2} & 0 & 0 & 0 & 0 & \dots & 0 & 0 & 0 & 0 & 0 & 0 \\ G_{A1,1} & G_{A1,2} & G_{A1,3} & 0 & 0 & 0 & \dots & 0 & 0 & 0 & 0 & 0 & 0 \\ G_{A2,1} & G_{A2,2} & G_{A2,3} & G_{A2,4} & 0 & 0 & \dots & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & G_{A3,2} & G_{A3,3} & G_{A3,4} & G_{A3,5} & 0 & \dots & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & G_{A4,3} & G_{A4,4} & G_{A4,5} & G_{A4,6} & \dots & 0 & 0 & 0 & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 0 & 0 & \dots & G_{An-4,n-5} & G_{An-4,n-4} & G_{An-4,n-3} & G_{An-4,n-2} & G_{An-4,n-1} & G_{An-4,n} \\ 0 & 0 & 0 & 0 & 0 & 0 & \dots & 0 & G_{An-3,n-4} & G_{An-3,n-3} & G_{An-3,n-2} & G_{An-3,n-1} & G_{An-3,n} \\ 0 & 0 & 0 & 0 & 0 & 0 & \dots & 0 & 0 & G_{An-2,n-3} & G_{An-2,n-2} & G_{An-2,n-1} & G_{An-2,n} \\ 0 & 0 & 0 & 0 & 0 & 0 & \dots & 0 & 0 & 0 & G_{An-1,n-2} & G_{An-1,n-1} & G_{An-1,n} \\ 0 & 0 & 0 & 0 & 0 & 0 & \dots & 0 & 0 & 0 & 0 & G_{An,n-1} & G_{An,n} \end{bmatrix}$$

[Equation 44]

$$G_B = \begin{bmatrix} G_{B0,1} & G_{B0,2} & 0 & 0 & 0 & 0 & \dots & 0 & 0 & 0 & 0 & 0 & 0 \\ G_{B1,1} & G_{B1,2} & G_{B1,3} & 0 & 0 & 0 & \dots & 0 & 0 & 0 & 0 & 0 & 0 \\ G_{B2,1} & G_{B2,2} & G_{B2,3} & G_{B2,4} & 0 & 0 & \dots & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & G_{B3,2} & G_{B3,3} & G_{B3,4} & G_{B3,5} & 0 & \dots & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & G_{B4,3} & G_{B4,4} & G_{B4,5} & G_{B4,6} & \dots & 0 & 0 & 0 & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 0 & 0 & \dots & G_{Bn-4,n-5} & G_{Bn-4,n-4} & G_{Bn-4,n-3} & G_{Bn-4,n-2} & G_{Bn-4,n-1} & G_{Bn-4,n} \\ 0 & 0 & 0 & 0 & 0 & 0 & \dots & 0 & G_{Bn-3,n-4} & G_{Bn-3,n-3} & G_{Bn-3,n-2} & G_{Bn-3,n-1} & G_{Bn-3,n} \\ 0 & 0 & 0 & 0 & 0 & 0 & \dots & 0 & 0 & G_{Bn-2,n-3} & G_{Bn-2,n-2} & G_{Bn-2,n-1} & G_{Bn-2,n} \\ 0 & 0 & 0 & 0 & 0 & 0 & \dots & 0 & 0 & 0 & G_{Bn-1,n-2} & G_{Bn-1,n-1} & G_{Bn-1,n} \\ 0 & 0 & 0 & 0 & 0 & 0 & \dots & 0 & 0 & 0 & 0 & G_{Bn,n-1} & G_{Bn,n} \end{bmatrix}$$

[Equation 45]

$$G_C = \begin{bmatrix} G_{C0,1} & G_{C0,2} & 0 & 0 & 0 & 0 & \dots & 0 & 0 & 0 & 0 & 0 & 0 \\ G_{C1,1} & G_{C1,2} & G_{C1,3} & 0 & 0 & 0 & \dots & 0 & 0 & 0 & 0 & 0 & 0 \\ G_{C2,1} & G_{C2,2} & G_{C2,3} & G_{C2,4} & 0 & 0 & \dots & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & G_{C3,2} & G_{C3,3} & G_{C3,4} & G_{C3,5} & 0 & \dots & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & G_{C4,3} & G_{C4,4} & G_{C4,5} & G_{C4,6} & \dots & 0 & 0 & 0 & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 0 & 0 & \dots & G_{Cn-4,n-5} & G_{Cn-4,n-4} & G_{Cn-4,n-3} & G_{Cn-4,n-2} & G_{Cn-4,n-1} & G_{Cn-4,n} \\ 0 & 0 & 0 & 0 & 0 & 0 & \dots & 0 & G_{Cn-3,n-4} & G_{Cn-3,n-3} & G_{Cn-3,n-2} & G_{Cn-3,n-1} & G_{Cn-3,n} \\ 0 & 0 & 0 & 0 & 0 & 0 & \dots & 0 & 0 & G_{Cn-2,n-3} & G_{Cn-2,n-2} & G_{Cn-2,n-1} & G_{Cn-2,n} \\ 0 & 0 & 0 & 0 & 0 & 0 & \dots & 0 & 0 & 0 & G_{Cn-1,n-2} & G_{Cn-1,n-1} & G_{Cn-1,n} \\ 0 & 0 & 0 & 0 & 0 & 0 & \dots & 0 & 0 & 0 & 0 & G_{Cn,n-1} & G_{Cn,n} \end{bmatrix}$$

[Equation 46]

$$G_D = \begin{bmatrix} G_{D0,1} & G_{D0,2} & 0 & 0 & 0 & 0 & \dots & 0 & 0 & 0 & 0 & 0 & 0 \\ G_{D1,1} & G_{D1,2} & G_{D1,3} & 0 & 0 & 0 & \dots & 0 & 0 & 0 & 0 & 0 & 0 \\ G_{D2,1} & G_{D2,2} & G_{D2,3} & G_{D2,4} & 0 & 0 & \dots & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & G_{D3,2} & G_{D3,3} & G_{D3,4} & G_{D3,5} & 0 & \dots & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & G_{D4,3} & G_{D4,4} & G_{D4,5} & G_{D4,6} & \dots & 0 & 0 & 0 & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 0 & 0 & \dots & G_{Dn-4,n-5} & G_{Dn-4,n-4} & G_{Dn-4,n-3} & G_{Dn-4,n-2} & G_{Dn-4,n-1} & G_{Dn-4,n} \\ 0 & 0 & 0 & 0 & 0 & 0 & \dots & 0 & G_{Dn-3,n-4} & G_{Dn-3,n-3} & G_{Dn-3,n-2} & G_{Dn-3,n-1} & G_{Dn-3,n} \\ 0 & 0 & 0 & 0 & 0 & 0 & \dots & 0 & 0 & G_{Dn-2,n-3} & G_{Dn-2,n-2} & G_{Dn-2,n-1} & G_{Dn-2,n} \\ 0 & 0 & 0 & 0 & 0 & 0 & \dots & 0 & 0 & 0 & G_{Dn-1,n-2} & G_{Dn-1,n-1} & G_{Dn-1,n} \\ 0 & 0 & 0 & 0 & 0 & 0 & \dots & 0 & 0 & 0 & 0 & G_{Dn,n-1} & G_{Dn,n} \end{bmatrix}$$

[0195] In this case, the control force u_i to be generated at the vertically movable dampers 7 of the number i bogie 4_i is expressed by the following recurrence relation.

[Equation 47]

$$\begin{aligned} u_i = & G_{Ai,i-1} \dot{z}_{Bi-1} + G_{Ai,i} \dot{z}_{Bi} + G_{Ai,i+1} \dot{z}_{Bi+1} + G_{Ai,i+2} \dot{z}_{Bi+2} \\ & + G_{Bi,i-1} z_{Bi-1} + G_{Bi,i} z_{Bi} + G_{Bi,i+1} z_{Bi+1} + G_{Bi,i+2} z_{Bi+2} \\ & + G_{Ci,i-1} \dot{\theta}_{i-1} + G_{Ci,i} \dot{\theta}_i + G_{Ci,i+1} \dot{\theta}_{i+1} + G_{Ci,i+2} \dot{\theta}_{i+2} \\ & + G_{Di,i-1} \theta_{i-1} + G_{Di,i} \theta_i + G_{Di,i+1} \theta_{i+1} + G_{Di,i+2} \theta_{i+2} \end{aligned}$$

[0196] Focusing on the above-described recurrence relation, the control force u_i to be generated at the vertically movable dampers 7 of the number i bogie 4_i is determined based on only the motions of the number $i-1$ vehicle body, the number i vehicle body, the number $i+1$ vehicle body, and the number $i+2$ vehicle body. In other words, the controller 162_i is disposed very close to the vertically movable dampers 7, and the controller 162_i determines the control force u_i from the acceleration information of the its own vehicle body (the vehicle body 2_i), the adjacent vehicle body (the vehicle body 2_{i+1}), and the vehicle bodies (the vehicle bodies 2_{i-1} and 2_{i+2}) further adjacent to the respective vehicle bodies 2_i.

and 2_{i+1} according to the above-described recurrence relation. In this case, the length of the wiring laid in the railway train 161 is increased to a length corresponding to four vehicles, but the performance of the controller 162_i approaches the performance of the controller that calculates the control force in consideration of the vibrations of all of the vehicle bodies (the vehicle bodies 2_1 to 2_n), like the first embodiment.

[0197] In this manner, the tenth embodiment can also acquire a similar result and effect to the second embodiment. Further, the tenth embodiment calculates the control force u_i of the bogie 4_i based on the vibrations of the two vehicle bodies and the two vehicle bodies respectively on the opposite front and rear sides of the bogie 4_i , i.e., the total four vehicle bodies of the vehicle bodies 2_{i-1} , 2_i , 2_{i+1} , and 2_{i+2} , thereby succeeding in acquiring a vibration reduction effect close to the control in consideration of the vibrations of all of the vehicle bodies (the vehicle bodies 2_1 to 2_n).

[0198] The tenth embodiment calculates the control force u_i of the bogie 4_i based on the vibrations of the four vehicle bodies 2_{i-1} , 2_i , 2_{i+1} , and 2_{i+2} . However, the present invention is not limited thereto. For example, the controller may calculate the control force u_i of the bogie 4_i based on vibrations of six vehicle bodies, or may calculate the control force u_i of the bogie 4_i based on vibrations of eight vehicle bodies. Further, the controller does not necessarily have to calculate the control force based on vibrations of vehicle bodies corresponding to an even number, and may calculate the control force u_i of the bogie 4_i based on vibrations of three or more vehicles corresponding to an odd number. In other words, the present embodiment can be realized by calculating the control force u_i of the bogie 4_i without using a vibration of at least one vehicle body located away from the bogie 4_i that is the control target, among the n vehicle bodies 2_1 to 2_n . In this case, a vehicle body located away from the bogie 4_i is preferentially set as the vehicle body that is not used in the calculation of the control force u_i , because this is a vehicle body less influential on the control force u_i of the bogie 4_i .

[0199] Further, the tenth embodiment may be combined with any of the third to ninth embodiments.

[0200] Next, Figs. 33 and 34 illustrate an eleventh embodiment of the present embodiment. The eleventh embodiment is characterized in that the coupling bogie is provided with vertically movable dampers independently respectively mounted between the bogie and the vehicle body in front of the bogie, and between the bogie and the vehicle body behind the bogie. Similar elements of the eleventh embodiment to the above-described second embodiment will be identified

by the same reference numerals as the second embodiment, and will not be described especially.

[0201] A railway train 171 according to the eleventh embodiment includes the vehicle body 2_i , the coupling portion 3_i , the bogie 4_i , vertically movable dampers 172_{iF} and 172_{iR} , the acceleration sensor 9_i , a controller 173_i , and the like in a substantially similar manner to the railway train 31 according to the second embodiment.

[0202] The vertically movable damper 172_{iF} corresponds to the cylinder apparatus, and is disposed between the vehicle body 2_i and the bogie 4_i on each of the right and left sides at the front of the bogie 4_i . The vertically movable damper 172_{iF} is configured in a similar manner to the vertically movable damper 7, and includes the actuator 7A. A control signal (an instruction current) according to a number i bogie front side control force instruction u_{iF} is supplied from the control apparatus 173_i into the actuator 7A of the vertically movable damper 172_{iF} . As a result, the damping force of the vertically movable damper 172_{iF} is variably controlled according to the control signal.

[0203] The vertically movable damper 172_{iR} corresponds to the cylinder apparatus, and is disposed between the vehicle body 2_{i+1} and the bogie 4_i on each of the right and left sides at the rear of the bogie 4_i . The vertically movable damper 172_{iR} is configured in a similar manner to the vertically movable damper 7, and includes the actuator 7A. A control signal (an instruction current) according to a number i bogie rear side control force instruction u_{iR} is supplied from the control apparatus 173_i into the actuator 7A of the vertically movable damper 172_{iR} . As a result, the damping force of the vertically movable damper 172_{iR} is variably controlled according to the control signal.

[0204] The control apparatus 173_i is configured in a substantially similar manner to the control apparatus 32_i according to the second embodiment, and includes the vibration control unit 33. However, the control apparatus 173_i includes a division unit 174 that divides the number i bogie control force instruction u_i output from the vibration control unit 33 into the number i bogie front side control force instruction u_{iF} and the number i bogie rear side control force instruction u_{iR} .

[0205] According to the eleventh embodiment, the bogie 4_i directly supports the vehicle body 2_i on the front side of the bogie 4_i and the vehicle body 2_{i+1} on the rear side of the bogie 4_i with use of the vertically movable dampers 172_{iF} and 172_{iR} , respectively. In this case, if the vertically movable dampers 172_{iF} and 172_{iR} output respectively different control forces, this results in application of a moment for causing pitching of the bogie 4_i onto the bogie 4_i , thereby leading to the possibility of deteriorating a road-hugging property of the bogie 4_i to affect a braking distance.

[0206] Therefore, it is desirable to supply uniform control force instructions to the vertically movable dampers 172_{iF} and 172_{iR} on the front side and the rear side. In the coupling bogie train, the vehicle bodies are vertically inflexibly coupled to each other, whereby the vertically movable dampers 172_{iF} and 172_{iR} on the front side and the rear side have substantially equal stroke speeds and amounts. Therefore, supplying instructions in such a manner that the vertically movable dampers 172_{iF} and 172_{iR} on the front side and the rear side have equal damping coefficients allows the respective dampers to generate substantially equal damping forces.

