

- [54] **ACTIVE ROLL CONTROLLING TRUCK STABILIZING MECHANISM**
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- [73] Assignee: United Aircraft Corporation, East Hartford, Conn.
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- [52] U.S. Cl. ....105/164, 105/171, 105/182 R, 105/199 A, 105/210
- [51] Int. Cl. ....B61f 3/08, B61f 5/24, B61f 5/40
- [58] Field of Search .....105/3, 4 R, 157 R, 164, 171, 105/182 R, 185, 190 R, 191, 197 R, 197 B, 210, 199 A

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[57] **ABSTRACT**

A stabilizing railway vehicle suspension apparatus incorporates swing arms, actuators, springs and a control system so disposed as to automatically impart both rolling and lateral transverse motions to the car body when operating on curved track. The swing arms are mounted on the truck bolster and are directed upwardly and outwardly to their pivotal mountings on the roll platform upon which the car body is suspended by springs. Upon signal from an accelerometer mounted on the roll platform or truck the control system actuates the mechanism so as to roll and translate the car body in a manner that provides improved passenger comfort and improved stability against overturning.

8 Claims, 14 Drawing Figures

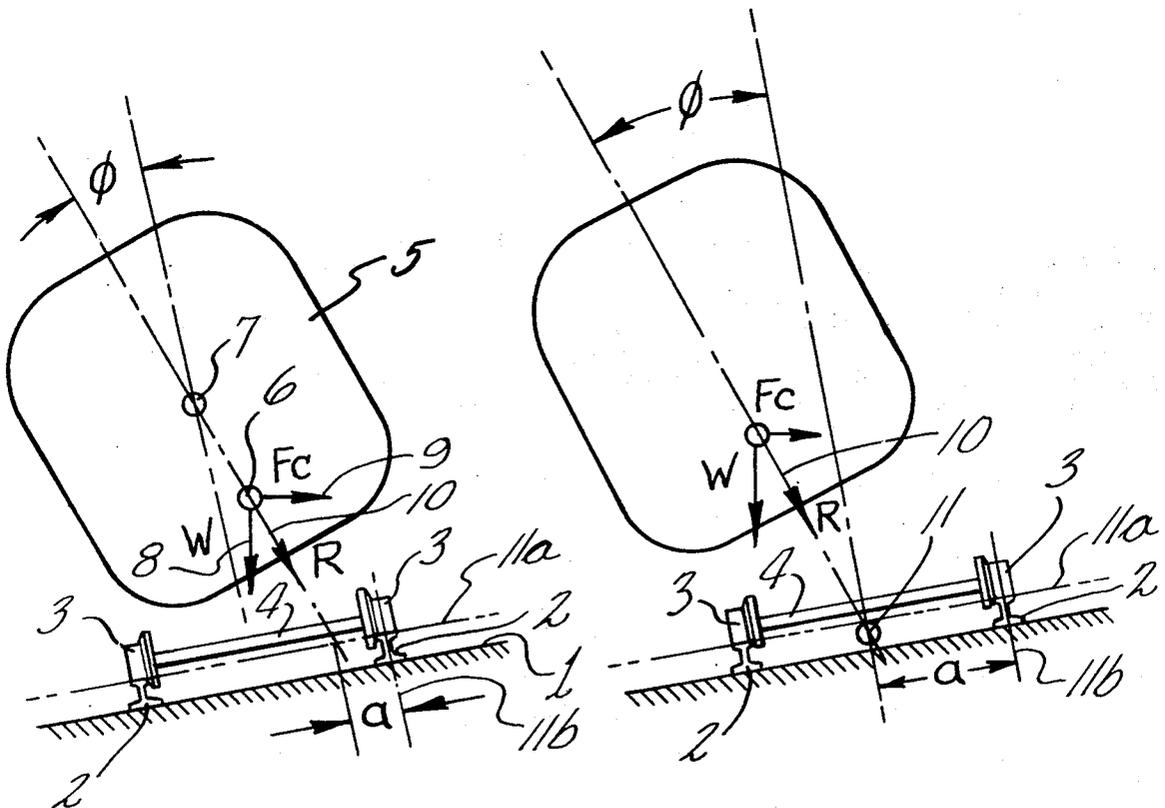


FIG. 1A

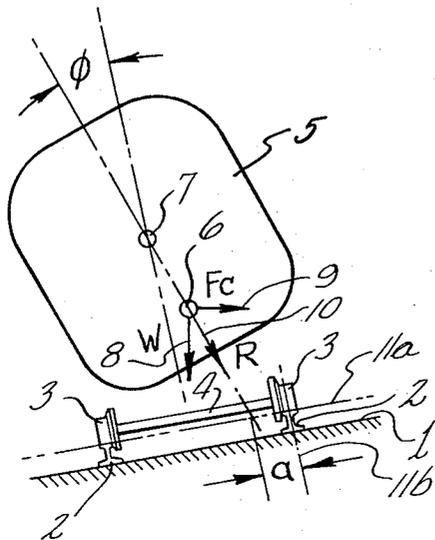
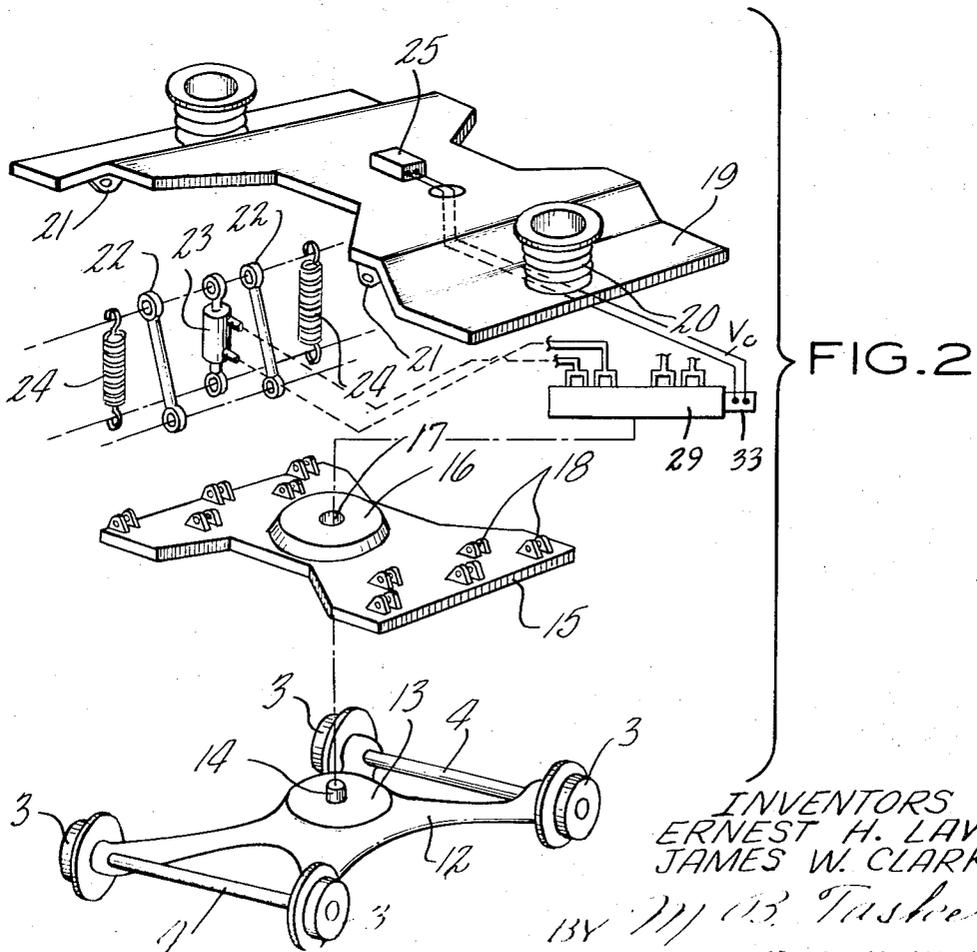
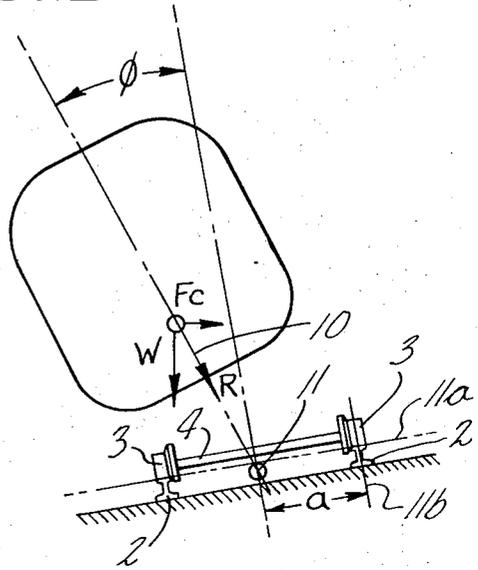


FIG. 1B



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FIG. 3

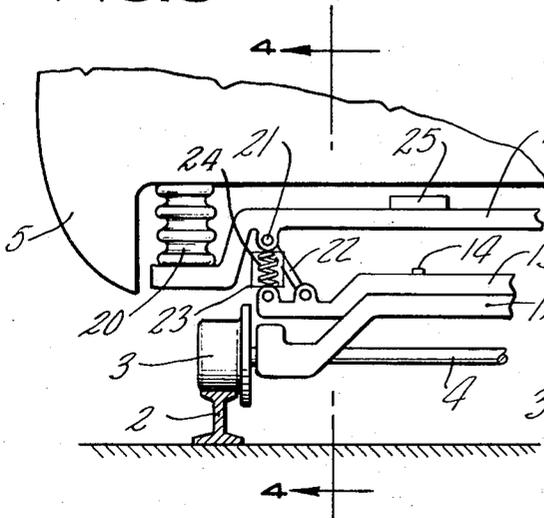


FIG. 4

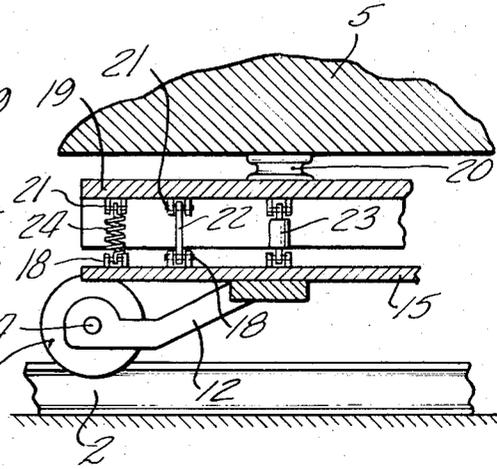


FIG. 5A

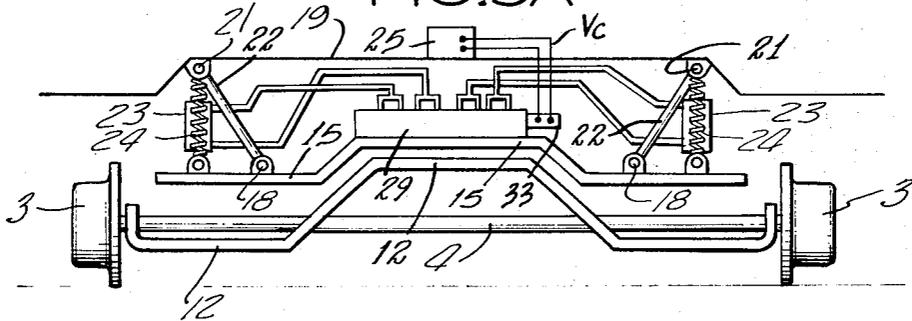
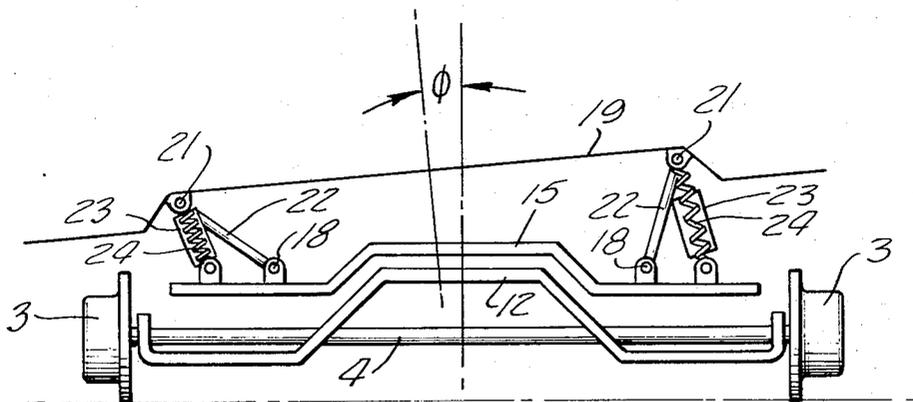


