

Description

TECHNICAL FIELD OF THE INVENTION

[0001] This invention relates to a vibration suppression device that suppresses vibration in a railway vehicle.

DESCRIPTION OF RELATED ART

[0002] A semi-active suspension that does not require power is installed in a railway vehicle to suppress aerodynamic vibration in a vehicle body.

[0003] As disclosed in JP10-297485A, for example, this type of semi-active suspension is constituted by an air spring that absorbs an impact of a vehicle body received by a bogie, a damper that extends and compresses as the vehicle body vibrates laterally relative to the bogie, an acceleration sensor that detects acceleration in a lateral direction of the vehicle body, and a controller that controls an operation of the damper in accordance with a detection signal from the acceleration sensor.

[0004] The controller controls the operation of the damper using the sky-hook semi-active control rule, whereby the vibration energy of the damper is used to suppress lateral vibration in the vehicle body.

SUMMARY OF THE INVENTION

[0005] To ensure smooth traveling in a bend section and suppress deviation to one side of the rails, a tread on the wheels of the railway vehicle, which contact the rails rotatably, is provided with a gradient so that the left and right wheels are respectively oriented toward the inside of the rails. Hence, when the railway vehicle travels along a line section, the bogie tends to be snake motion.

[0006] This snake motion of the bogie is suppressed by setting the gradient provided on the tread of the wheel appropriately, setting the hardness of a bush provided on the suspension appropriately, and so on.

[0007] However, when wear on the tread of the wheel and deterioration of the bush advance with age, or when the railway vehicle travels in a location having poor track conditions, large, high-frequency lateral vibration may occur in the bogie.

[0008] In skyhook semi-active control, a damping force of the damper in a direction that causes the vehicle body to vibrate is set at zero. Hence, when large, high-frequency lateral vibration occurs in the bogie of a railway vehicle installed with a semi-active suspension and sky-hook semi-active control is performed, lateral vibration of the vehicle body is suppressed, but since the damping force of the damper is insufficient, it may be impossible to suppress lateral vibration of the bogie sufficiently. In this case, the vibration of the bogie is superimposed on the vibration of the vehicle body, and as a result, the passenger comfort of the vehicle deteriorates.

[0009] This invention has been designed in consideration of the problems described above, and it is an object

thereof to provide a vibration suppression device for a railway vehicle installed with a semi-active suspension, which is capable of preventing deterioration of the passenger comfort of the railway vehicle even when lateral vibration occurs in a bogie.

[0010] In order to achieve above object, this invention provides a vibration suppression device for a railway vehicle, which suppresses vibration in the railway vehicle. The vibration suppression device for a railway vehicle comprises a damper having a variable damping force, which extends and compresses in accordance with lateral vibration of a vehicle body relative to a bogie, first control means that control the damping force of the damper using sky-hook semi-active control in order to suppress the lateral vibration of the vehicle body, vertical direction acceleration detecting means that detect acceleration in a vertical direction of the vehicle body, determining means that determine whether or not lateral vibration has occurred in the bogie on the basis of the acceleration detected by the vertical direction acceleration detecting means, second control means that cause the damper to operate so as to suppress the lateral vibration of the bogie and switching control means that switch from the first control means to the second control means when lateral vibration is determined to have occurred in the bogie.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1 is a system diagram of a vibration suppression device for a railway vehicle according to an embodiment of this invention.

[0012] FIG. 2 is a constitutional diagram of a variable damping force damper.

[0013] FIG. 3 is a flowchart showing a control procedure for determining whether or not lateral vibration has occurred in a bogie.

[0014] FIG. 4 is a flowchart showing a control procedure for determining whether or not the lateral vibration in the bogie has been eliminated.

PREFERRED EMBODIMENTS OF THE INVENTION

[0015] Embodiments of this invention will be described below with reference to the drawings.

[0016] A vibration suppression device according to an embodiment of this invention is installed in a railway vehicle 1 shown in FIG. 1.

[0017] The railway vehicle 1 comprises a bogie 3 that travels along a pair of rails 2 extending in parallel, and a vehicle body 10 that is supported by the bogie 3 and carries people and objects.

[0018] One bogie 3 is provided at each of a front portion and a rear portion of the vehicle body 10. The bogie 3 comprises left and right wheels 4 that roll along the pair of rails 2, an axle 5 that supports the wheels 4 rotatably, a bogie frame 6 that is supported by the axle 5 and carries the vehicle body 10, and left and right suspension springs

7 that are interposed between the axle 5 and the bogie frame 6 and absorb vertical direction movement of the axle 5.

[0019] The wheel 4 has a tread 4a that contacts the rail 2 rotatably. The tread 4a is provided with a gradient that inclines relative to a rotary central axis of the wheel 4 to ensure smooth traveling in bend sections and suppress deviation to one side of the rail 2. The gradient of the left and right wheels 4 is formed such that the left and right wheels 4 are respectively oriented toward the inside of the left and right rails 2 by gravity of the railway vehicle 1.

[0020] Left and right air springs 8 are interposed between the bogie frame 6 and the vehicle body 10. The air springs 8 support the vehicle body 10 relative to the bogie 3, and absorb vertical direction movement of the bogie 3.

[0021] A damper 9 is disposed between the bogie 3 and the vehicle body 10. The damper 9 extends and compresses in a horizontal lateral direction (to be referred to hereafter as a "lateral direction") relative to an advancement direction of the railway vehicle 1 in order to suppress vibration in the lateral direction of the vehicle body 10.

[0022] The damper 9 is a variable damping force damper in which a resistance applied to hydraulic oil (hydraulic fluid) that flows as the damper 9 extends and compresses is variable, and forms a semi-active suspension. The damping force of the damper 9 is switched continuously by signals output from a controller 20 installed in the vehicle.

[0023] The controller 20 is constituted by a CPU, ROM, RAM, and so on, and controls an operation of the damper 9 on the basis of signals from various sensors.