[0207] In light thereof, the division unit 174 sets each of the control force instructions u_{iF} and u_{iR} to be supplied to the vertically movable dampers 172_{iF} and 172_{iR} on the front side and the rear side to a half of the number i bogie control force instruction u_i . The number i bogie front side control force instruction u_{iF} is input into a number i bogie front side

current output unit 175_{iF}, and the number i bogie rear side control force instruction u_{iR} is input into a number i bogie rear side current output unit 175_{iR}. These current output units 175_{iF} and 175_{iR} supply instruction currents according to the control force instructions u_{iF} and u_{iR} to the vertically movable dampers 172_{iF} and 172_{iR} of the bogie 4_i.

[0208] In this manner, the eleventh embodiment can also acquire a similar result and effect to the second embodiment.

[0209] The eleventh embodiment is configured in such a manner that the pneumatic springs 5 are provided between the bogie 4_i and the coupling portion 3_i. However, the pneumatic springs 5 may be provided between the bogie 4_i and the vehicle bodies 2_i and 2_{i+1}, respectively, like a railway train 181 according to a fifth modification illustrated in Fig. 35.

[0210] The eleventh embodiment may be applied to the first embodiment, and may be combined with any of the third to tenth embodiments.

[0211] Next, Fig. 36 illustrates a twelfth embodiment of the present invention. The twelfth embodiment is characterized in that the controller also performs vibration reduction control even against rolling of the vehicle body. Similar elements of the twelfth embodiment to the above-described second embodiment will be identified by the same reference numerals as the second embodiment, and will not be described especially.

[0212] A controller 191_i according to the twelfth embodiment is configured in a substantially similar manner to the controller 32_i according to the second embodiment, and includes the vibration control unit 33. In addition thereto, the controller 191_i includes a rolling vibration control unit 192 that outputs control force instructions u_{irollL} and u_{irollR} for reducing rolling of the vehicle bodies 2_i and 2_{i+1}, a left side control force instruction calculation unit 193_L that calculates a number i bogie left side control force instruction u_{imixL} based on the number i bogie control force instruction u_i and the control force instruction u_{irollL} , and a right side control force instruction calculation unit 193_R that calculates a number i bogie right side control force instruction u_{imixR} based on the number i bogie control force instruction u_i and the control force instruction u_{irollR} . The rolling vibration control unit 192 detects rolling of the vehicle bodies 2_i and 2_{i+1} with use of, for example, acceleration sensors (not illustrated) mounted on both lateral sides of the vehicle bodies 2_i and 2_{i+1}.

[0213] The number i bogie control force instruction u_i is a sum of the control forces for the vertically movable dampers 7 mounted on the left and right sides of the bogie 4_i. Therefore, the control force instruction calculation units 193_L and 193_R calculate the number i bogie left side control force instruction u_{imixL} for the vertically movable damper 7 on the left side of the number i bogie 4_i, and the number i bogie right side control force instruction u_{imixR} for the vertically movable damper 7 on the right side of the number i bogie 4_i based on the following equations, respectively.

[Equation 48]

$$u_{imixL} = u_{irollL} + \frac{u_i}{2}$$

[Equation 49]

$$u_{imixR} = u_{irollR} + \frac{u_i}{2}$$

[0214] The number i bogie left side control force instruction u_{imixL} is input into a number i bogie left side current output unit 194_{iL}, and the number i bogie right side control force instruction u_{imixR} is input into a number i bogie right side current output unit 194_{iR}. These current output units 194_{iL} and 194_{iR} supply instruction currents according to the control force instructions u_{imixL} and u_{imixR} to the vertically movable damper 7 on the left side of the bogie 4_i and the vertically movable damper 7 on the right side of the bogie 4_i, respectively.

[0215] In this manner, the twelfth embodiment can also acquire a similar result and effect to the second embodiment. The twelfth embodiment can also reduce rolling in addition to pitching and bouncing of the vehicle body 2_i.

[0216] According to the twelfth embodiment, the equations 48 and 49 are formulated with weights for rolling and the vertical vibration set substantially equally to each other. However, these weights for addition may be arbitrarily changed.

[0217] Further, according to the twelfth embodiment, the control targets are set to three degree of freedom, i.e., the two degrees of freedom of vibrations, bouncing and pitching with rolling added thereto. However, the present invention is not limited thereto. For example, the controller may be configured to deal with a higher-order motion equation established by adding rolling and yawing of the vehicle body and a motion of the bogie, thereby controlling the ride comfort by applying the present invention while reducing other vibration modes than the vertical vibration.

[0218] Further, the twelfth embodiment may be applied to the first embodiment, and may be combined to any of the third to eleventh embodiments.

[0219] Further, according to the above-described respective embodiments, the coupling bogie 4_i is disposed at the coupling portion 3_i that couples the two vehicle bodies 2_i and 2_{i+1}. However, the present invention is not limited thereto.

For example, a coupling bogie 202_i may be disposed at a different position from the coupling portion 3_i, like a railway train 201 according to a sixth modification illustrated in Fig. 37. In this case, for example, the coupling bogie 202_i is mounted under the vehicle body 2_i at the rear end of the vehicle body 2_i, which is an end of the vehicle body 2_i closer to the vehicle body 2_{i+1} adjacent to the vehicle body 2_i, and supports the vehicle body 2_i and the like via spring members such as the pneumatic springs 5. Further, according to the above-described respective embodiments, the coupling bogie 4_i includes four wheels 6, but may include two wheels 6, like the coupling bogie 202_i.

[0220] Further, the above-described respective embodiments have been described based on the example in which the vertically movable damper 7 is a semi-active damper, but may use an active damper (any of an electric actuator and a hydraulic actuator) instead of the semi-active damper. Use of the active damper can further effectively improve the ride comfort.

[0221] Further, according to the above-described respective embodiments, the controllers 10, 22, 32_i, 41_i, 51_i, 71_i, 81_i, 103_i, 113_i, 123_i, 132_i, 143_i, 151_i, 162_i, 173_i, and 191_i reduce the vertical vibration of the vehicle body 2_i such as bouncing and pitching, but may reduce a lateral vibration of the vehicle body 2_i.

[0222] Next, an aspect of the present invention corresponding to one of the above-described embodiments will be described. According to the aspect of the present invention, the controller calculates the instruction value for the actuator based on the detection value of the first vibration detector configured to detect the vibration of the first vehicle body and the detection value of the second vibration detector configured to detect the vibration of the second vehicle body. Therefore, it is possible to control the vertically movable damper of the bogie in consideration of influence of the vehicle bodies on each other even when the plurality of vehicle bodies coupled to each other via the coupling bogie is influentially linked to each other. As a result, it is possible to reduce the vibration of the vehicle body in the entire coupling bogie train including the plurality of vehicle bodies to improve the ride comfort.

[0223] According to another aspect of the present invention, one or more vehicle bodies are further additionally coupled to the first vehicle body and/or the second vehicle body. The controller calculates the instruction value for the actuator without using a vibration of at least one vehicle body located away from the coupling portion among the added vehicle bodies. Therefore, it is possible to reduce the length of the cable that connects the various kinds of sensors and the vertically movable damper to the control apparatus, compared to, for example, controlling the vibration based on the vibrations of all of the vehicle bodies, thereby realizing simplification of the wiring layout and a reduction in a noise. In addition thereto, it is possible to simplify the ride comfort control calculation, thereby reducing the manufacturing cost.

[0224] According to still another aspect of the present invention, the railway train further includes another cylinder apparatus disposed between the coupling bogie and the second vehicle body and configured to exert an application force adjustable by another actuator, and the controller calculates the instruction value for the other actuator based on the detection value of the first vibration detector and the detection value of the second vibration detector. As a result, even when different cylinder apparatuses are provided between the first and second vehicle bodies and the coupling bogie, respectively, the controller can improve the ride comfort of the coupling bogie train by adjusting the application forces of these cylinder apparatuses.

[0225] According to still another aspect of the present invention, the controller includes the high-pass filter configured to remove a component of a lower frequency than a resonance point of bouncing and pitching of the first and second vehicle bodies from the detection value of the first vibration detector and the detection value of the second vibration detector. Therefore, it is possible to remove the component of a gradual acceleration change, for example, like a change in a slope of a road surface, from the detection values of the first and second vibration detectors, thereby providing control against only a vibration such as pitching and bouncing. As a result, it is possible to prevent the cylinder apparatus from generating an unnecessary application force on an ascending slope track or a descending slope track, thereby improving the ride comfort on the ascending slope track and the like.

[0226] According to still another aspect of the present invention, the railway train further includes the inter-vehicle displacement sensor configured to detect the inter-vehicle displacement between the first vehicle body and the second vehicle body. The second vibration detector calculates the vibration of the second vehicle body based on the detection value of the first vibration detector and the detection value of the inter-vehicle displacement sensor. Therefore, it is possible to detect the vibrations of the first and second vehicle bodies with use of the first vibration detector and the inter-vehicle displacement sensor disposed about the first vehicle body.

[0227] Although only some exemplary embodiments of this invention have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the exemplary embodiments without materially departing from the novel teaching and advantages of this invention. Accordingly, all such modifications are intended to be included within the scope of this invention.

Claims

1. A suspension control system comprising:

a coupling portion configured to couple at least two vehicle bodies and connect a first vehicle body and a second vehicle body adjacent to each other in such a manner that a driving force can be transmitted therebetween;
a coupling bogie configured to provide a support on at least a second vehicle body side of the first vehicle body via a spring member;

a cylinder apparatus disposed between the coupling bogie and the first vehicle body and configured to exert an application force adjustable by an actuator;
a controller configured to control the actuator;

a first vibration detector configured to detect a vibration of the first vehicle body; and

a second vibration detector configured to detect a vibration of the second vehicle body,

wherein the controller calculates an instruction value for the actuator based on a detection value of the first vibration detector and a detection value of the second vibration detector.

2. The suspension control system according to claim 1, wherein a single vehicle body or a plurality of vehicle bodies is further additionally coupled to the first vehicle body and/or the second vehicle body, and
wherein the controller calculates the instruction value for the actuator without using a vibration of at least one vehicle body located away from the coupling portion among the added vehicle bodies.

3. The suspension control system according to claim 1 or 2, further comprising a second cylinder apparatus disposed between the coupling bogie and the second vehicle body and configured to exert an application force adjustable by a second actuator,
wherein the controller calculates an instruction value for the second actuator based on the detection value of the first vibration detector and the detection value of the second vibration detector.

4. The suspension control system according to any of claims 1 to 3, wherein the controller includes a high-pass filter configured to remove a component of a lower frequency than a resonance frequency of bouncing and pitching of the first and second vehicle bodies from the detection value of the first vibration detector and the detection value of the second vibration detector.

5. The suspension control system according to any of claims 1 to 4, further comprising an inter-vehicle displacement sensor configured to detect an inter-vehicle displacement between the first vehicle body and the second vehicle body,
wherein the second vibration detector calculates the vibration of the second vehicle body based on the detection value of the first vibration detector and a detection value of the inter-vehicle displacement sensor.