FIG. 5B



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FIG. 6

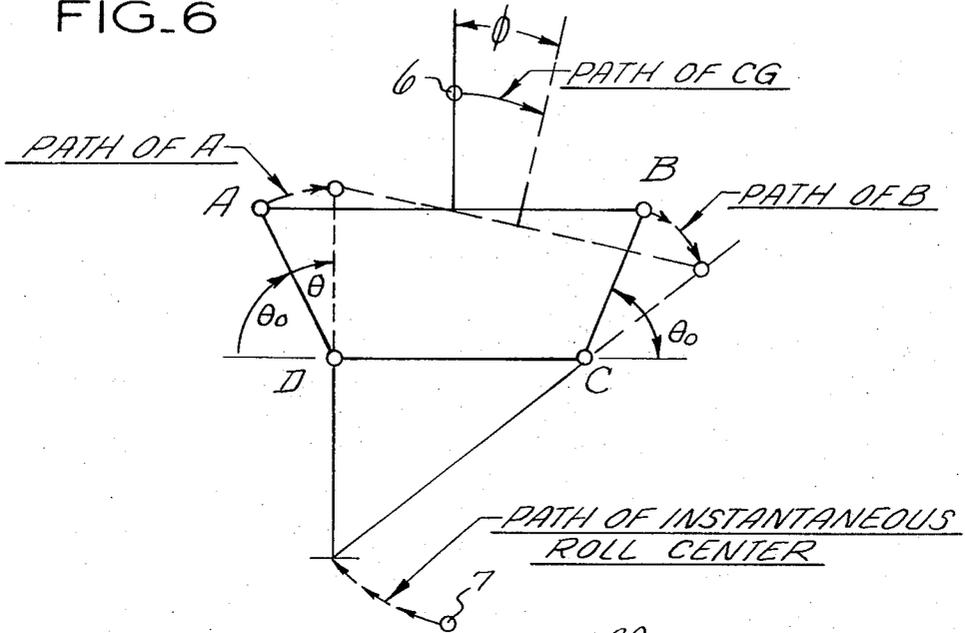
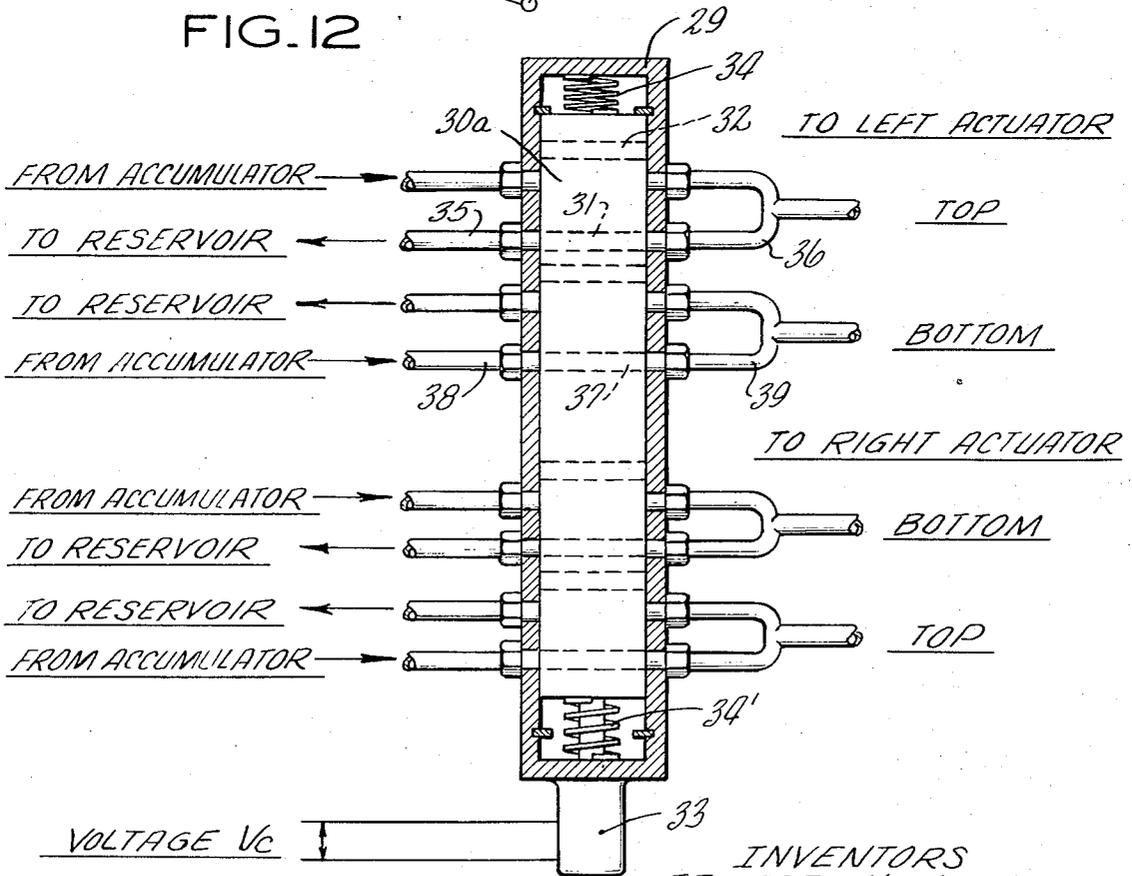