[0024] The vehicle body 10 is provided with an acceleration sensor 15 serving as means for detecting acceleration of the vehicle body 10. An acceleration signal detected by the acceleration sensor 15 is output to the controller 20.

[0025] The acceleration sensor 15 detects biaxial acceleration, i.e. acceleration ax in the lateral direction of the vehicle body 10 and acceleration az in the vertical direction of the vehicle body 10. It should be noted that the acceleration ax and the acceleration az may be detected by provided two acceleration sensors that each detect acceleration on a single axis as the means for detecting acceleration of the vehicle body 10.

[0026] Next, referring to FIG. 2, the damper 9 will be described.

[0027] The damper 9 comprises a cylinder 32 in which hydraulic oil is sealed, a piston 34 accommodated slidably within the cylinder 32, and a rod 33, one end of which is coupled to the piston 34 and another end of which extends to the external cylinder 32. The cylinder 32 is connected to one of the bogie 3 and the vehicle body 10, and the rod 33 is connected to the other. When the vehicle body 10 displaces relative to the bogie 3 in the lateral direction, the piston 34 slides within the cylinder 32.

[0028] The internal cylinder 32 is partitioned by the piston 34 into a rod side pressure chamber 35 and an end side pressure chamber 36. Further, a tank chamber 37 which is independent of the rod side pressure chamber 35 and the end side pressure chamber 36 is provided in the internal of the cylinder 32.

[0029] The damper 9 comprises a uniflow passage 41 that leads the hydraulic oil from the rod side pressure chamber 35 into the tank chamber 37, an extension side check valve 51 that is provided in a passage connecting the end side pressure chamber 36 to the tank chamber 37 and only allows the hydraulic oil to flow from the tank chamber 37 into the end side pressure chamber 36, a compression side check valve 52 that is provided on the piston 34 and only allows the hydraulic oil to flow from the end side pressure chamber 36 to the rod side pressure chamber 35, and an orifice 53 that applies resistance to hydraulic oil flowing through a passage that connects the rod side pressure chamber 35 to the tank chamber 37.

[0030] A solenoid proportional relief valve 42 and a damping valve 43 are equipped in series in the uniflow passage 41 together with an electromagnetic switch valve 44 that selectively leads the hydraulic oil to the solenoid proportional relief valve 42 or the damping valve 43. A valve-opening pressure of the solenoid proportional relief valve 42 is set in accordance with a signal output from the controller 20. The damping valve 43 generates a damping force that is proportionate to the piston speed of the damper 9. The position of the electromagnetic switch valve 44 is switched by a signal output from the controller 20.

[0031] The damper 9 comprises a communication passage 45 that connects the rod side pressure chamber 35 to the end side pressure chamber 36. An extension side unloading valve 46 having a valve-opening position 46a in which the damper 9 is unloaded during an extension side stroke of an extension/compression operation of the damper 9 is interposed in the communication passage 45.

[0032] The damper 9 also comprises a communication passage 47 that connects the end side pressure chamber 36 to the tank chamber 37. A compression side unloading valve 48 having a valve-opening position 48a in which the damper 9 is unloaded during a compression side stroke of the extension/compression operation of the damper 9 is interposed in the communication passage 47.

[0033] The extension side unloading valve 46 and compression side unloading valve 48 operate during skyhook semi-active control, and are opened and closed in accordance with a signal output by the controller 20.

[0034] Next, an operation of the damper 9 will be described.

[0035] First, a case in which the damper 9 does not perform skyhook semi-active control will be described.

[0036] The controller 20 closes both the extension side unloading valve 46 and the compression side unloading valve 48 such that these two valves are OFF. Further, the controller 20 controls the solenoid proportional relief

valve 42 to a constant valve-opening pressure by switching the electromagnetic switch valve 44 to a position in which the hydraulic oil is led to the solenoid proportional relief valve 42. Hence, when skyhook semi-active control is not performed, the damper 9 functions as a passive damper.

[0037] In the compression side stroke of the damper 9, the extension side check valve 51 closes and the compression side check valve 52 opens such that an amount of hydraulic oil corresponding to an infiltration volume of the rod 33 flows from the rod side pressure chamber 35 into the tank chamber 37 through the orifice 53 and the uniflow passage 41.

[0038] In the extension side stroke of the damper 9, the compression side check valve 52 closes and the extension side check valve 51 opens such that the hydraulic oil in the rod side pressure chamber 35 flows from the tank chamber 37 into the end side pressure chamber 36 through the orifice 53 and the uniflow passage 41.

[0039] The area ratio of the piston 34 and the rod 33 is set at 2:1, and therefore the flow rate of the hydraulic oil that flows out of the rod side pressure chamber 35 is equal in the compression side stroke and the extension side stroke of the damper 9. In other words, the flow rate of the hydraulic oil flowing through the orifice 53 and the uniflow passage 41 is equal in the compression side stroke and the extension side stroke, and therefore an identical damping characteristic is obtained.

[0040] Hence, when the damper 9 does not perform skyhook semi-active control, the damper 9 enters an on-load state, in which damping force is generated, during both the extension side stroke and the compression side stroke.

[0041] It should be noted that when an abnormality or the like occurs in the controller 20, the electromagnetic switch valve 44 is switched to a position in which the hydraulic oil is led to the damping valve 43, whereby the damper 9 functions as a passive damper having a constant damping coefficient.

[0042] Next, a case in which the damper 9 performs skyhook semi-active control will be described.

[0043] During sky-hook semi-active control, the controller 20 opens one of the extension side unloading valve 46 and the compression side unloading valve 48 to switch that valve ON, and closes the other valve to switch that valve OFF. Further, the controller 20 controls the valve-opening pressure of the solenoid proportional relief valve 42 by switching the electromagnetic switch valve 44 to a position in which the hydraulic oil is led to the solenoid proportional relief valve 42.