Fig. 1

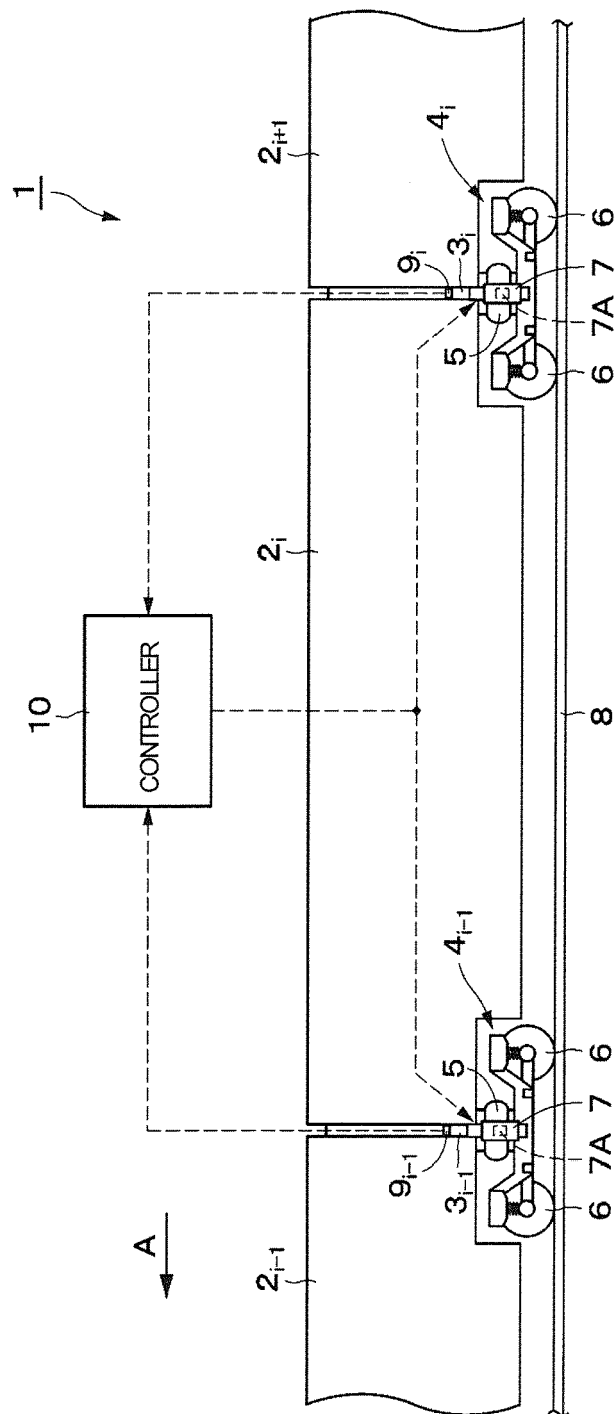


Fig. 2

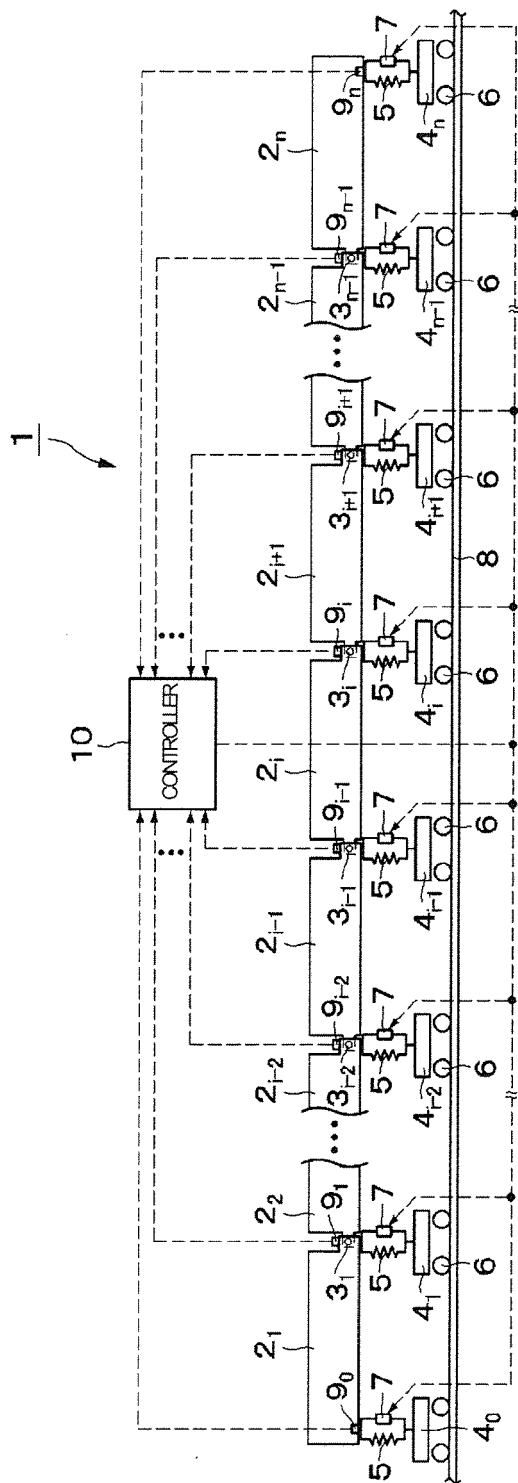


Fig. 3

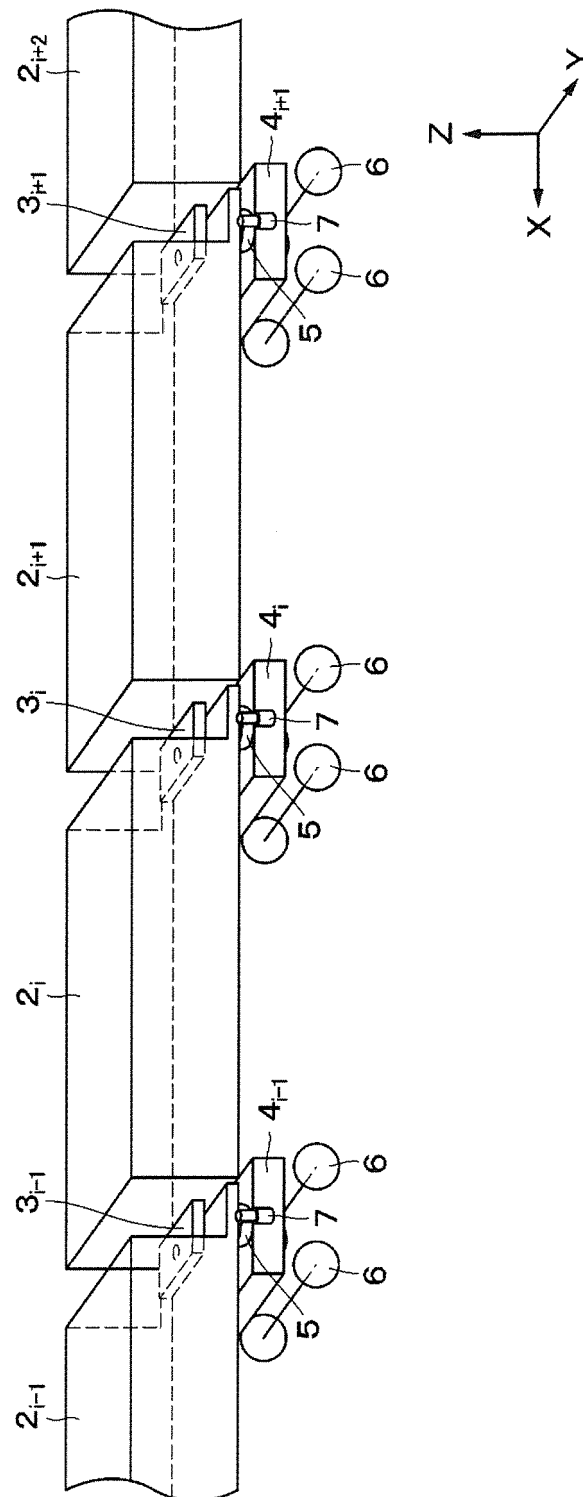


Fig. 4

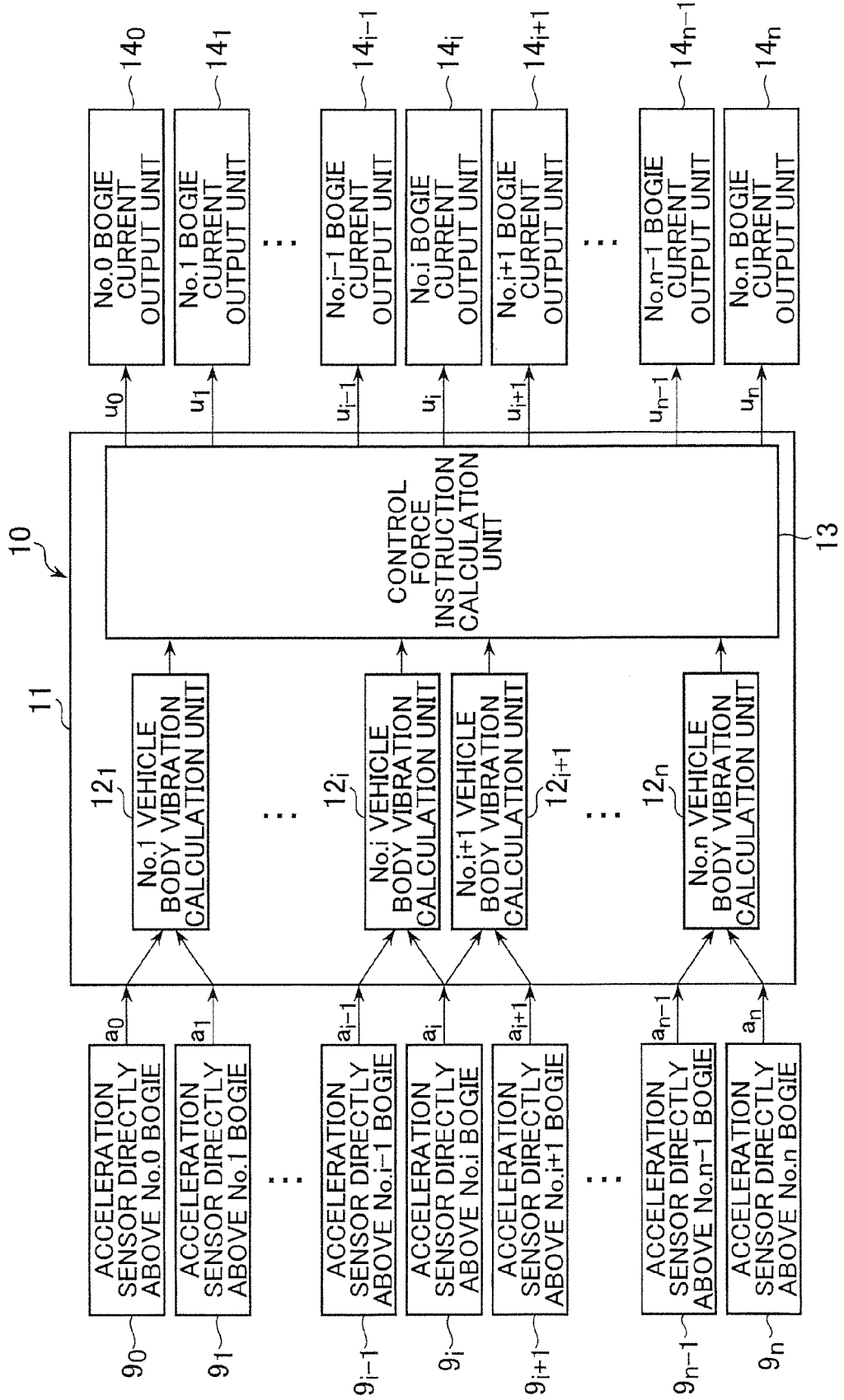


Fig. 5

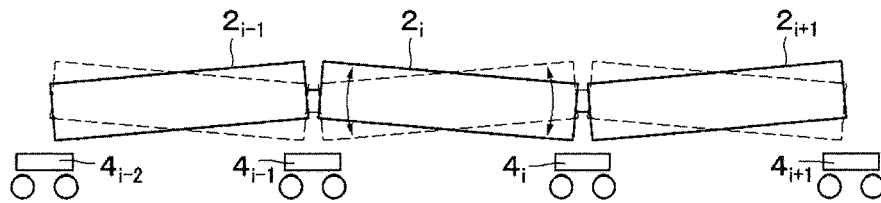


Fig. 6

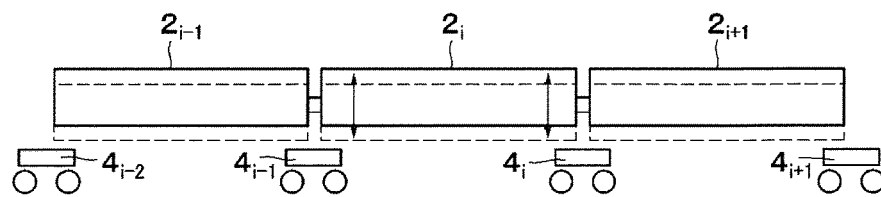


Fig. 7

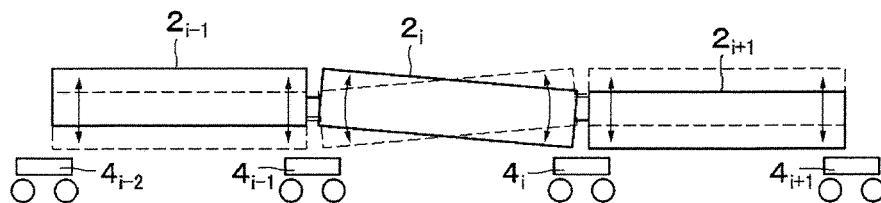


Fig. 8

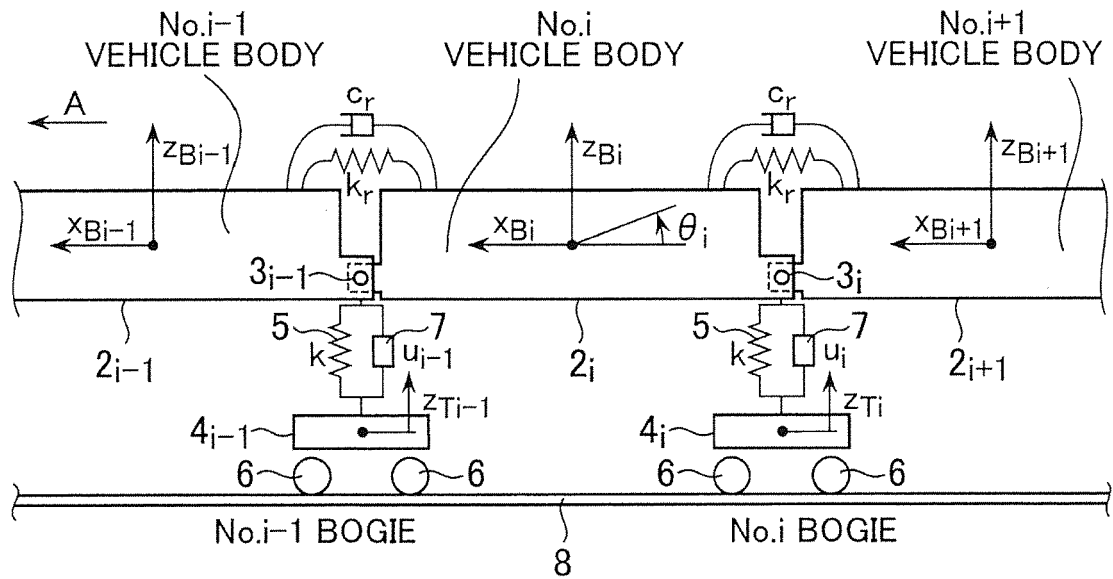


Fig. 9