FIG. 12



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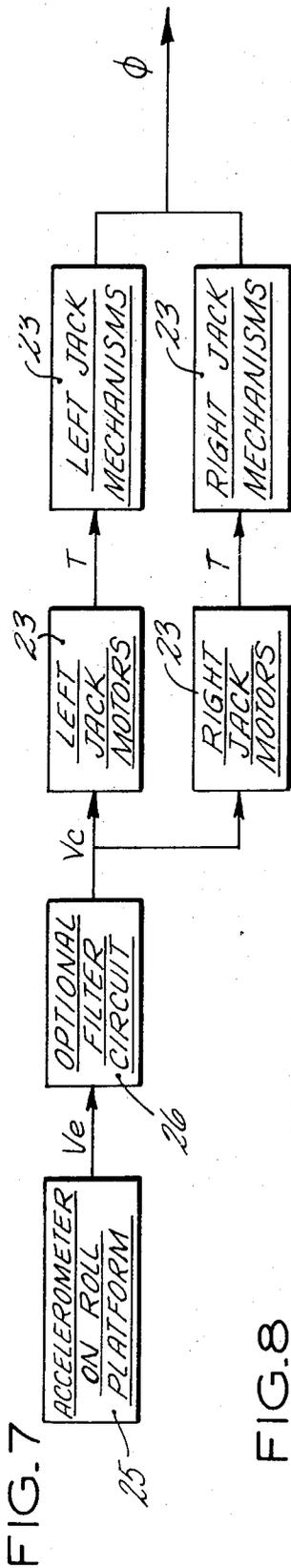


FIG. 7

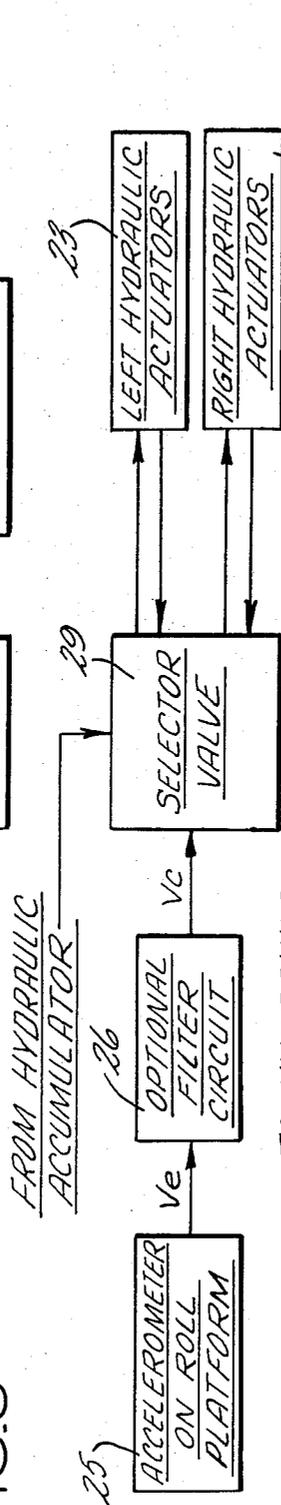
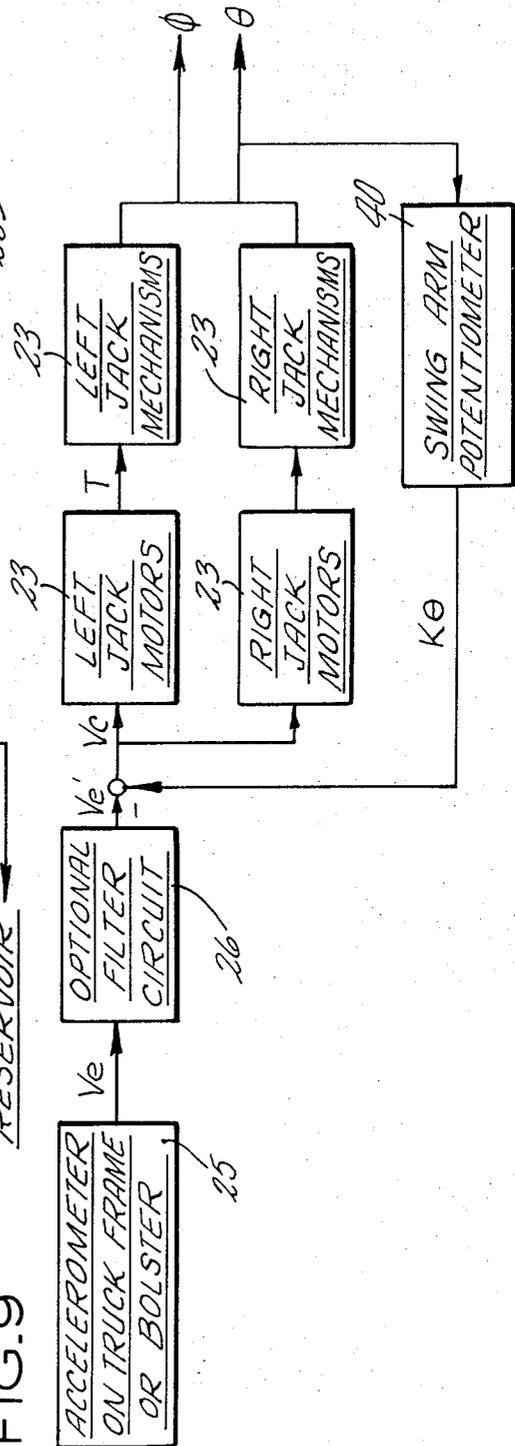