[0044] During sky-hook semi-active control in which the extension side unloading valve 46 is opened to be ON and the compression side unloading valve 48 is closed to be OFF, the hydraulic oil in the rod side pressure chamber 35 flows into the end side pressure chamber 36 through the extension side unloading valve 46 in the extension side stroke of the damper 9. Accordingly, the damping force generated by the damper 9 becomes ex-

tremely low due to pressure loss in the passage. In the compression side stroke of the damper 9, on the other hand, the hydraulic oil in the rod side pressure chamber 35 flows into the tank chamber 37 through the uniflow passage 41, and a damping force based on a control command is generated by the solenoid proportional relief valve 42.

[0045] During sky-hook semi-active control in which the extension side unloading valve 46 is closed to be OFF and the compression side unloading valve 48 is opened to be ON, the hydraulic oil in the rod side pressure chamber 35 flows into the end side pressure chamber 36 through the uniflow passage 41 in the extension side stroke of the damper 9, and a damping force based on a control command is generated by the solenoid proportional relief valve 42. In the compression side stroke of the damper 9, on the other hand, the hydraulic oil in the end side pressure chamber 36 flows into the tank chamber 37 through the compression side unloading valve 48. Accordingly, the damping force generated by the damper 9 becomes extremely low due to pressure loss in the passage.

[0046] Hence, by switching one of the extension side unloading valve 46 and the compression side unloading valve 48 ON during skyhook semi-active control, a damping force can be generated in only one of the extension side stroke and the compression side stroke.

[0047] Next, skyhook semi-active control (first control means) will be described in detail.

[0048] In the sky-hook semi-active control law, it is imagined that an immobile side wall is present on the side of the vehicle body 10 and an imaginary damper is disposed between the side wall and the vehicle body 10. When the direction of the damping force generated by the imaginary damper is identical to the direction of the damping force generated by the damper 9, the damping force generated by the imaginary damper is generated as the damping force of the damper 9. Further, when the direction of the damping force generated by the imaginary damper is opposite to the direction of the damping force generated by the damper 9, the damping force of the damper 9 is set to be extremely low.

[0049] As an example of sky-hook semi-active control, a damping force F is calculated by the controller 20 in the following manner, where X is a lateral direction displacement of the vehicle body 10, Y is a lateral direction displacement of the bogie 3, dX/dt is a lateral direction absolute velocity of the vehicle body 10, $d(X-Y)/dt$ is a lateral direction relative velocity between the vehicle body 10 and the bogie 3, and C_s is a sky-hook damping coefficient. The lateral direction absolute velocity dX/dt of the vehicle body 10 is calculated by subjecting the lateral direction acceleration a_x of the vehicle body 10, which is detected by the acceleration sensor 15, to integration processing in the controller 20. Further, the lateral direction relative velocity $d(X-Y)/dt$ between the vehicle body 10 and the bogie 3 is detected by a stroke sensor or the like that detects the stroke of the damper 9.

[0050] When $(dX/dt) \times \{d(X-Y)/dt\} \geq 0$, the damping force F is calculated using the following Equation (1).

[0051] $F = CS \times (dX/dt)$ (1)

[0052] When $(dX/dt) \times \{d(X-Y)/dt\} < 0$, the damping force F is calculated as close to zero using the following Equation (2).

[0053] $F \approx 0$ (2)

[0054] The damping force F calculated by the controller 20 is output to the damper 9 as a control command. The damper 9 then controls the operations of various valves, such as the extension side unloading valve 46, the compression side unloading valve 48, and the solenoid proportional relief valve 42, in the manner described above to generate the damping force F corresponding to the control command.

[0055] In a normal passive damper, a damping force corresponding to the piston speed of the damper is generated irrespective of the extension/compression direction. Therefore, depending on the vibration direction of the bogie 3 and vehicle body 10, vibration in the vehicle body 10 may actually increase. In sky-hook semi-active control, the damping force of the damper 9 in the direction that causes the vehicle body 10 to vibrate is controlled to a value as close to zero by the extension side unloading valve 46 and compression side unloading valve 48, as shown above in Equation (2). More specifically, when the vibration direction of the bogie 3 and vehicle body 10 is identical but the speed of the bogie 3 exceeds the speed of the vehicle body 10, the damping force F of the damper 9 is controlled to a value as close to zero to ensure that the lateral vibration of the bogie 3 is not transmitted to the vehicle body 10.

[0056] When wear on the tread 4a of the wheel 4 and deterioration of the bush advance with age, or when traveling in a location having poor track conditions, lateral vibration, which is large, high-frequency rolling, may occur in the bogie 3.

[0057] When lateral vibration occurs in the bogie 3 and sky-hook semi-active control is performed similarly to normal travel, the damping force of the damper 9 in the direction that causes the vehicle body 10 to vibrate is set at zero, and therefore a force for suppressing the lateral vibration does not act on the bogie 3. As a result, lateral vibration of the bogie 3 may be encouraged, and in this case, the lateral vibration of the bogie 3 is superimposed on the lateral vibration of the vehicle body 10 such that high speed travel of the railway vehicle 1 is impaired.

[0058] To deal with this problem, the controller 20 determines whether or not lateral vibration has occurred in the bogie 3, and having determined the presence of lateral vibration in the bogie 3, the controller 20 switches the control mode of the damper 9 from skyhook semi-active control to a control mode (second control means) in which the damper 9 acts to suppress the lateral vibration of the bogie 3.

[0059] More specifically, during normal travel in which lateral vibration does not occur in the bogie 3, the controller 20 causes the damper 9 to perform sky-hook semi-

active control by calculating the damping force F on the basis of Equations (1) and (2) described above to suppress lateral vibration of the vehicle body 10. In other words, the controller 20 controls the damping force of the damper 9 in accordance with the lateral direction absolute velocity dX/dt of the vehicle body 10.