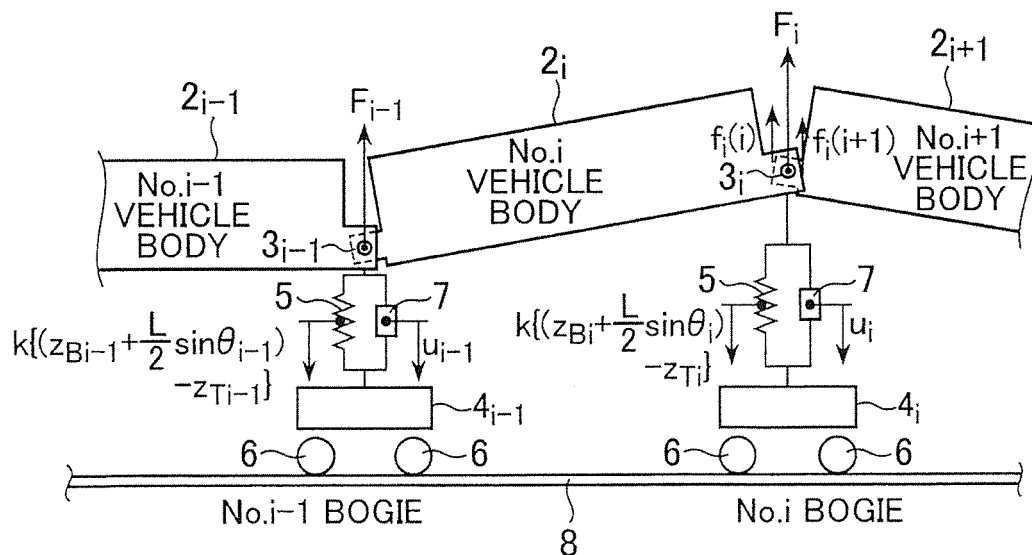


Fig. 10

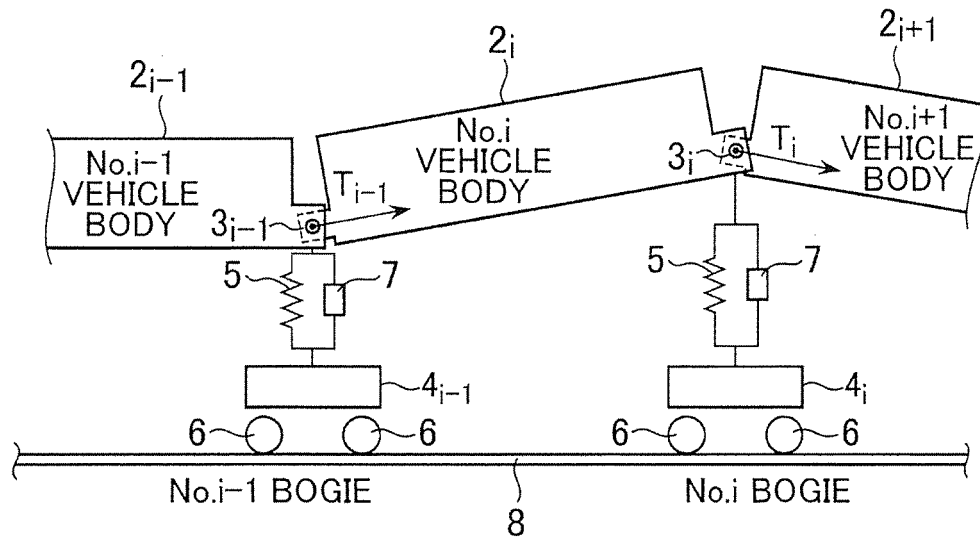


Fig. 11

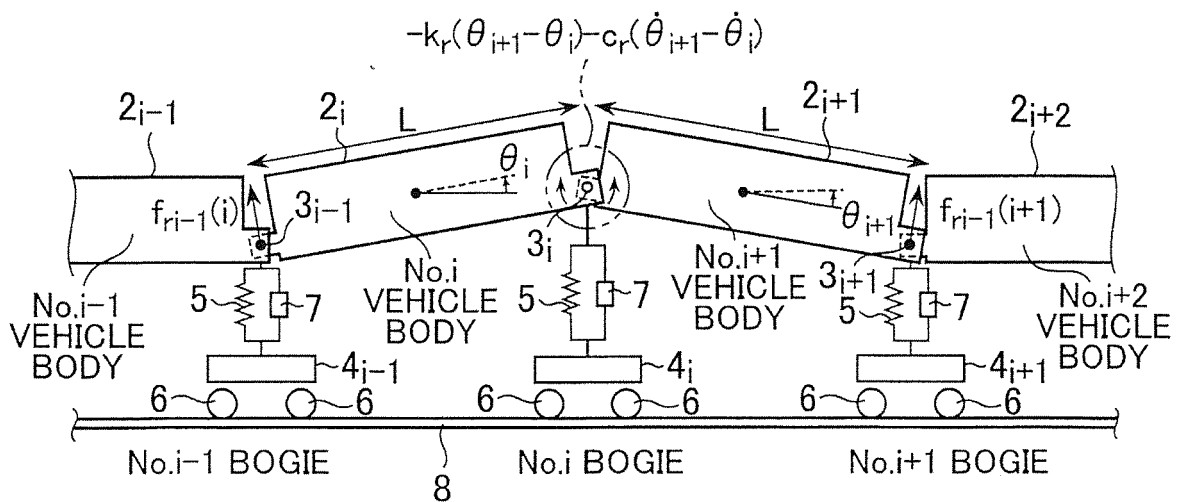


Fig. 12

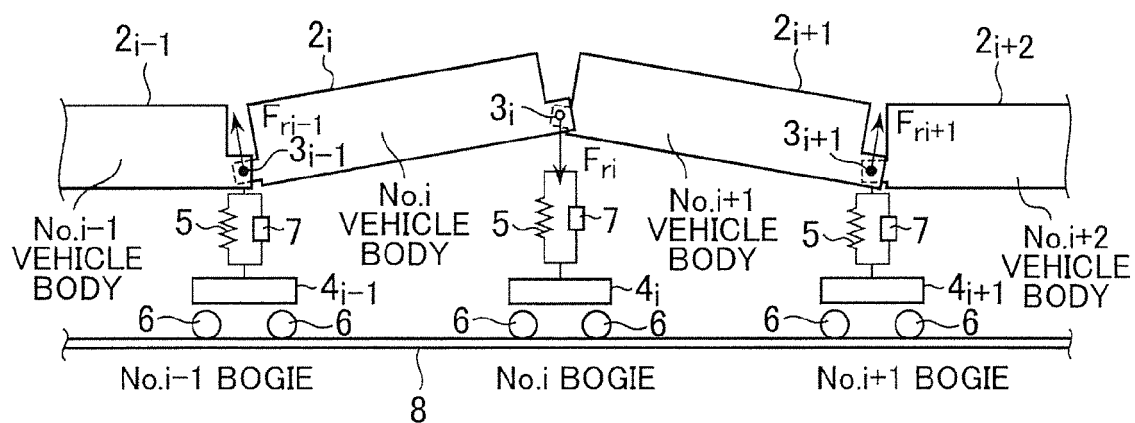


Fig. 13

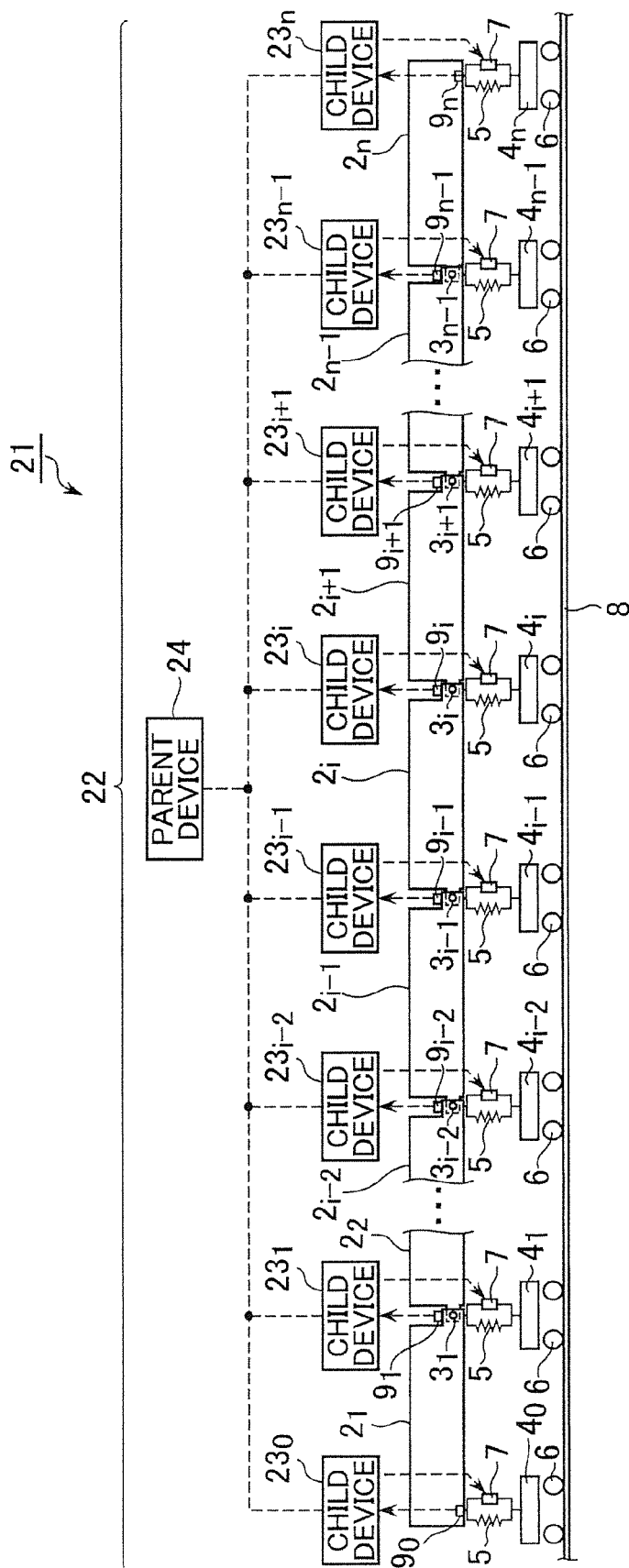


Fig. 14

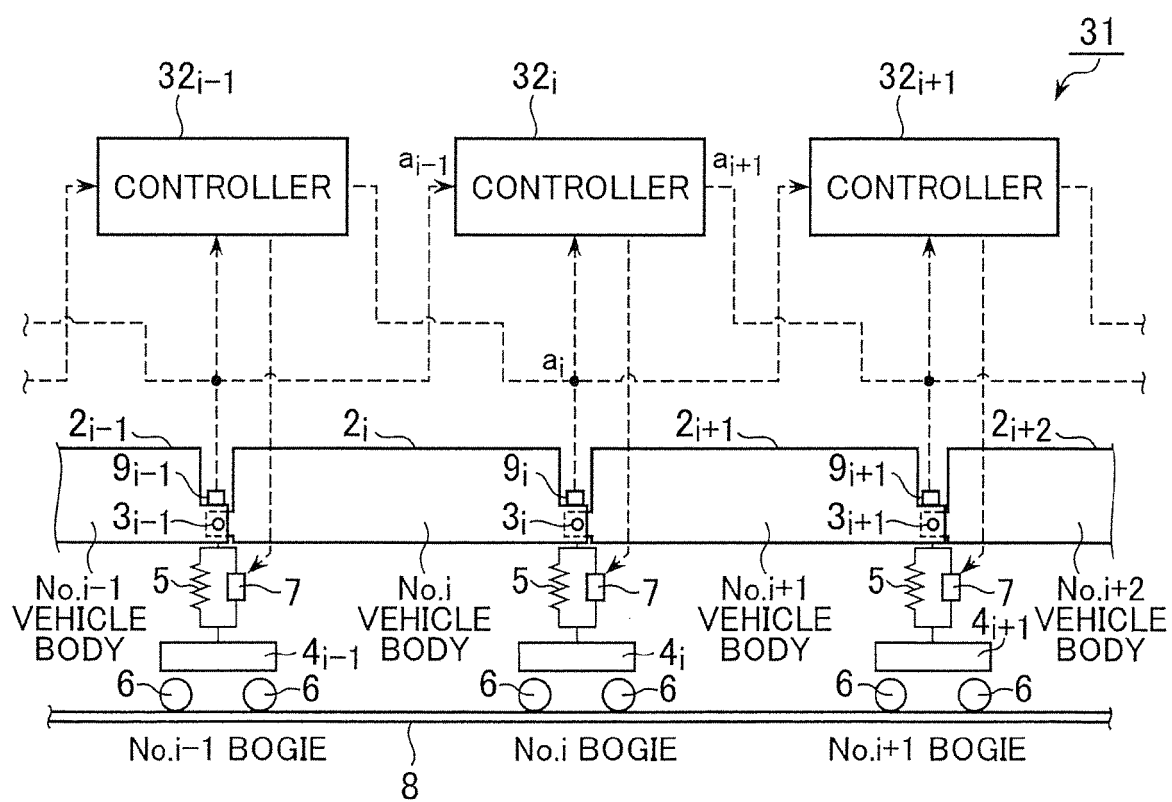


Fig. 15

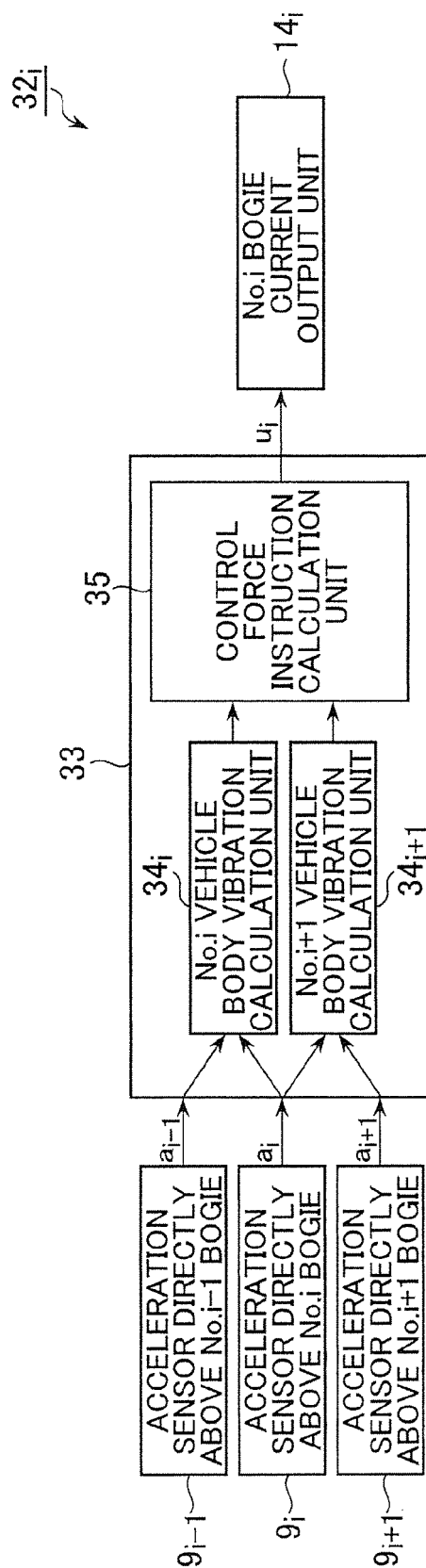


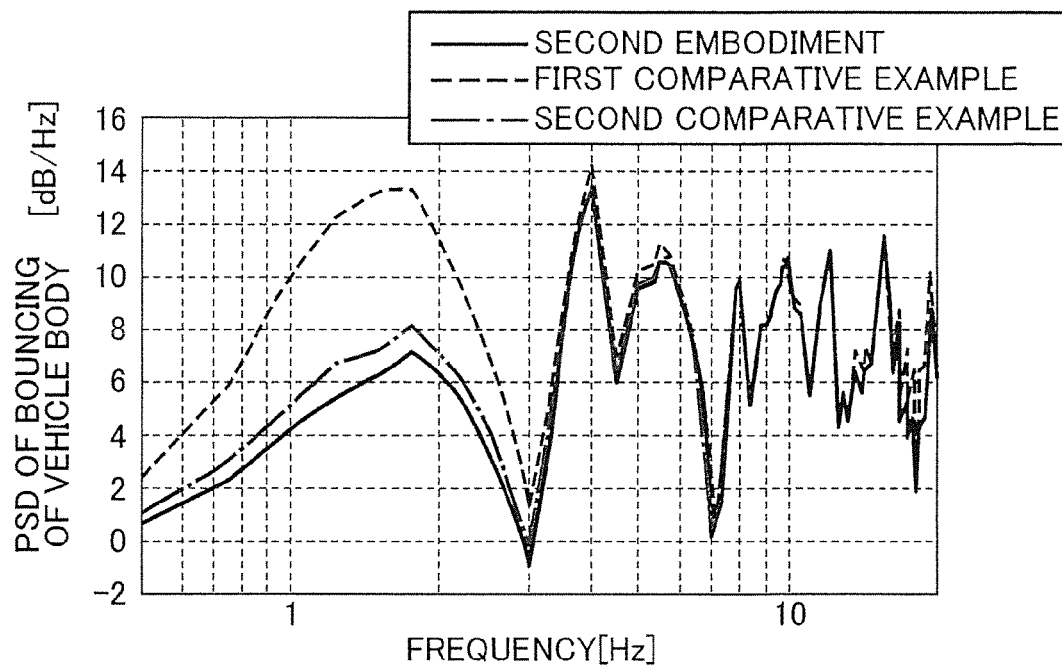
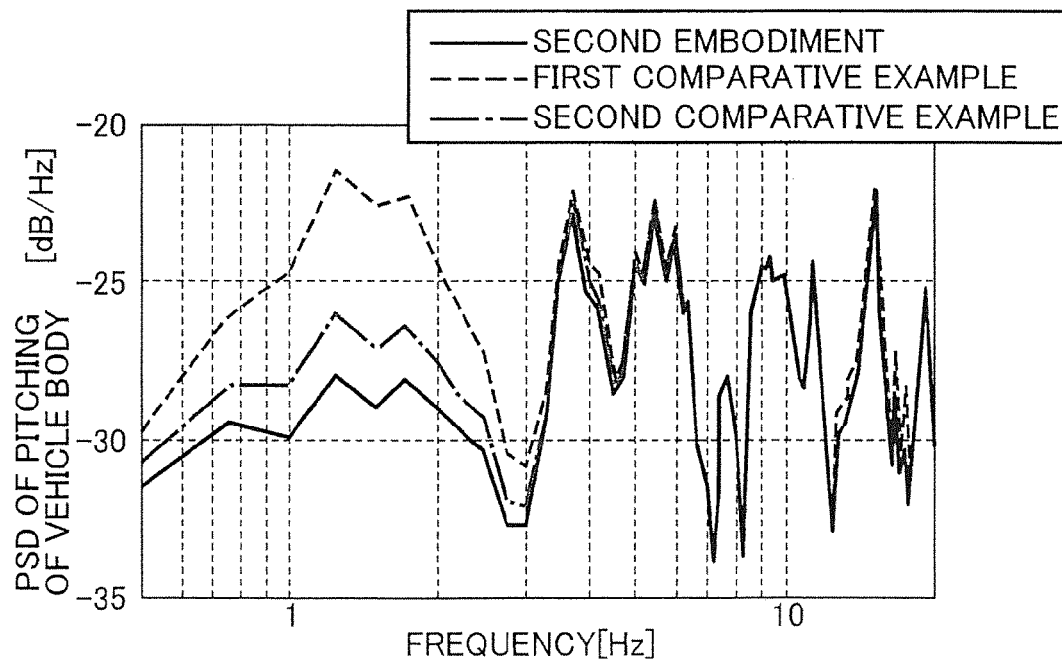
Fig. 16*Fig. 17*