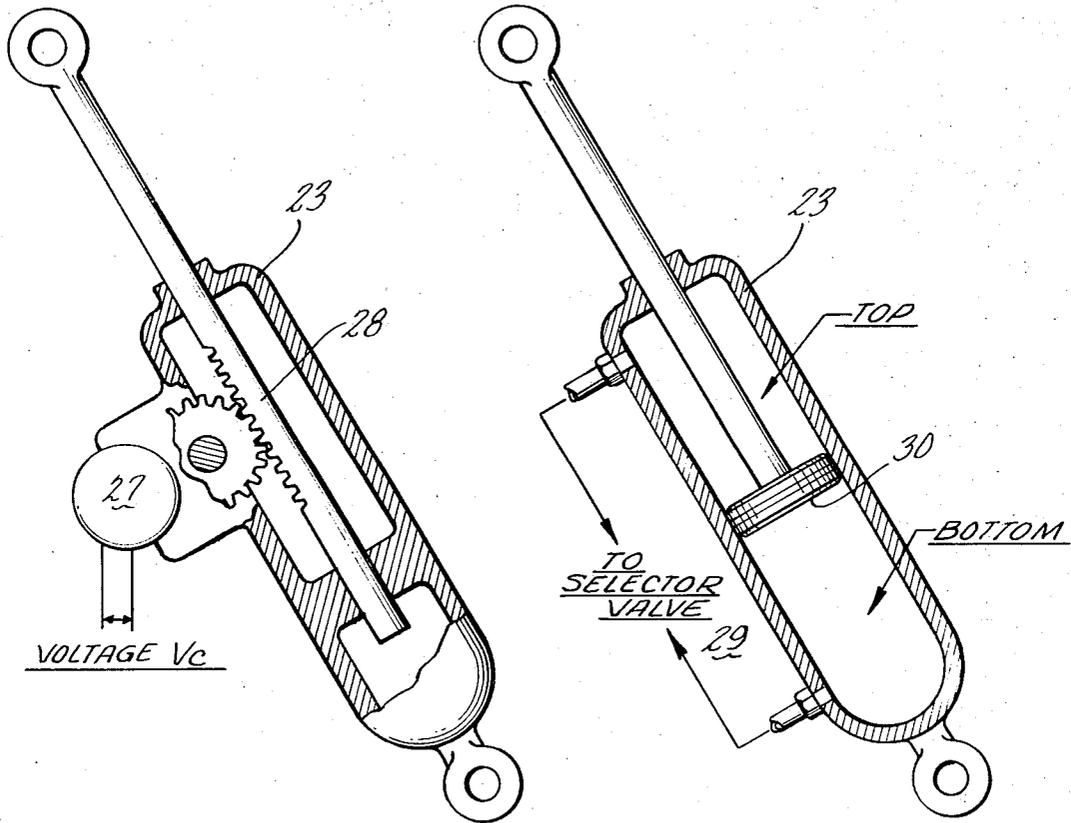
FIG. 8



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FIG. 10

FIG. 11



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# ACTIVE ROLL CONTROLLING TRUCK STABILIZING MECHANISM

## BACKGROUND OF THE INVENTION

In the interest of passenger comfort and also to guard against a tendency of the car to overturn outwardly when negotiating a curve, it has been the practice to bank the roadbed to at least partially eliminate the lateral accelerations acting on the passengers and, to some degree, to stabilize the car on curves. With the advent of the turbo-jet-driven trains which operate at much higher speeds a system of passive, pendulous suspension of the car body has been used which enables these faster trains to operate on existing road beds which were banked for trains operating at much lower speeds without passenger discomfort. In this passive roll control system, however, inclination of the car body on a curve resulted in greatly increasing the possibility of overturning the vehicle outwardly if the curve is traversed too fast or overturning the vehicle inwardly if the curve is traversed too slowly.

## SUMMARY OF THE INVENTION

This invention relates to railway vehicle suspension systems. Specifically, it relates to improved apparatus for suspending and controlling the angular and lateral transverse position of a railway car body during traverse of curved track in such a manner as to provide good riding qualities for the passengers therein and also to increase the stability of the railway vehicle with respect to overturning. Improved riding qualities are obtained by angularly rolling the car body so as to effectively eliminate the lateral component of acceleration that would be experienced by the passengers in the curve. Improved stability is obtained by translating the car body laterally inward toward the center of curvature if the curve is traversed at a speed greater than the speed used in designing the roadbed banking or track superelevation. Similarly, improved stability is obtained by translating the car body laterally outward from the center of curvature if the curve is transversed at a speed below the design speed for the roadbed or track superelevation. As will be described herein, these effects are obtained by a combination of linkages between the axle or truck frame, hydraulic or electromechanical actuators, and a control system employing one or more accelerometers.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A is a cross-sectional schematic view of a railway vehicle traversing a curve, showing the forces acting upon a pendulously suspended railway vehicle car body over which the present invention is an improvement;

FIG. 1B is a similar view showing the forces acting upon a car body of a vehicle equipped with the positive roll suspension system of this invention;

FIG. 2 shows an exploded view of a railway truck employing the improved apparatus of this invention.

FIG. 3 shows a cross-sectional view of the improved apparatus looking in the fore or aft direction of the railway vehicle;

FIG. 4 shows a cross-sectional view taken on line 4—4 of FIG. 3;

FIGS. 5A and 5B are schematic cross-sectional diagrams illustrating the operation of the improved apparatus; the electrical and hydraulic elements shown in FIG. 5A being omitted in FIG. 5B for purposes of clarity

FIG. 6 is a schematic diagram showing the kinematics of operation of the improved apparatus including the path of the car body center of gravity and the path of the instantaneous roll center;

FIG. 7 is a block diagram of the essential elements of a preferred embodiment of the roll control system employing electro-mechanical actuator mechanisms;

FIG. 8 is a similar block diagram of the control system for an alternate embodiment employing hydraulic actuators;

FIG. 9 is a block diagram of a control system in which the sensing accelerometer would be differently located from the location in FIGS. 7 and 8.

FIG. 10 is a cross-sectional diagram of an electro-mechanical actuator;

FIG. 11 is a cross-sectional diagram of a hydraulic actuator; and

FIG. 12 is a cross-sectional diagram of a selector valve that could be employed in an hydraulically actuated system.