[0060] On the other hand, when lateral vibration occurs in the bogie 3, the controller 20 makes an opening command issued to the solenoid proportional relief valve 42 constant and switches both the extension side unloading valve 46 and the compression side unloading valve 48 OFF. As a result, sky-hook semi-active control is halted, and the damper 9 functions as a passive damper that generates damping force in accordance with the relative velocity between the bogie 3 and the vehicle body 10, regardless of the lateral direction absolute velocity dX/dt of the vehicle body 10. Thus, the damper 9 acts to suppress the lateral vibration of the bogie 3. It should be noted that by constituting the solenoid proportional relief valve 42 to operate mechanically such that the damping force generated by the damper 9 becomes constant, lateral vibration in the bogie 3 can be suppressed more effectively.

[0061] Hence, during normal travel, the damping force of the damper 9 is generated in accordance with the lateral direction speed of the vehicle body 10 through sky-hook semi-active control, and when lateral vibration occurs in the bogie 3, the damping force of the damper 9 is generated according to the relative velocity between the bogie 3 and the vehicle body 10.

[0062] Next, a method of determining whether or not lateral vibration has occurred in the bogie 3 will be described.

[0063] When lateral vibration occurs in the bogie 3, the bogie 3 meanders, causing the vehicle body 10 to oscillate in the lateral direction, the vehicle body frame 6 to oscillate in the vertical direction via the suspension springs 7 due to the gradient provided on the tread 4a of the wheels 4. As a result, the vehicle body 10 oscillates in the vertical direction via the air springs 8. If skyhook semi-active control is performed by the damper 9 at this time, a lateral direction acceleration amplitude (acceleration variation) A_x of the vehicle body 10 is suppressed to be small, but a vertical direction acceleration amplitude (acceleration variation) A_z of the vehicle body 10 cannot be suppressed.

[0064] Therefore, by detecting the vertical direction acceleration amplitude A_z of the vehicle body 10 together with the lateral direction acceleration amplitude A_x of the vehicle body 10, it is possible to determine accurately that lateral vibration has occurred in the bogie 3. The controller 20 determines whether or not lateral vibration has occurred in the bogie 3 on the basis of the lateral direction acceleration a_x of the vehicle body 10 and the vertical direction acceleration a_z of the vehicle body 10, which are detected by the acceleration sensor 15.

[0065] Next, a control procedure for determining whether or not lateral vibration has occurred in the bogie

3 will be described with reference to a flowchart shown in FIG. 3. The following procedure is executed by the controller 20.

[0066] First, in a step 1, the detection signal detected by the acceleration sensor 15 is subjected to filter processing to read the lateral direction acceleration a_x and vertical direction acceleration a_z of the vehicle body 10.

[0067] Next, in a step 2, the acceleration amplitude A_x , which is the difference between a maximum value $\text{Max}(a_x)$ and a minimum value $\text{Min}(a_x)$ of the acceleration a_x read within a predetermined time period, is calculated. Further, the acceleration amplitude A_z , which is the difference between a maximum value $\text{Max}(a_z)$ and a minimum value $\text{Min}(a_z)$ of the acceleration a_z read within a predetermined time period, is calculated in a similar manner.

[0068] Next, in a step 3, a determination is made as to whether or not a sum $\alpha A_x + \beta A_z$ of αA_x , which is obtained by multiplying a lateral direction acceleration weighting coefficient α by the lateral direction acceleration amplitude A_x , and βA_z , which is obtained by multiplying a vertical direction acceleration weighting coefficient β by the vertical direction acceleration amplitude A_z , is equal to or greater than a predetermined reference value $\text{Max}1$.

[0069] When it is determined in the step 3 that $\alpha A_x + \beta A_z$ is smaller than the reference value $\text{Max}1$, the routine advances to a step 8, where an abnormality count value C_z is cleared.

[0070] When it is determined in the step 3 that $\alpha A_x + \beta A_z$ is equal to or greater than the reference value $\text{Max}1$, the routine advances to a step 4, where the abnormality count value C_z is incremented by one.

[0071] Next, in a step 5, a determination is made as to whether or not the count value C_z has reached a predetermined determination value C_{za} .

[0072] When it is determined in the step 5 that the count value C_z has reached the determination value C_{za} , it is determined that lateral vibration has occurred in the bogie 3, and therefore the routine advances to a step 6, where a lateral vibration occurrence determination bit B is established.

[0073] Finally, in a step 7, the abnormality count value C_z is initialized, whereupon the routine is terminated. Thereafter, the procedure described above is repeated.

[0074] When the lateral vibration occurrence determination bit B is established in the manner described above, the control mode of the damper 9 is switched (switching control means) in a separate routine from sky-hook semi-active control to the control mode in which the damper 9 acts to suppress the lateral vibration of the bogie 3. As a result, the lateral vibration of the bogie 3 is suppressed by the operation of the damper 9, and thus the traveling stability of the railway vehicle 1 is increased.

[0075] In the above description, the occurrence of lateral vibration in the bogie 3 is determined on the basis of both the lateral direction acceleration a_x of the vehicle body 10 and the vertical direction acceleration a_z of the

vehicle body 10, but as noted above, when skyhook semi-active control is performed by the damper 9, the lateral direction acceleration amplitude A_x of the vehicle body 10 is suppressed to be small. Therefore, the occurrence of lateral vibration in the bogie 3 may be determined using only the vertical direction acceleration amplitude A_z , which is not easily affected by sky-hook semi-active control. More specifically, the number of times that the acceleration amplitude A_z reaches or exceeds a reference value may be counted such that when the count value reaches a determination value, it is determined that lateral vibration has occurred in the bogie 3.

[0076] As another parameter for determining the occurrence of lateral vibration in the bogie 3, the number of times that either value of the vertical direction acceleration amplitude A_z and lateral direction acceleration amplitude A_x of the vehicle body 10 reaches or exceeds a reference value may be counted such that when the count value reaches a determination value, it is determined that lateral vibration has occurred in the bogie 3.

[0077] As another parameter for determining the occurrence of lateral vibration in the bogie 3, the number of times that the values of both the vertical direction acceleration amplitude A_z and lateral direction acceleration amplitude A_x reach or exceed a reference value may be counted such that when the count value reaches a determination value, it is determined that lateral vibration has occurred in the bogie 3.