Fig. 18

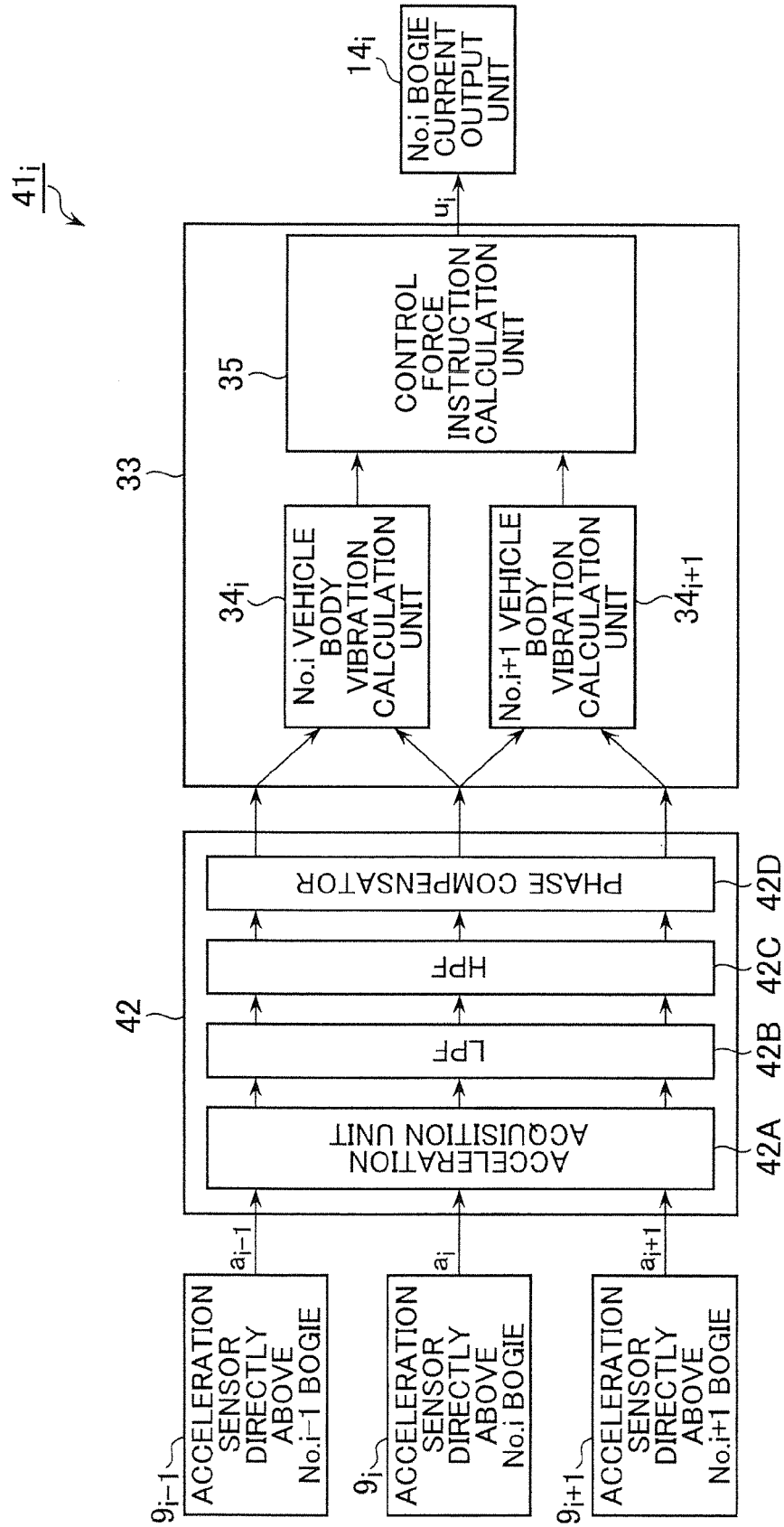


Fig. 19

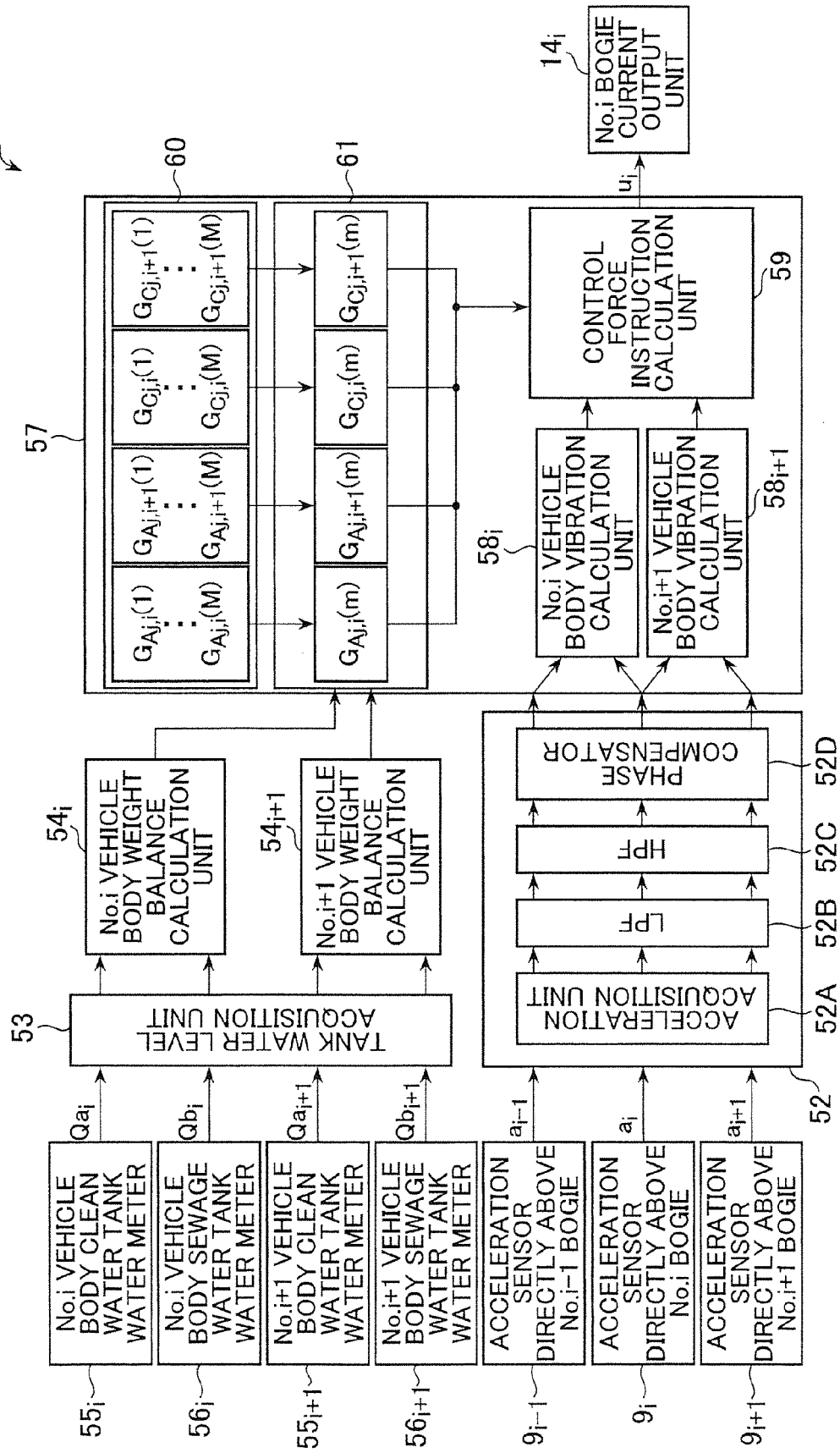


Fig. 20

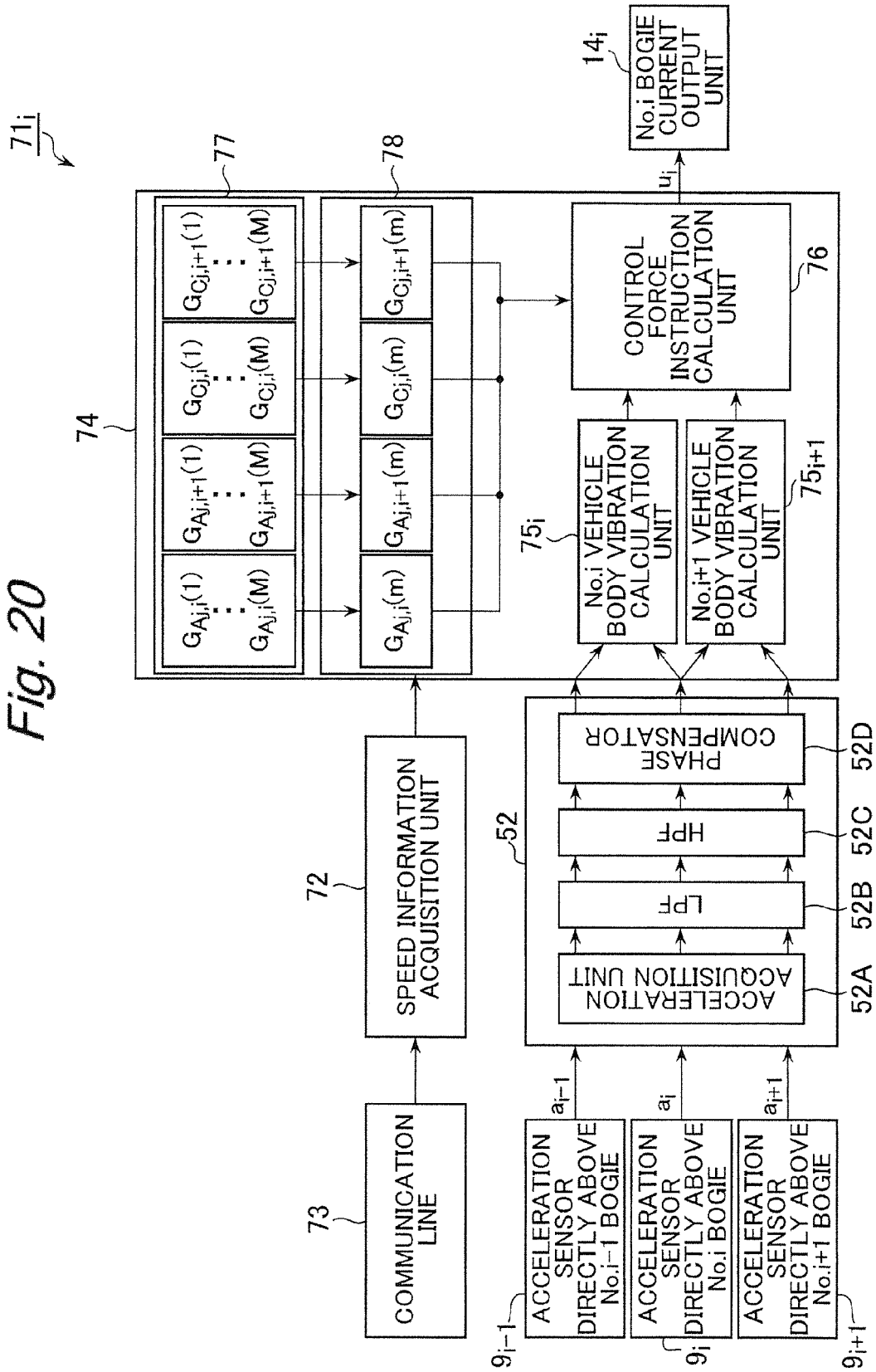


Fig. 21

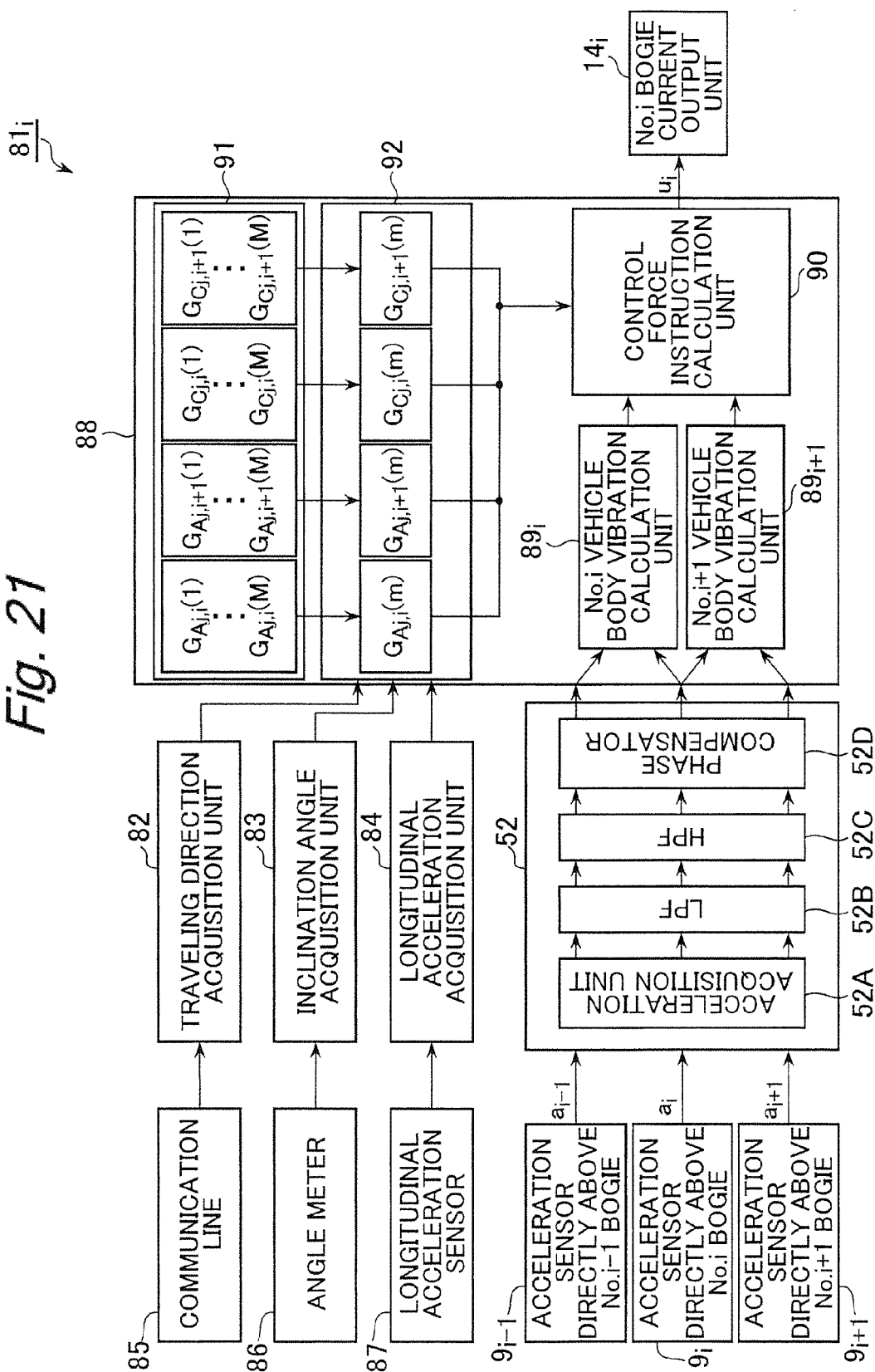


Fig. 22

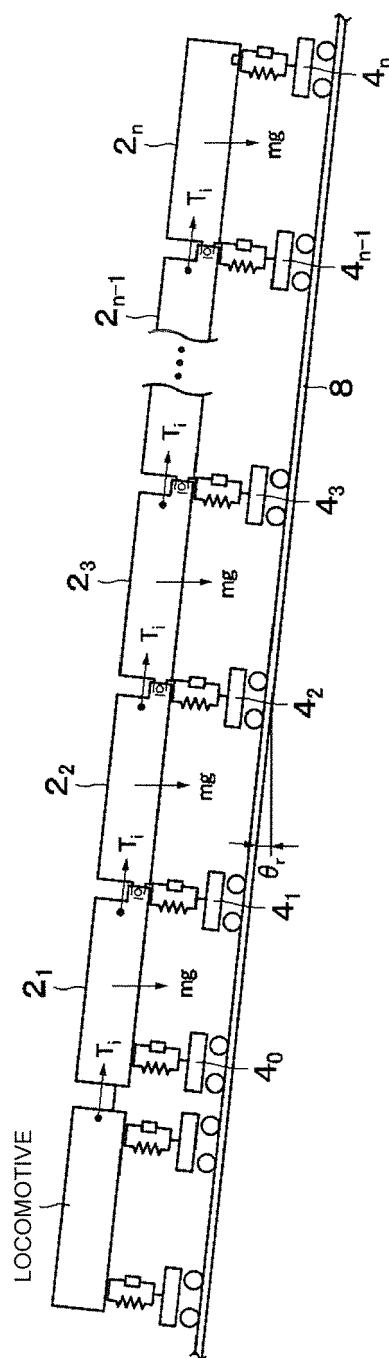