## DESCRIPTION OF THE PREFERRED EMBODIMENT

At the present time, railway vehicles are usually suspended with respect to their transporting wheels and axles or truck frames by various suspension linkages employing steel or air bag springs, swing arms, and sometimes hydraulic shock absorbers or the like. These prior art arrangements employ the suspension system primarily to provide a passenger ride which is adequate with respect to shocks induced by roadbed unevenness, track irregularities, crossing of switches, etc. Attempt is also made in their design to alleviate to some degree important ride quality problems arising from lateral accelerations of the car body produced in curves. However, such conventional systems do not adequately alleviate lateral accelerations on the passengers under all conditions. Moreover, inclination of the car body in a direction tending to decrease stability of the railway vehicle, thereby greatly increasing the possibility of overturning outward if the curve is traversed too fast or inward if the curve is traversed too slowly. In addition, this lateral translation, when combined with the lateral accelerations felt by the passengers, causes apprehension and discomfort on the part of the passengers.

One prior art technique that has been employed in the attempt to correct the above mentioned deficiencies is illustrated schematically in FIG. 1A. This figure shows a passive pendulous suspension system in which 1 is the surface of the roadbed, 2 are the rails, 3 is the wheel set, 4 is the axle, and 5 is the outline of the car body. In this suspension system, the center of gravity 6 of the car body is below the car body pivot axis 7, that is, the center of gravity is below the center of rotation. The primary forces acting upon the car body in the curve are shown as the car body weight 8, the centrifugal force 9, and the resultant 10 of the weight and the centrifugal force which acts along the car body centerline through the center of gravity and the center of

rotation. Under the combined influences of the weight and centrifugal force, the car body rotates about center of rotation 7 through an angle  $\phi$  such that there is no net transverse or lateral acceleration upon the passengers, that is, there is no acceleration perpendicular to the car body centerline.

One disadvantage of this prior art system is that it is most readily applied to car body configurations in which the car bodies are supported from single-axle wheel sets and frame apparatus located between cars. This allows a frame to be constructed such that the center of rotation 7 can be above the center of gravity 6. This construction is not readily applicable to railway vehicles in which the car body is suspended from two multiple-axle trucks beneath the car body. A second very significant disadvantage is that the roll of the car body causes the resultant force 10 to pass closer to the outside rail if the train traverses the curve at a speed higher than the design speed for the roadbed banking. Conversely, the resultant force 10 passes closer to the inside rail if the speed is less than the design speed for banking of the roadbed. The distance  $a$  shown in FIG. 1A, which is the distance between the intersection of the line of action of the resultant force 10 and the track plane 11a and a line 11b through the center of rail 2, is therefore an indication of the contribution of the car body to the stability of the vehicle. If the resultant force passes outside of the outside rail in FIG. 1A, then the car body contributes markedly to the tendency for the vehicle to overturn outward. An analogous situation exists for overturning inward. Thus the destabilizing influence of the car body rotation in this prior art method places important restrictions on the range of speeds at which these vehicles can traverse a given curve. This tendency to overturn also causes restrictions to be placed on the car body roll angle  $\phi$  which in turn additionally comprises the range of operating speeds because of passenger comfort considerations.

FIG. 1B indicates the more desirable inclination and translation of the car body which occurs with the structure of the present invention. By the apparatus to be described herein the car body is forcefully rotated through the same angle  $\phi$  and is also translated laterally such that the resultant force 10 intersects the rail plane 11a at 11 in such a manner that the distance  $a$  is increased. This figure shows the operation when the railway vehicle traverses the curve at a speed above the design speed for roadbed banking. A similar situation exists when the railway vehicle traverses a curve at a speed below the design speed for roadbed banking. The effect is obtained by lowering the location of the roll center 7. Although points 7 and 11 are shown coinciding in FIG. 1B, this is not a necessary requirement of the invention. The locations of points 7 and 11 will be determined by such factors as the dimensions of the car body, the lengths of the swing arms, to be described subsequently, allowable translation of the car body to be consistent with interference restrictions on operating envelopes on multiple-track curves, etc.

By comparison of FIGS. 1A and 1B it can be seen that the present invention provides not only improved riding qualities but also a marked improvement in stability against overturning. This invention may also be employed for suspension systems between car bodies or, as described subsequently, may be employed with multiple-axle trucks beneath car bodies.

An exploded view of the mechanism required for achieving this combined rolling and lateral translatory car body motion is shown in FIG. 2. In this figure are shown the lower truck frame 12 upon which are mounted the wheel sets 3 and axles 4, the truck frame center plate 13, the pivot pin 14, the bolster, or upper truck frame 15, the bolster centerplate 16, the pivot pin hole 17 a plurality of mounting lugs 18, the roll platform 19, the car body air springs 20, a plurality of mounting lugs 21, swing arms 22, the left-hand actuator 23, the left-hand springs 24 and accelerometer 25. This figure is intended for illustrative purposes only. The mechanism may be applied to a single-axle suspension between car bodies or beneath a car body. When applied to a truck, the truck may have more than two axles; the car body may be mounted on the roll platform using a different spring arrangement, or a different number of springs; and, as discussed subsequently, the accelerometer may be mounted in a different location. The symmetrically disposed right-hand actuators, swing arms, and springs on the opposite side of the truck from that shown in FIG. 2 have been omitted for purposes of clarity.

The truck frame 12 is pivotally mounted with respect to the bolster 15 to allow the truck to yaw about pivot pin 14 in a manner similar to that of conventional railway trucks. The swing arms 22 and their opposite counterparts are pivotally mounted to the bolster by means of pins which extend through lugs 18 and are pivotally mounted to the roll platform 19 by means of pins through lugs 21. It should be particularly noted here that these swing arms are rigid links and are directed outward and upward from the bolster 15 to the roll platform 19. The outwardly directed swing arms are the key feature of the present invention in that lateral translational motion of the roll platform with respect to the bolster 15 is accompanied by rotation of the roll platform 19 about a longitudinal fore-and-aft axis. Forceful motion of the roll platform 19 is achieved by extending and shortening actuators 23 which are also pivotally mounted to the bolster 15 by means of pins through lugs 18 and to the roll platform 19 by means of pins through lugs 21. The function of the springs 24, which are pivotally mounted in like manner, is to return the roll platform to the center position in the event that hydraulic or electric power to the actuators fails. The control system required to achieve proper operation of the system will be described subsequently. The outwardly directed swing arms, the springs 24 and the actuator 23 are clearly shown in FIGS. 3 and 4.