[0078] As a further parameter for determining the occurrence of lateral vibration in the bogie 3, a sum $a_x + a_z$ of the lateral direction acceleration a_x and the vertical direction acceleration a_z may be used, and the number of times that this sum $a_x + a_z$ reaches or exceeds a reference value may be counted such that when the count value reaches a determination value, it is determined that lateral vibration has occurred in the bogie 3.

[0079] Next, a control procedure for determining whether or not lateral vibration in the bogie 3 has been eliminated will be described with reference to a flowchart shown in FIG. 4. The following procedure is executed by the controller 20.

[0080] First, in a step 11, the detection signal detected by the acceleration sensor 15 is subjected to filter processing to read the lateral direction acceleration a_x and vertical direction acceleration a_z of the vehicle body 10.

[0081] Next, in a step 12, the acceleration amplitude A_x , which is the difference between the maximum value $\text{Max}(a_x)$ and minimum value $\text{Min}(a_x)$ of the acceleration a_x read within a predetermined time period, is calculated. Further, the acceleration amplitude A_z , which is the difference between the maximum value $\text{Max}(a_z)$ and minimum value $\text{Min}(a_z)$ of the acceleration a_z read within a predetermined time period, is calculated in a similar manner.

[0082] Next, in a step 13, a determination is made as to whether or not the sum $\alpha A_x + \beta A_z$ of αA_x , which is obtained by multiplying the lateral direction acceleration

weighting coefficient α by the lateral direction acceleration amplitude A_x , and βA_z , which is obtained by multiplying the vertical direction acceleration weighting coefficient P by the vertical direction acceleration amplitude A_z , is equal to or smaller than a predetermined reference value $Min1$.

[0083] When it is determined in the step 13 that $\alpha A_x + \beta A_z$ is larger than the reference value $Min1$, the routine advances to a step 18, where an abnormality count value R_z is cleared.

[0084] When it is determined in the step 13 that $\alpha A_x + \beta A_z$ is equal to or smaller than the reference value $Min1$, the routine advances to a step 14, where the abnormality count value R_z is incremented by one.

[0085] Next, in a step 15, a determination is made as to whether or not the count value R_z has reached a predetermined determination value R_{za} .

[0086] When it is determined in the step 15 that the count value R_z has reached the determination value R_{za} , it is determined that lateral vibration in the bogie 3 has been eliminated, and therefore the routine advances to a step 16, where the lateral vibration occurrence determination bit B is cleared.

[0087] Finally, in a step 17, the abnormality count value R_z is initialized, whereupon the routine is terminated. Thereafter, the procedure described above is repeated.

[0088] When the lateral vibration occurrence determination bit B is cleared in the manner described above, the control of the damper 9 is returned to skyhook semi-active control in a separate routine. In so doing, lateral vibration of the vehicle body 10 is suppressed by an operation of the damper 9, and thus passenger comfort is maintained in a favorable state.

[0089] According to the embodiment described above, the following actions and effects are exhibited.

[0090] During normal travel, lateral vibration of the vehicle body 10 is suppressed by subjecting the damping force of the damper 9 to skyhook semi-active control, thereby maintaining the passenger comfort in a favorable state. On the other hand, when high-frequency lateral vibration occurs in the bogie 3, the operation of the damper 9 is switched, and as a result, the high-frequency lateral vibration of the bogie 3 is suppressed, enabling an improvement in the traveling stability of the railway vehicle 1. Hence, deterioration of the passenger comfort of the railway vehicle 1 can be prevented even when lateral vibration occurs in the bogie 3.

[0091] Further, when lateral vibration occurs in the bogie 3, the damper 9 functions as a passive damper having a constant damping force, and therefore the lateral vibration of the bogie 3 is suppressed by the damping force generated by the damper 9, leading to an improvement in the traveling stability of the railway vehicle 1.

[0092] Further, when lateral vibration occurs in the bogie 3, both the extension side unloading valve 46 and the compression side unloading valve 48 are closed to OFF such that the damper 9 does not enter an unloaded state during an extension/compression operation. Therefore,

the damper 9 generates damping force in both the compression side stroke and the extension side stroke, whereby lateral vibration of the bogie 3 is suppressed, enabling an improvement in the traveling stability of the railway vehicle 1.

[0093] Further, the occurrence of lateral vibration in the bogie 3 is determined on the basis of an acceleration detection signal, which is detected by the acceleration sensor 15 provided in the vehicle body 10. Hence, there is no need to provide the bogie 3 with an acceleration sensor or the like, and as a result, increases in the cost of the device can be suppressed.

[0094] Further, when skyhook semi-active control is performed by the damper 9, the lateral direction acceleration amplitude of the vehicle body 10 is suppressed to be small, but the vertical direction acceleration amplitude of the vehicle body 10 cannot be suppressed. Therefore, by determining whether or not lateral vibration has occurred in the bogie 3 on the basis of the vertical direction acceleration of the vehicle body 10, it is possible to determine accurately whether or not lateral vibration has occurred in the bogie 3.

[0095] Moreover, when the occurrence of lateral vibration in the bogie 3 is determined on the basis of both the lateral direction acceleration and the vertical direction acceleration of the vehicle body 10, which are detected by the biaxial acceleration sensor 15, the occurrence of lateral vibration in the bogie 3 can be determined even more accurately.

[0096] Other embodiments are illustrated below.

[0097] (1) When lateral vibration occurs in the bogie 3, sky-hook semi-active control may be continued such that the damping force F of the damper 9 is calculated on the basis of Equation (1) and the skyhook damping coefficient C_s is set to be large. In this case, the damping force F of the damper 9 increases when lateral vibration occurs in the bogie 3, and therefore lateral vibration of the bogie 3 is suppressed, enabling an improvement in the travelling stability of the railway vehicle 1.