Fig. 23

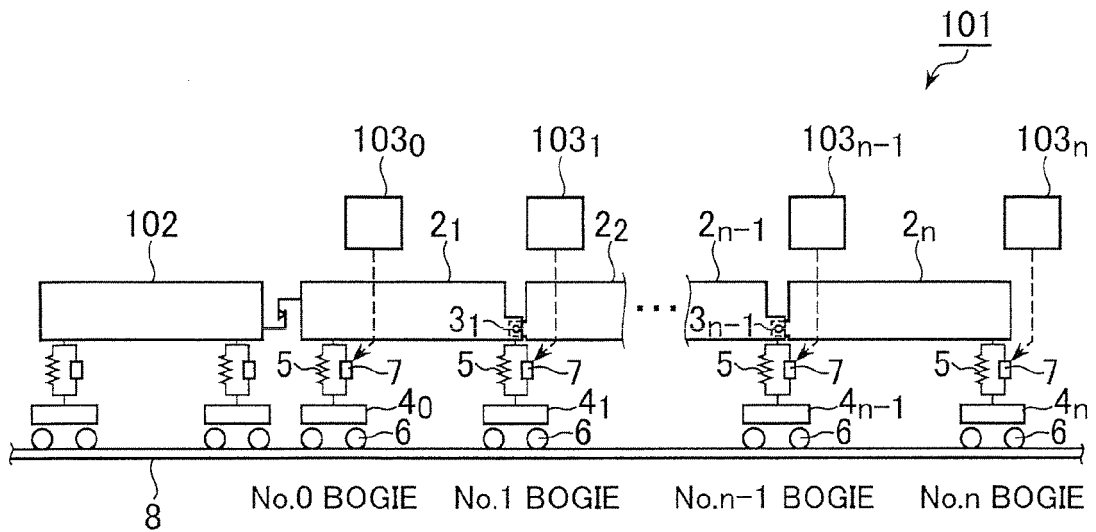


Fig. 24

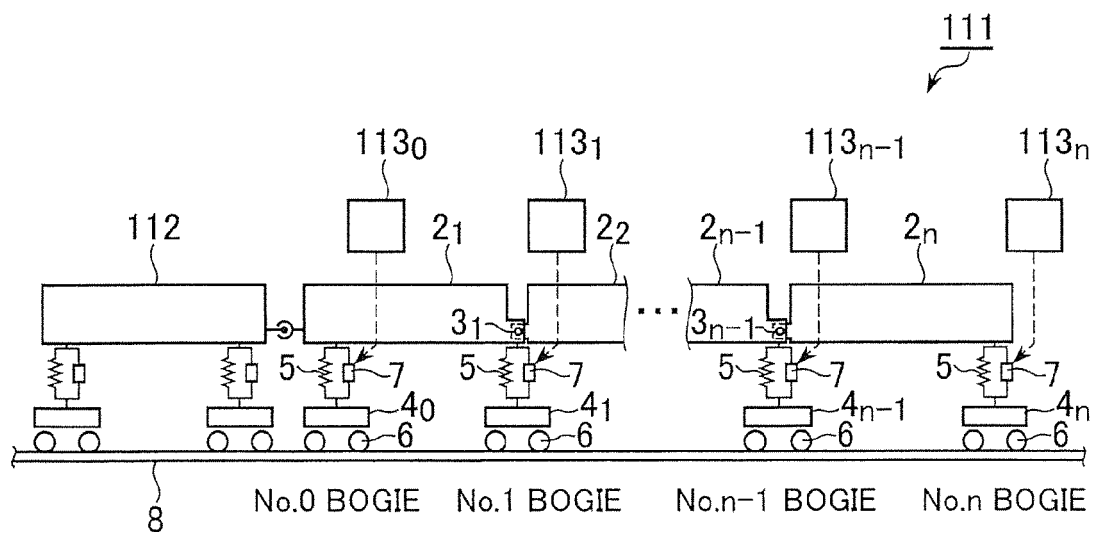


Fig. 25

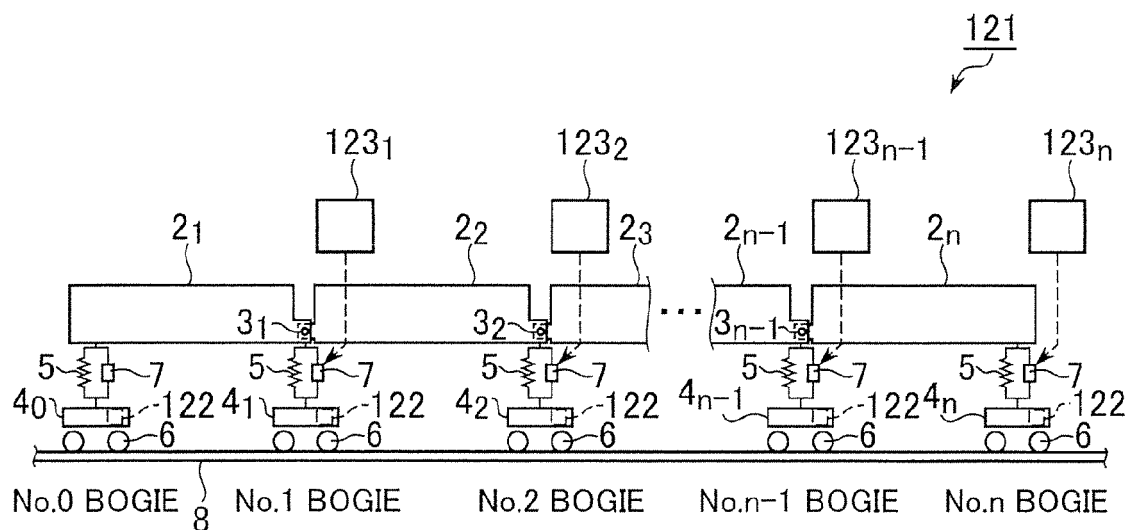


Fig. 26

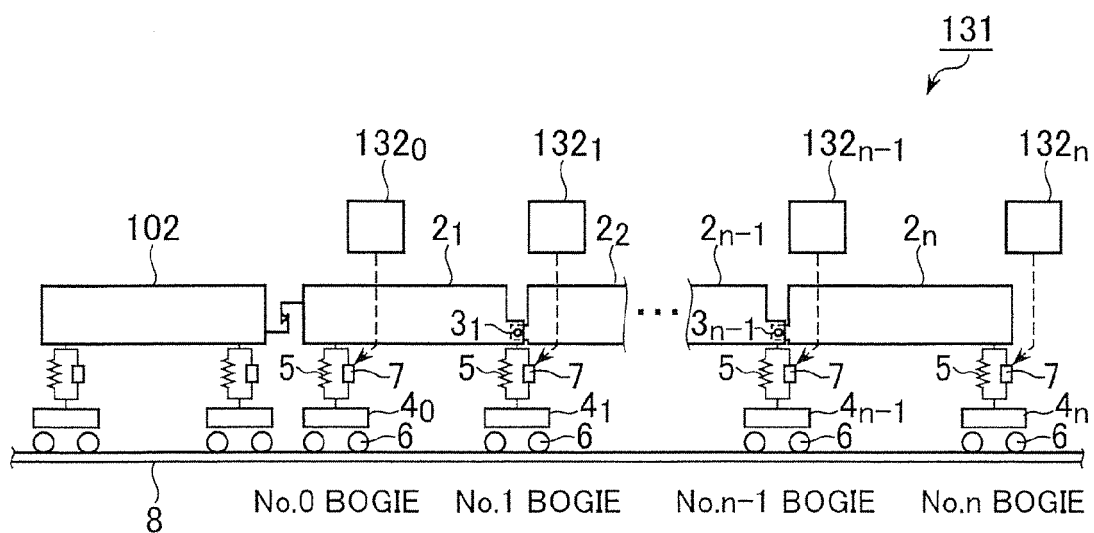


Fig. 27

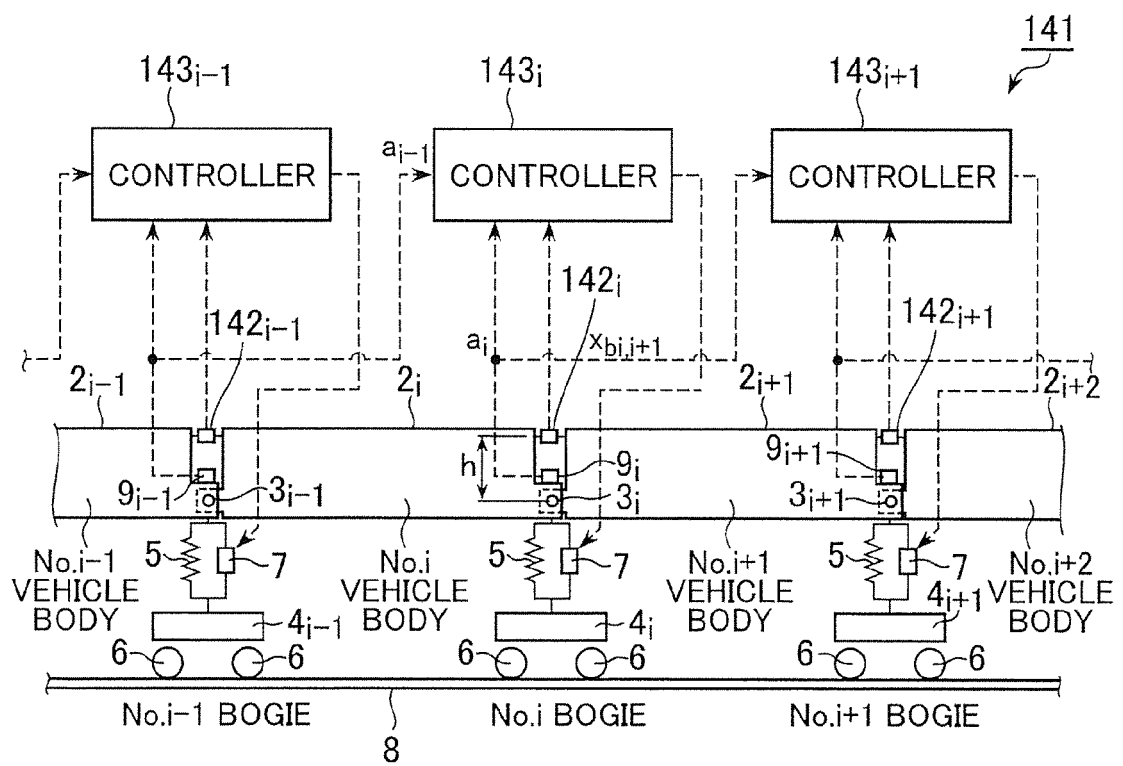