FIG. 5A is a schematic drawing showing the apparatus in operation either on a straight track or a curved track at exactly the design speed for roadbed banking. In this situation there is no requirement for car body roll angle or lateral translation and the two actuators 23 are extended equally. The force levels in these actuators may be zero in this condition or they may be nonzero. FIG. 5B shows the operation of the system when a roll angle in the counterclockwise direction and a lateral translation of the car body to the left is required. Upon signal from the control system, the right-hand actuator 23 is extended while the left-hand actuator 23 is shortened. This causes swing arms 22 to rotate about their axes 18, thereby lowering the left-hand side of roll platform 19 in FIG. 5B and raising the right-hand side. This rolling motion of the platform

is accompanied by translation of the roll platform to the left. When this motion takes place, the left-hand spring 24 is compressed and the right-hand spring is extended, thereby providing forces which would restore the roll platform to its initial condition in the event of a failure of the actuators. It will be understood that springs 24, due to the spacing of their coils and their pivotal attachment, act both in compression and tension.

FIG. 6 shows the kinematics of operation of this apparatus. Line AB represents the roll platform 19, line DC represents bolster 15, line AD represents the left-hand swing arm 22, line BC represents the right-hand swing arm 22. The paths of the car body center of gravity 6 and the instantaneous roll center 7 are also shown. The dashed lines in this figure show the orientation of the swing arms and the roll platform after a signal to roll the car body clockwise.

As an example, in an actual installation of this apparatus the distance DC in FIG. 6 might be 32 inches, the distance AB might be 55 inches, the distances AD and BC might be 23 inches, and the angle  $\theta_0$  might be  $60^\circ$ . When the swing arm AD and BC are rotated through an angle  $\theta$  of  $30^\circ$  clockwise as shown in FIG. 6, the car body roll angle  $\theta$  would be  $12^\circ$  and the center of gravity 6 of the car body would be translated laterally to the right a distance of 16 inches. For this geometry, the usable range of swing arm angles  $\theta$  might be  $30^\circ$  counterclockwise to  $30^\circ$  clockwise from the central position.

In the preferred embodiment of the invention, the output signal from accelerometer 25 attached to roll platform 19 in FIG. 2 is used by the control system to cause changes in the force levels in actuators 23. For this embodiment, the control system shown in the block diagram in FIG. 7 can be used. The output of the accelerometer is a voltage  $V_e$  proportional to the instantaneous acceleration of roll platform 19 in the lateral transverse direction. This acceleration is approximately equal to the lateral transverse acceleration that would be experienced by the passengers in the car body. The accelerometer output voltage  $V_e$  may have to pass through the optional filter circuit 26 in order to remove high frequency signals due to truck hunting, track irregularities and other sources tending to cause differences between the acceleration at the accelerometer and the acceleration of the car body center of gravity 6. This filter circuit would be a conventional low-pass electrical network which is well known to those familiar with the art. The output voltage  $V_c$ , or  $V_e$  if no filter circuit is utilized, then provides the signal to the appropriate jack motors and mechanisms 23 to extend or shorten their lengths. For example, if the accelerometer 25 in FIG. 2 indicates that the roll platform 19 is accelerating to the left, a positive voltage  $V_c$  would signal the left-hand jack motors in FIG. 2 to decrease the actuator length and signal the right-hand jack motors (not shown in FIG. 2) to increase the actuator length. This would cause counterclockwise rotation of arms 22 on the left-hand side in FIG. 2, thereby lowering the roll platform 19 on that side. Concurrently, rotation of the swing arms on the right-hand side of FIG. 2 would cause elevation of the right side of the roll platform. This combined action would cause the roll platform to roll in the counter-

clockwise direction and would cause the platform to be translated laterally to the left.

An example of the type of electromechanical actuator which could be used in this embodiment of the invention is shown in FIG. 10. Actuator 23 is shown to consist of a jack motor 27 and a rack and pinion device 28. When the motor is actuated by the voltage  $V_c$  the actuator 23 is caused to extend or contract depending upon the electrical sign of voltage  $V_c$ .

FIG. 8 shows an alternate embodiment in which the accelerometer 25 is also mounted upon the roll platform 19 but, instead of electromechanical actuators being used, hydraulic actuators are used. The signal voltage  $V_c$  actuates the selector valve 29 which in turn directs high pressure hydraulic fluid into the appropriate chambers of the left and right-hand hydraulic actuators 23. A possible configuration for the hydraulic actuators 23 is shown in FIG. 11 and a possible configuration for a selector valve is shown in FIG. 12. In FIG. 11 it can be seen that the introduction of high pressure hydraulic fluid from the hydraulic accumulator into the top chamber above the piston 30 and concurrent venting of the bottom chamber below piston 30 would cause a force downward and to the right in FIG. 11 which would result in shortening of the actuator strut. Similarly, introduction of high-pressure hydraulic fluid into the bottom chamber and venting of fluid from the top chamber would cause a force tending to extend the actuator.

The control selector valve shown in FIG. 12 consists of a case 29 and a shuttle valve 30a having a plurality of passages drilled diametrically, such as passages 31 and 32. The shuttle valve 30a is driven longitudinally along its axis of symmetry by solenoid 33 which is energized by the signal voltage  $V_c$ . Shuttle valve 30a acts against the springs 34 such that under zero voltage conditions the springs tend to center the valve in the neutral position. If, as in the preceding example, an acceleration is sensed by accelerometer 25, voltage  $V_c$  is given the appropriate electrical sign to cause the shuttle valve 30a to translate, thereby aligning the proper passages and connecting pipes to introduce high-pressure fluid into the proper chambers. In FIG. 12, passage 31 would permit hydraulic fluid to leave the top chamber on the left actuator through pipe 36 and enter the reservoir through pipe 35; simultaneously passage 37 would permit hydraulic fluid from the high pressure accumulator to flow through pipes 38 and 39 to the bottom chamber of the left actuator, thereby causing the left actuator to increase in length.