[0098] (2) When lateral vibration occurs in the bogie 3, the electromagnetic switch valve 44 shown in FIG. 2 may be switched to a position for leading the hydraulic oil into the damping valve 43 such that the damper 9 functions as a passive damper having a constant damping coefficient.

[0099] In this case, during normal travel the hydraulic oil flowing through the uniflow passage 41 is led to the solenoid proportional relief valve 42 and the valve-opening pressure of the solenoid proportional relief valve 42 is subjected to skyhook semi-active control by the controller 20. As a result, lateral vibration of the vehicle body 10 is suppressed such that passenger comfort is maintained in a favorable state.

[0100] When lateral vibration occurs in the bogie 3, the position of the electromagnetic switch valve 44 is switched such that the hydraulic oil flowing through the uniflow passage 41 is led to the damping valve 43. The damping valve 43 increases the damping force in pro-

portion to the piston speed of the damper 9, and therefore lateral vibration of the bogie 3 is suppressed by the damping force of the damper 9, enabling an improvement in the traveling stability of the railway vehicle 1.

[0101] This invention is not limited to the embodiments described above, and may of course be subjected to various modifications within the scope of the technical spirit thereof.

Claims

1. A vibration suppression device for a railway vehicle (1), which suppresses vibration in the railway vehicle (1), comprising:

a damper (9) having a variable damping force, which extends and compresses in accordance with lateral vibration of a vehicle body (10) relative to a bogie (3);

first control means that control the damping force of the damper (9) using sky-hook semi-active control in order to suppress the lateral vibration of the vehicle body (10);

vertical direction acceleration detecting means (15) that detect acceleration in a vertical direction of the vehicle body (10);

determining means that determine whether or not lateral vibration has occurred in the bogie (3) on the basis of the acceleration detected by the vertical direction acceleration detecting means (15);

second control means that cause the damper (9) to operate so as to suppress the lateral vibration of the bogie (3); and

switching control means that switch from the first control means to the second control means when lateral vibration is determined to have occurred in the bogie (3).

2. The vibration suppression device for a railway vehicle (1) as defined in Claim 1, wherein the second control means cause the damper (9) to function as a passive damper.

3. The vibration suppression device for a railway vehicle (1) as defined in Claim 1, wherein the second control means generate a damping force in accordance with a relative velocity between the vehicle body (10) and the bogie (3).

4. The vibration suppression device for a railway vehicle (1) as defined in Claim 1, wherein the second control means make the damping force of the damper (9) constant.

5. The vibration suppression device for a railway vehicle (1) as defined in Claim 1, wherein the second

control means make a damping coefficient of the damper (9) constant.

6. The vibration suppression device for a railway vehicle (1) as defined in Claim 1, wherein the first control means perform control such that the damping force of the damper (9) is generated in only one of an extension side stroke and a compression side stroke, and the second control means perform control such that the damping force of the damper (9) is generated in both the extension side stroke and the compression side stroke.

7. The vibration suppression device for a railway vehicle (1) as defined in Claim 6, wherein the first control means perform control such that the damping force of the damper (9) is not generated in a direction for causing the vehicle body to vibrate.

8. The vibration suppression device for a railway vehicle (1) as defined in any one of Claim 1 through Claim 7, further comprising lateral direction acceleration detecting means (15) that detect acceleration in a lateral direction of the vehicle body, wherein the first control means control the damping force of the damper (9) in accordance with an absolute velocity in the lateral direction of the vehicle body (10), which is calculated on the basis of the acceleration detected by the lateral direction acceleration detecting means (15).

9. The vibration suppression device for a railway vehicle (1) as defined in Claim 8, wherein the determining means determine whether or not lateral vibration has occurred in the bogie (3) on the basis of the acceleration detected by the vertical direction acceleration detecting means (15) and the acceleration detected by the lateral direction acceleration detecting means (15).