Fig. 28

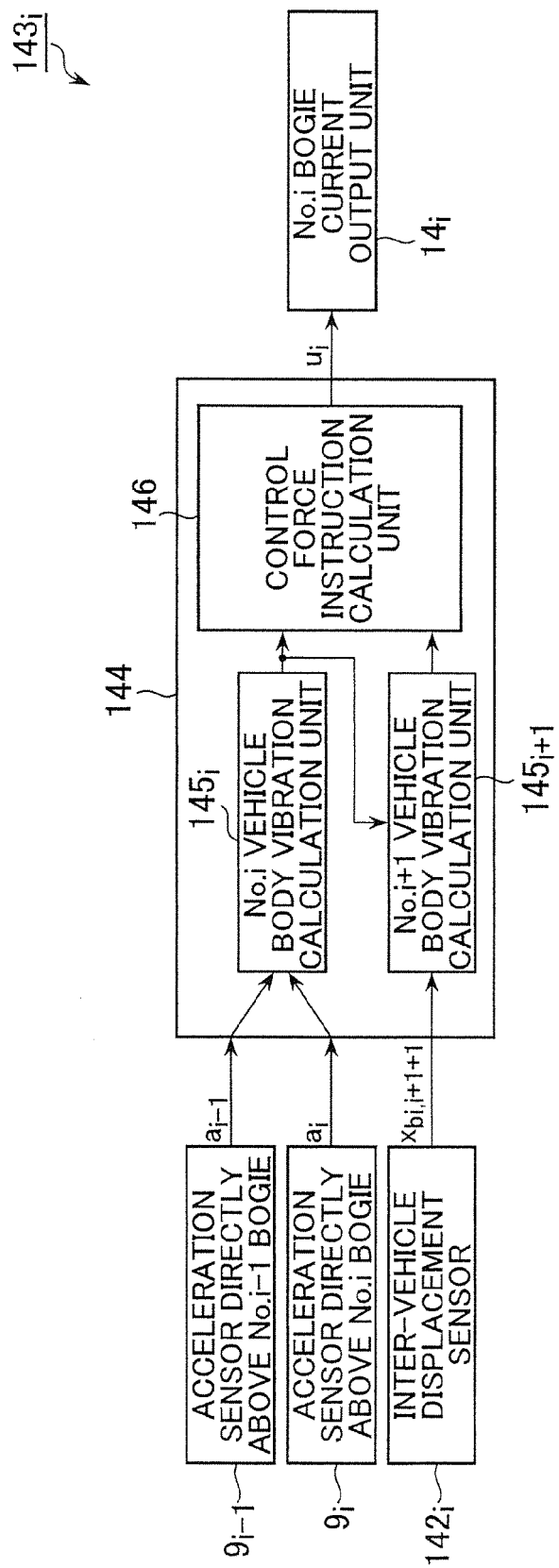


Fig. 29

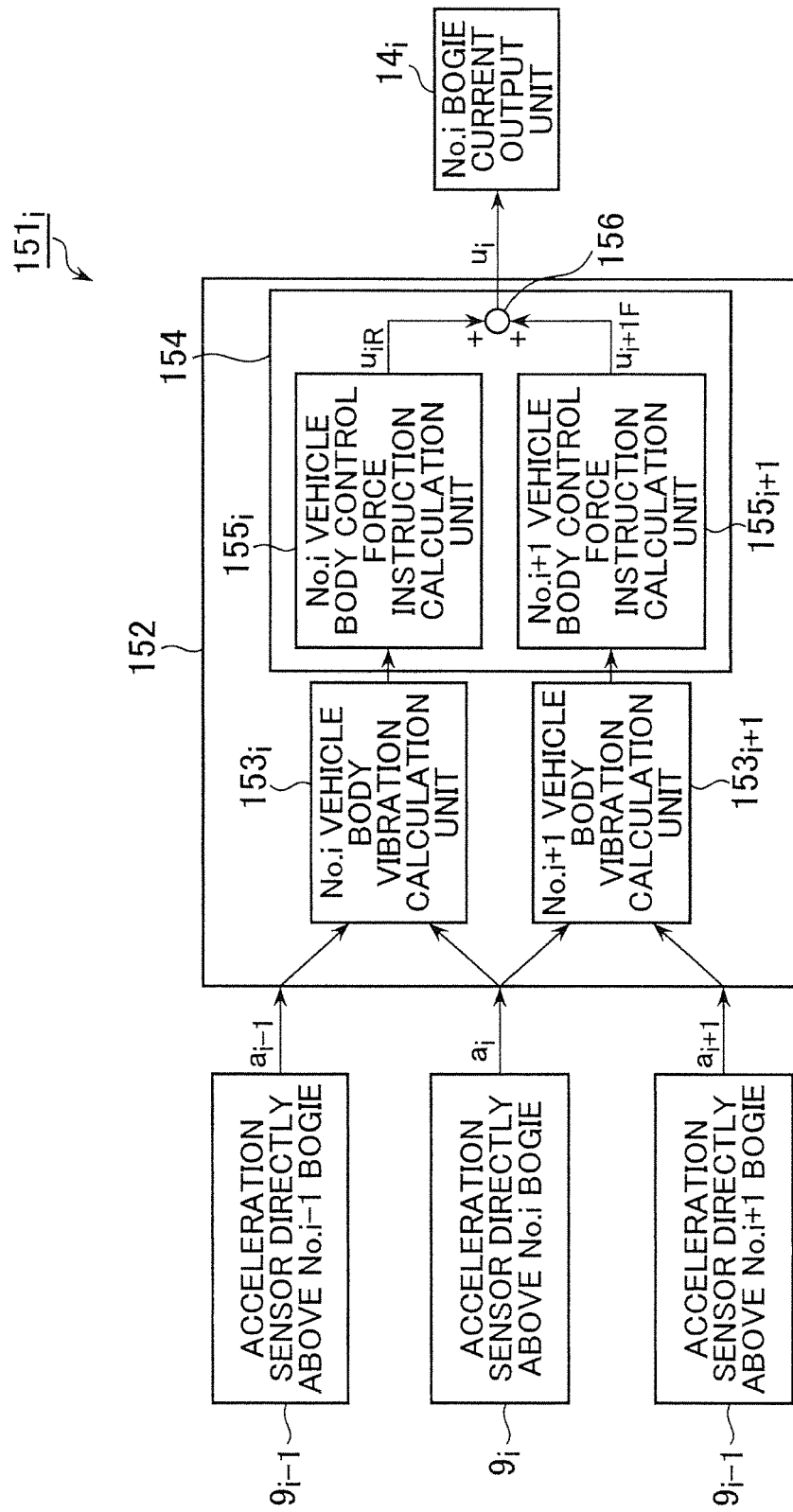


Fig. 30

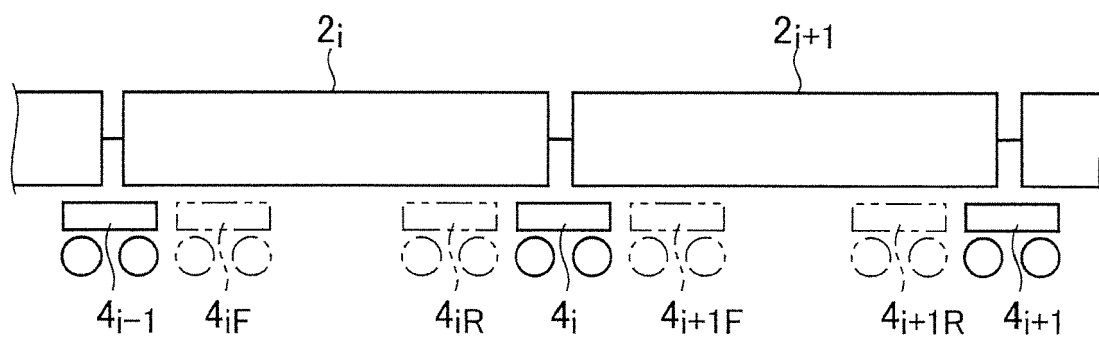


Fig. 31

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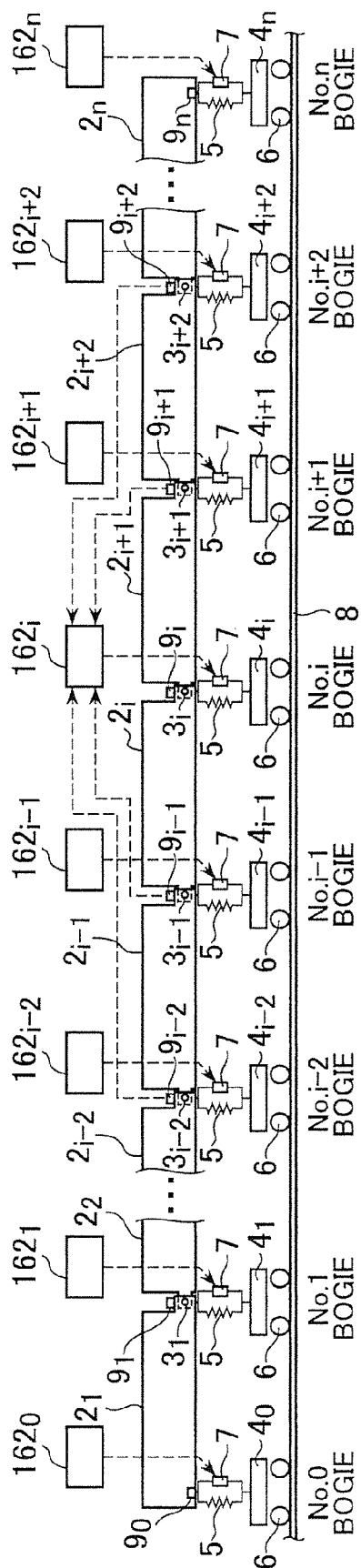