The details of the wiring in the case of the electromechanical actuations and the details of the hydraulic reservoir, pump, accumulator and associated pipes and flexible hoses, in the case of the hydraulic system, are not shown in these figures. These components are well known in the art. Moreover, it is not pertinent to the present invention to describe their locations. For convenience, they may be located within the car body, on the roll platform 19, on the bolster 15, or on the truck frame 12.

Still another embodiment of the invention is illustrated in the block diagram of FIG. 9. In this case the accelerometer 25 would be mounted on the truck frame 12 or the bolster platform 15. Since the accelerometer does not in this case directly measure the

acceleration of the roll platform 19, its signal must be modified by a signal from the swing arm potentiometer 40. This potentiometer measures the angular rotation of swing arm 22 relative to bolster 15 or the roll platform 19. When the voltage output of the swing arm potentiometer is subtracted from the Voltage  $V_e'$  as in FIG. 9, the resulting voltage  $V_c$  is equivalent to voltage  $V_c$  shown in the control system of FIGS. 7 and 8. The remaining portions of the system function identically as described previously. Although FIG. 9 shows the block diagram for the system employing electromechanical actuators, this system may also be used with hydraulic actuators.

I wish it to be understood that I do not desire to be limited to the exact details of construction shown and described, for obvious modifications will occur to a person skilled in the art.

We claim:

1. A railway vehicle suspension apparatus comprising a truck having a lower frame which supports the wheel sets, an upper frame mounted on said lower frame for pivotal movement, a roll platform above said truck on which a car body is mounted, roll control mechanism between said upper frame and said platform for forcibly imparting both rolling and inward transverse motions to said car body when traversing a curved section of track above the design speed for said track, said mechanism including rigid left- and right-hand swing arms having pivoted connections at their lower ends with said upper frame and extended upwardly and outwardly and having pivoted connections at their upper ends with said platform, actuating means for imparting said motions to said car body as controlled by said swing arms, and an accelerometer mounted on a part of the vehicle which is affected by lateral accelerations as said vehicle enters and leaves said curved section of track for controlling said actuating means.

2. A railway vehicle suspension apparatus comprising a truck adapted to run on parallel rails and having a lower frame which supports the wheel axles, wheels at the ends of said axles, a bolster pivotally mounted on said frame, a roll platform above said bolster which supports a car body, means for improving the stability of the vehicle against overturning by maintaining the line of action of the resultant of the weight and centrifugal force vectors between and well away from said rails when the vehicle is negotiating a curve including rigid left- and right-hand swing arms pivotally connected at their lower ends with said bolster and extended upwardly and outwardly and having their upper ends pivotally connected to said platform, actuator means for positively moving said platform as controlled by said swing arms, and control means including an accelerometer for energizing said actuator means both to roll said car body about a fore and aft axis and to bodily translate it laterally inward toward the center of said curve.

3. A railway vehicle suspension apparatus for high speed trains comprising a vehicle truck having a lower frame which supports the wheel axles, an upper frame mounted on said lower frame for movement about a vertical axis, a roll platform, a car body mounted on said platform, and active control mechanism mounted between said upper frame and said platform including

rigid left- and right-hand swing arms having pivoted connections at their lower ends with said upper frame, said swing arms having their upper ends extended upwardly and outwardly and having pivoted connections at their upper ends with said platform, springs connecting said upper frame and said platform, and left- and right-hand actuators for imparting both rolling and bodily lateral motion to said car body inward toward the center of curvature of a curved section of track, said actuators having pivotal connections at their lower and upper ends with said upper frame and with said platform respectively, an accelerometer mounted on a part of said vehicle which is affected by lateral accelerations as said vehicle enters and leaves said curved section of track, and control means responsive to variations in accelerometer voltage output for controlling said actuators to impart said inward motions to said body.

4. The suspension apparatus of claim 3 in which the springs connecting the upper frame and the platform are tension-compression springs capable of returning the car body to its initial position in the event of actuator failure.

5. The suspension apparatus of claim 2 in which the actuators are hydraulically operated by means of a selector valve.

6. The suspension apparatus of claim 3 in which the actuators are electrically operated through a reversible electric motor and rack and pinion mechanism.

7. A railway vehicle suspension apparatus comprising a truck having a lower frame which supports the wheel sets, an upper frame pivotally mounted on said lower frame, a roll platform above said truck on which a car body is mounted, roll control mechanism between said upper frame and said platform for forcibly imparting both rolling and inward transverse motions to said car body as the latter traverses a curved section of track above the design speed for the track, said mechanism including rigid left- and right-hand swing arms having pivoted connections at their lower ends with said upper frame and extended upwardly and outwardly and having pivoted connections at their upper ends with said platform, actuating means for imparting said motions to said body as controlled by said arms, means for energizing said actuators as said vehicle enters or leaves said curved section of track including an accelerometer mounted on said truck and a swing-arm potentiometer for modifying the output signal of said accelerometer which is responsive to changes in the angle between said swing arms and said platform.

8. A railway vehicle suspension apparatus comprising a truck having a lower frame which supports the wheel sets, an upper frame pivotally mounted on said lower frame, a roll platform above said truck on which a car body is mounted for the transportation of passengers, left- and right-hand swing arms having pivoted connections at their lower ends with said upper frame and extended upwardly and outwardly and having pivoted connections at their upper ends with said platform, and means between said upper frame and said platform including rigid left- and right-hand actuators operative when the vehicle traverses a curved section of track at a speed higher than the speed for which the curve was designed for positively translating said car body under control of said swing arms laterally inward

toward the center of curvature of the track to oppose vehicle overturning while angularly rolling said car body forcibly against centrifugal forces to eliminate the lateral component of acceleration acting on the passengers within the vehicle.

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