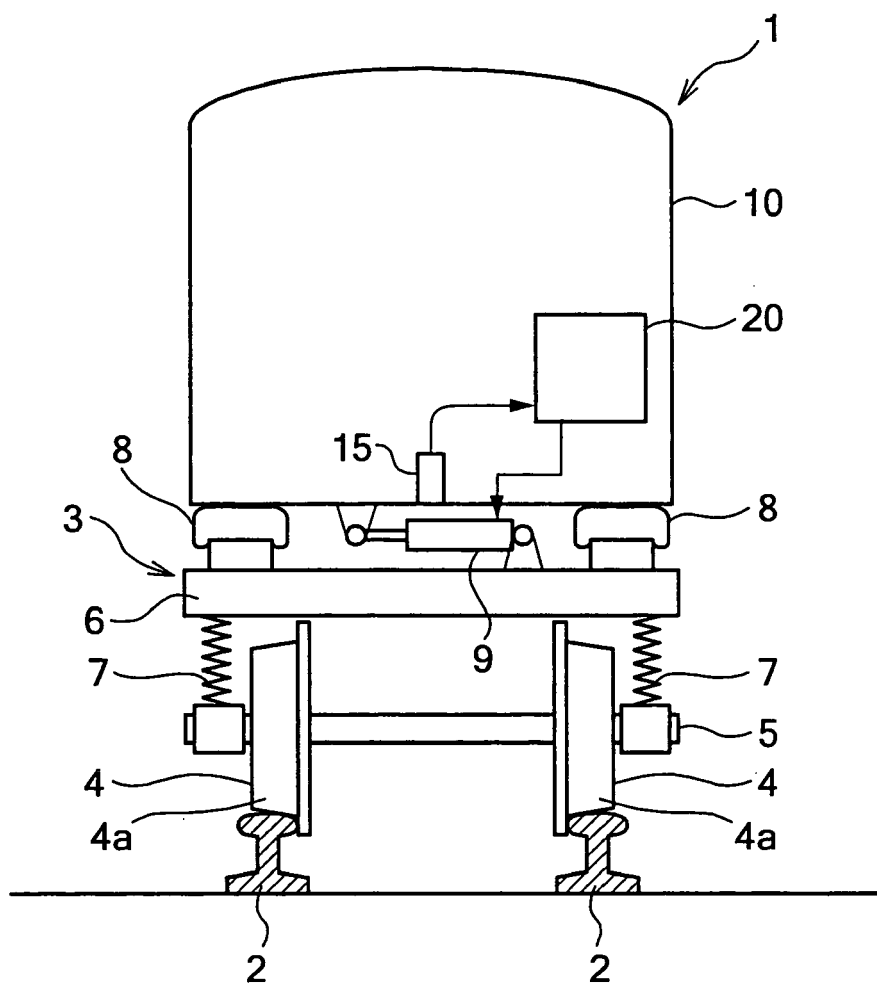


FIG.1

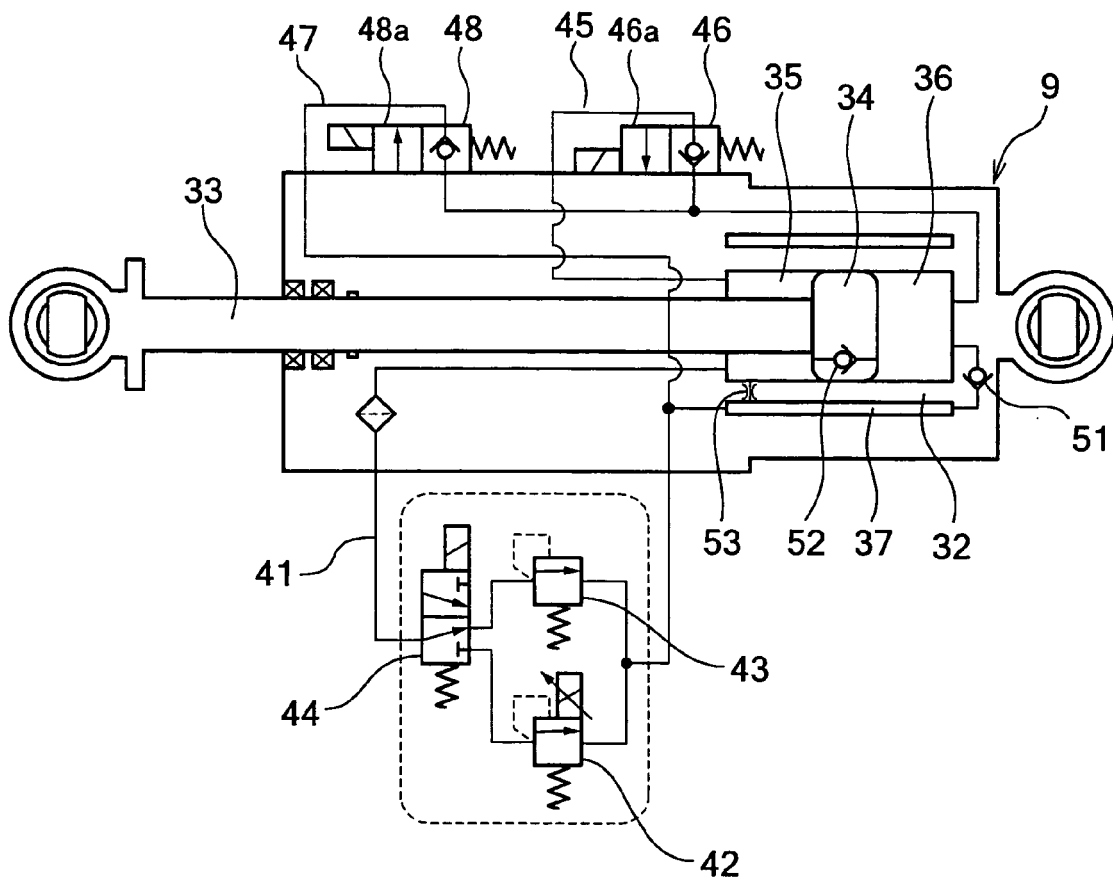


FIG.2

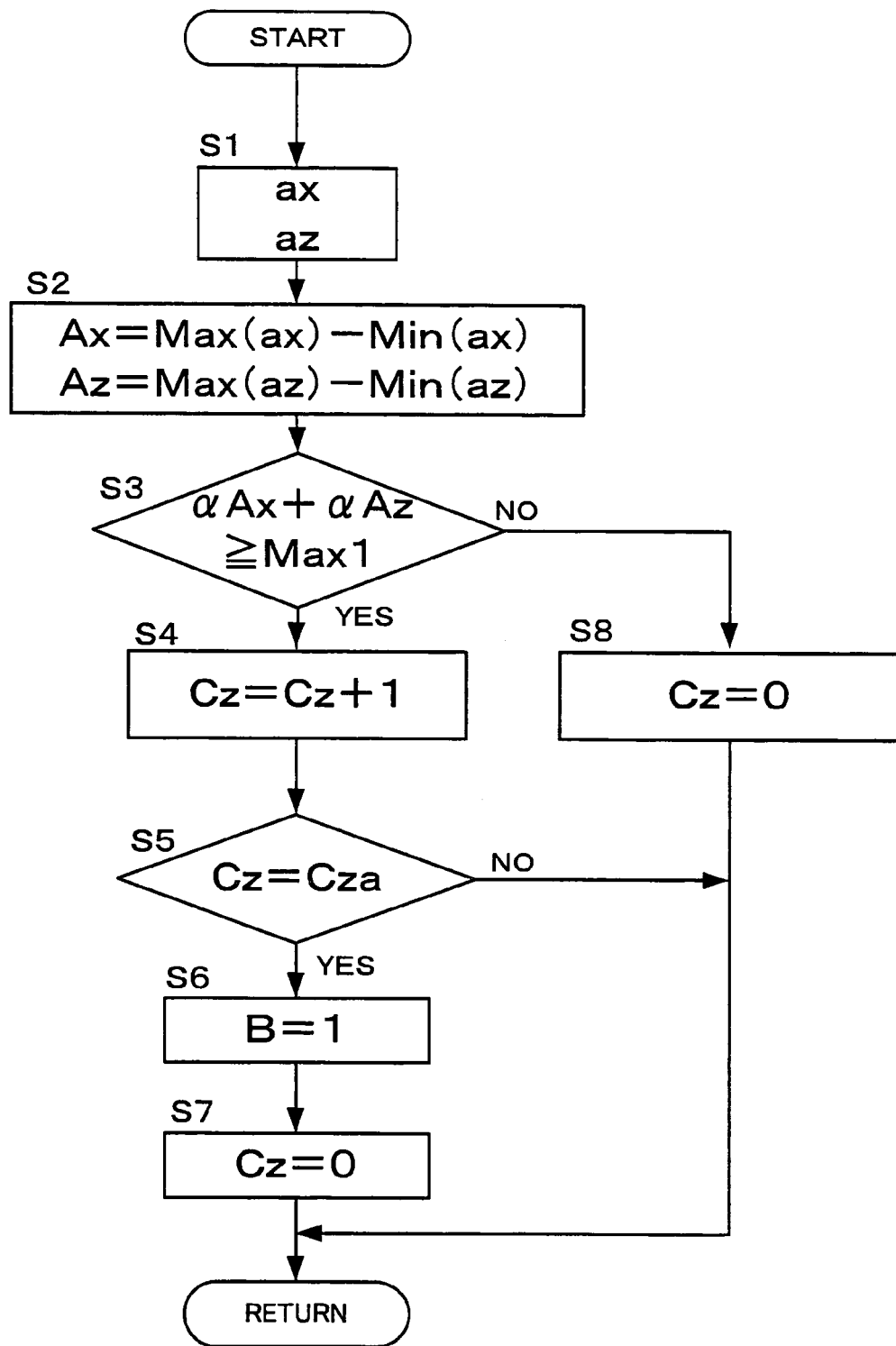