Fig. 32

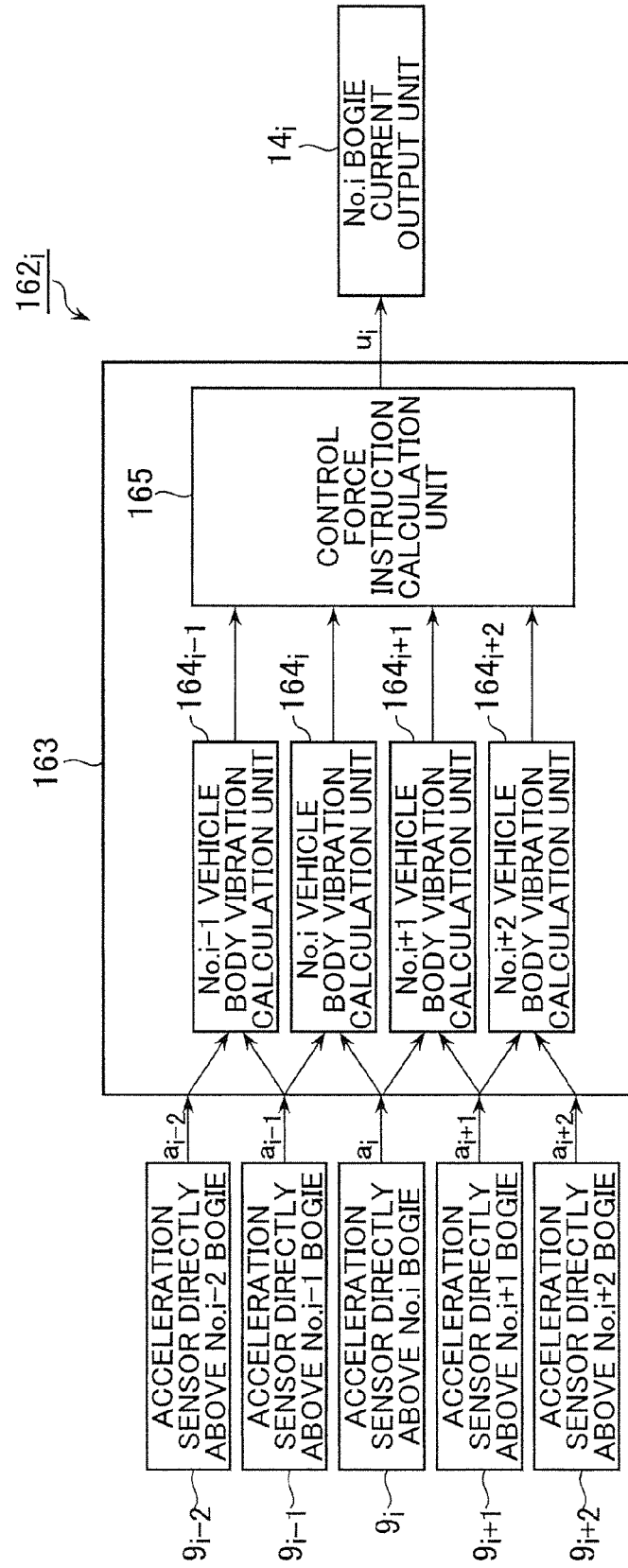


Fig. 33

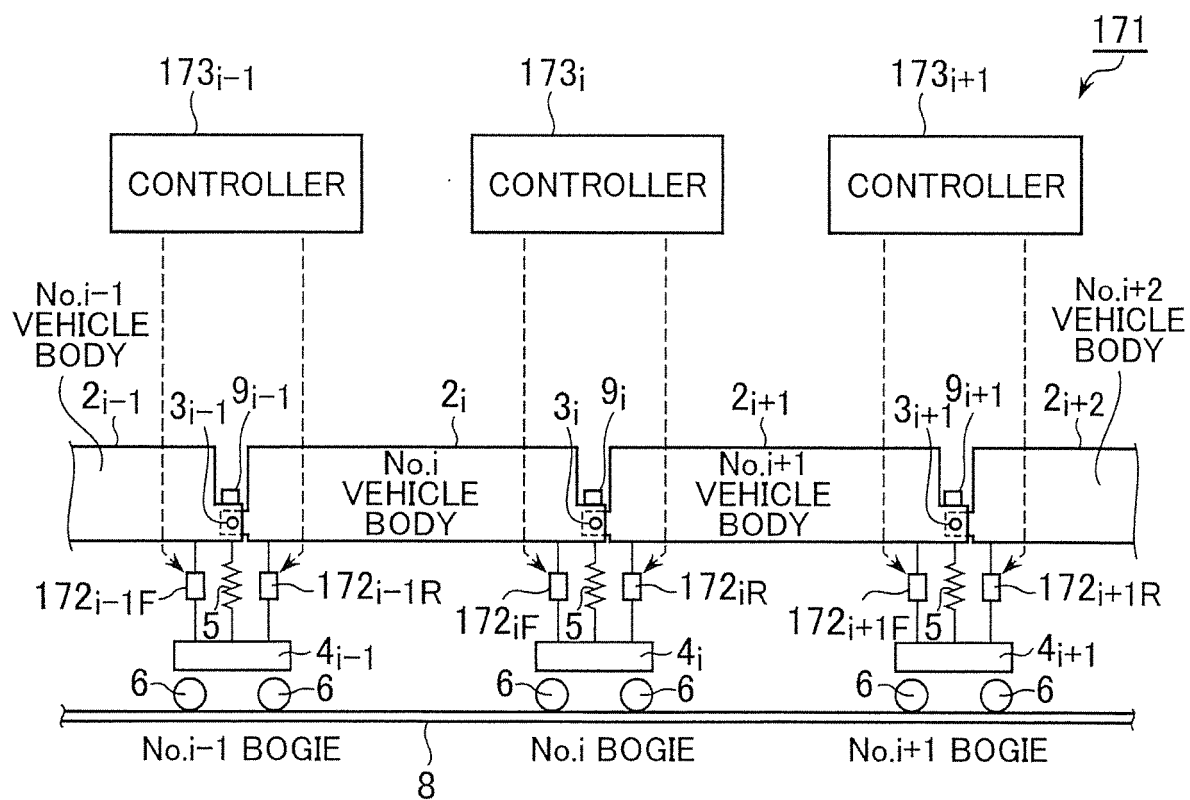


Fig. 34

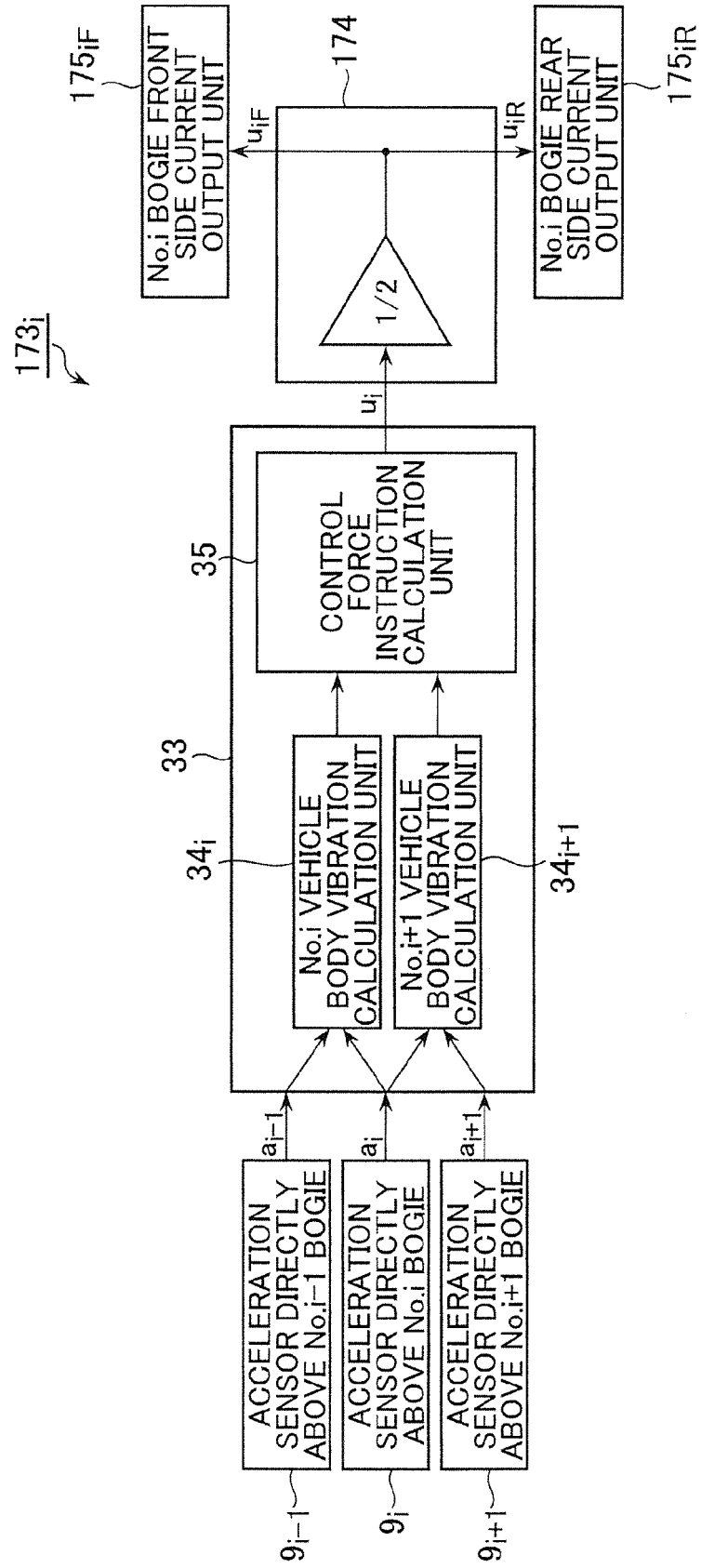


Fig. 35

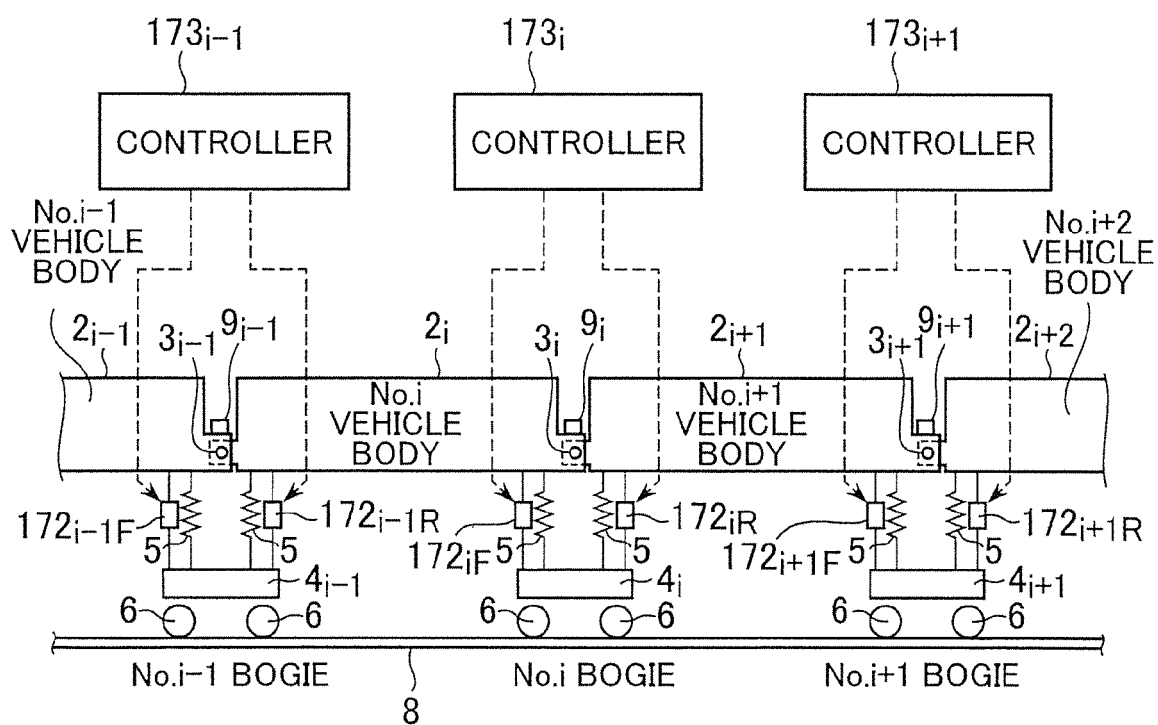


Fig. 36

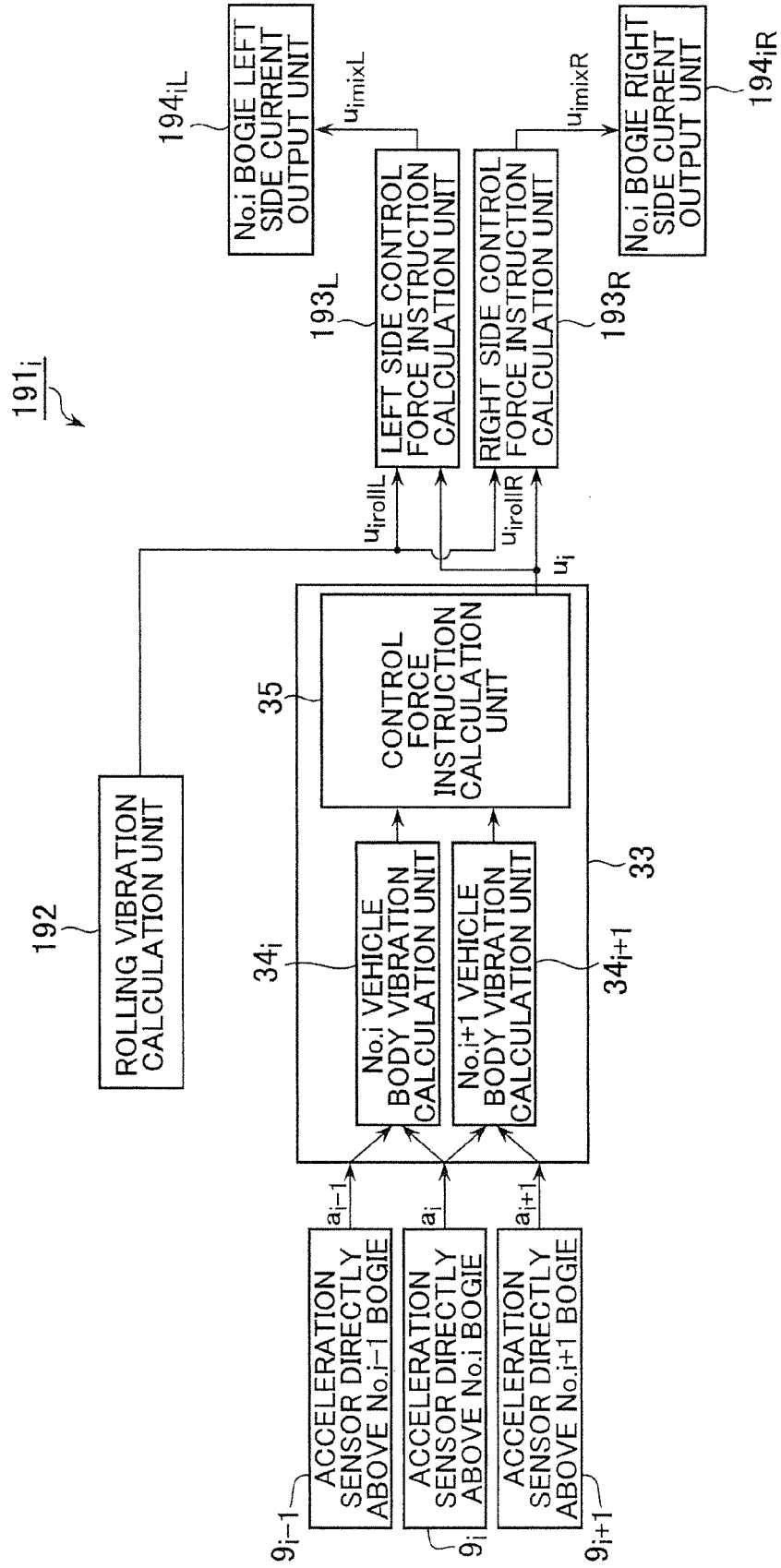
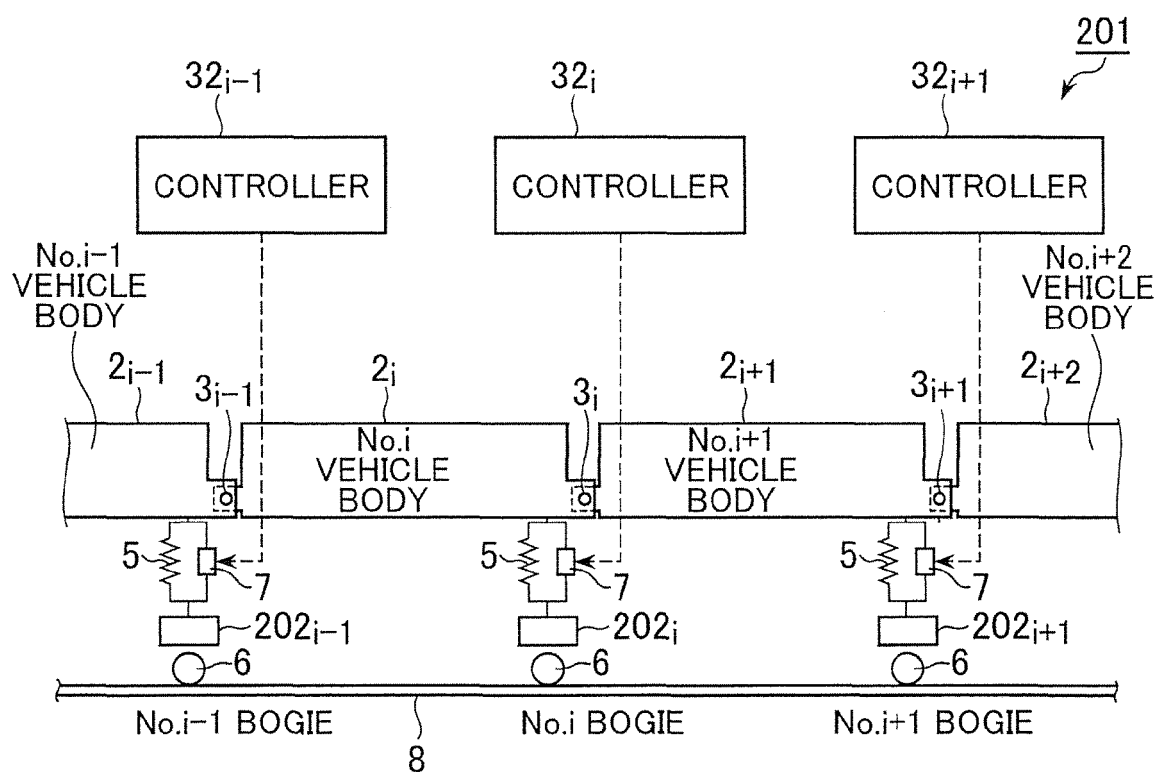


Fig. 37





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Application Number
EP 14 17 3863

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The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 6 February 2015	Examiner Lorandi, Lorenzo
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