FIG.3

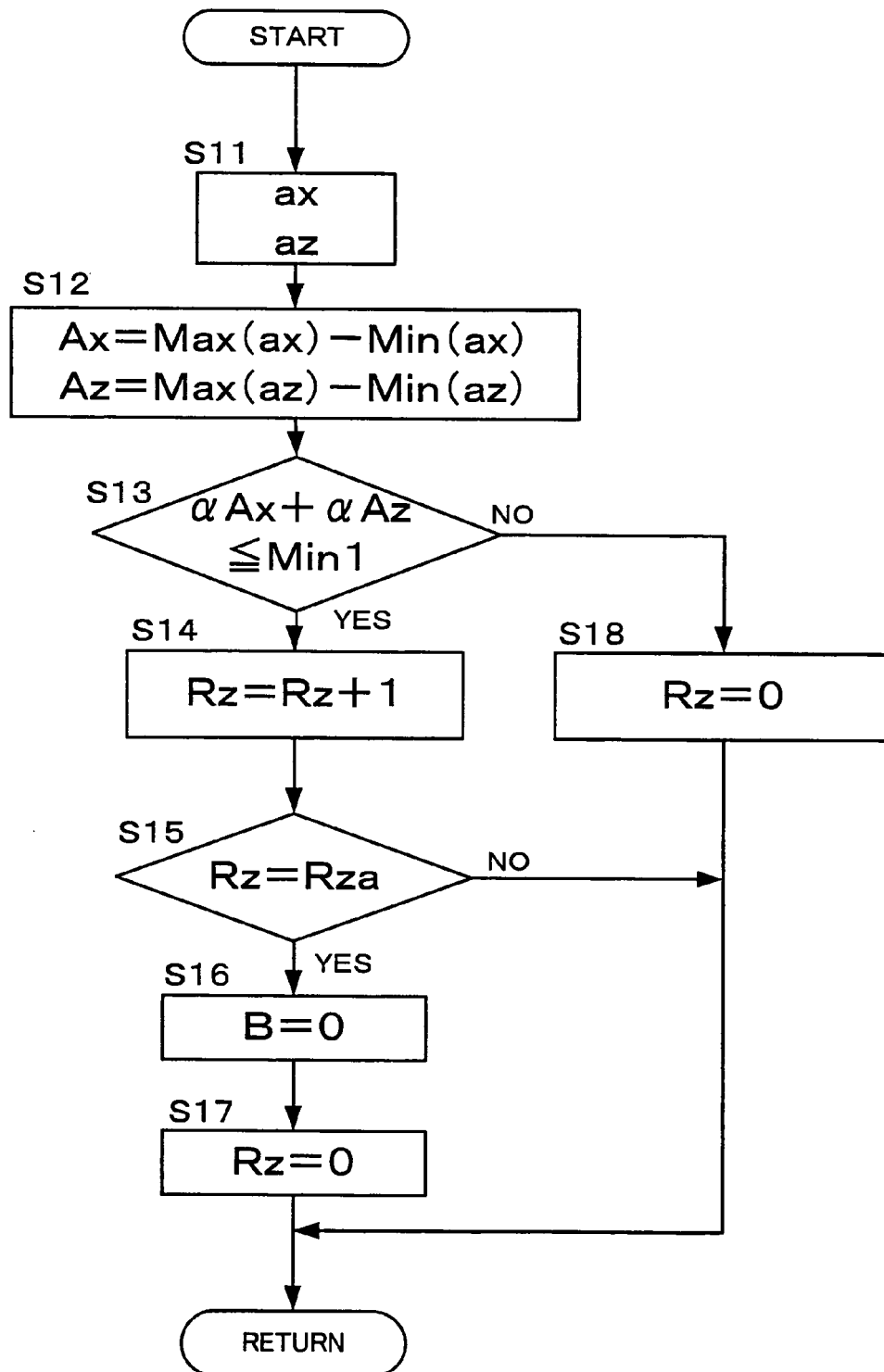


FIG.4

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 10297485 A [0003]