A STABILITY STUDY OF A THREE-POINT AND A FOUR-POINT SECONDARY SUSPENSION CONFIGURATION FOR A RAIL PASSENGER CAR

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Abstract

A dynamic analysis of a rail passenger car study was performed in order to evaluate the differences between a secondary air suspension bogie with three-point and a four-point control system. Dynamical analyses with different conditions of turning radius and velocities were performed and the L/V coefficients were calculated. The results have shown that there was not a best configuration for all conditions of velocities. The magnitudes of the L/V coefficients in the three-point configuration depend on the direction of the movement of the rail car. The four-point configuration showed an intermediate performance in all velocities. The best performance could be achieved with the development of a switch system that changes the configuration of the three-point system according to the direction of movement and velocity of the rail passenger car.

1. INTRODUCTION

A comparison study was performed in order to evaluate the dynamic behavior of a secondary suspension of a rail car using the three-point and a four-point leveling control system. In the industry there is not a consensus about which type of configuration is the best for safety

This project was sponsored by a Sao Paulo transportation company in Brazil (CPTM) which is responsible for the maintenance of the rail passenger cars in the city of Sao Paulo. Because safety issues CPTM asked for a study to determine if the three-point configuration is better than four-point configuration. Most of the rail passenger cars running in the city have a four-point leveling control system.

In the four-point configuration the vehicle is supported by two pneumatic bellows at each truck to form a four-point suspension in which each of the bellows is individually controlled by its own control leveling valve (two point at each truck). In the case of three-point configuration one of the trucks the two bellows are connected pneumatically to each other and are controlled by only one leveling valve (one truck with two points and the other with a single point).

The four-point configuration can create imbalance between vertical loads and this is more prominent at slow velocities. This disadvantage apparently does not appear in a three-point suspension system since the connection between the two bellows absorb the sway motion of the vehicle body. But the results have shown that the 3-point suspension system had different performance according to the direction of the movement and velocity.

2. METHODS

In order to study the behavior of the rail car using a three-point and a four-point suspension leveling control valves a complete multibody model of the rail car was developed using a multibody software MSC.Adams/Rail (Figure 1). A central role in this project is the thermodynamic model of the suspension air springs (bellows) and a correct pneumatic model of control leveling valves.

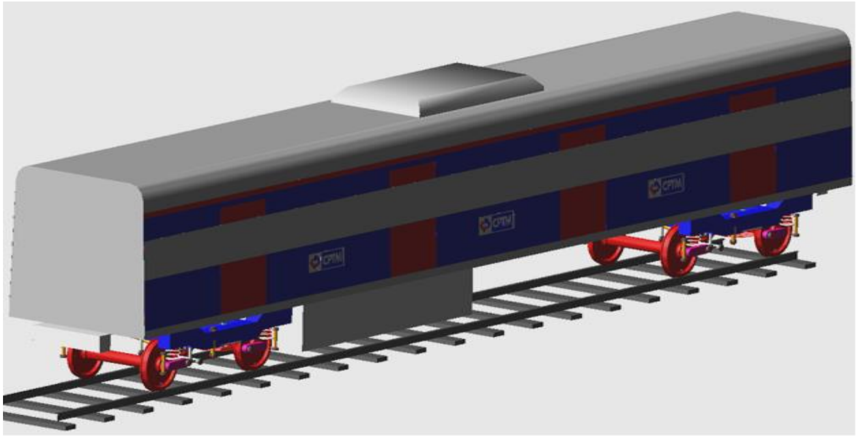

Figure 1: A complete multibody model of a rail passenger car in MSC.Adams/Rail 2005R2

The multibody model of the bogie developed for this project can be seen in Figure 2. As can be seen in the figure, the bogie has four primary helicoidal springs, with four vertical shock absorbers. The secondary suspension is composed of two air springs, vertical and yaw shock absorbers.

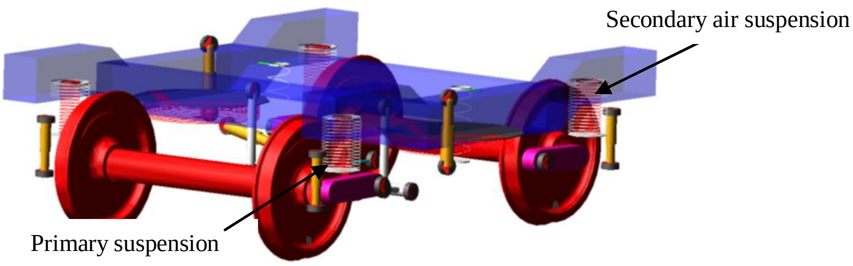

Figure 2: Bogie model in MSC.Adams/Rail 2005

The main characteristics of the rail can be seen in Table 1 below.

Track Width (m)	1.6
Track Type	TR-57
Wagon mass unladen (without passenger) (Kg)	25700
Wagon mass Laden (385 passengers) (Kg)	52650

Table 1: Rail Characteristics CPTM Série 2000

Two models of the rail passenger car were built: one model with four-point control leveling valves and one model with 3 point control leveling valves.

In the 4 point configuration, each air suspension has a unique control leveling valve. Also there is a compensator valve with cracking pressure of 1,47 bar (the valve opens when the difference of pressure between the air springs is higher than 1,47 bar).

In the 3-point configuration two air springs are controlled by one leveling valve and the two air springs are connected by means a tube and the pressures inside the elastic chamber are equal.

The analyses were performed in three different configuration (see Figure 3). The three point-configuration analyses were performed in both directions, in order to study the dynamic behavior and the influence of the pneumatic control in L/V coefficient for the front wheelset.

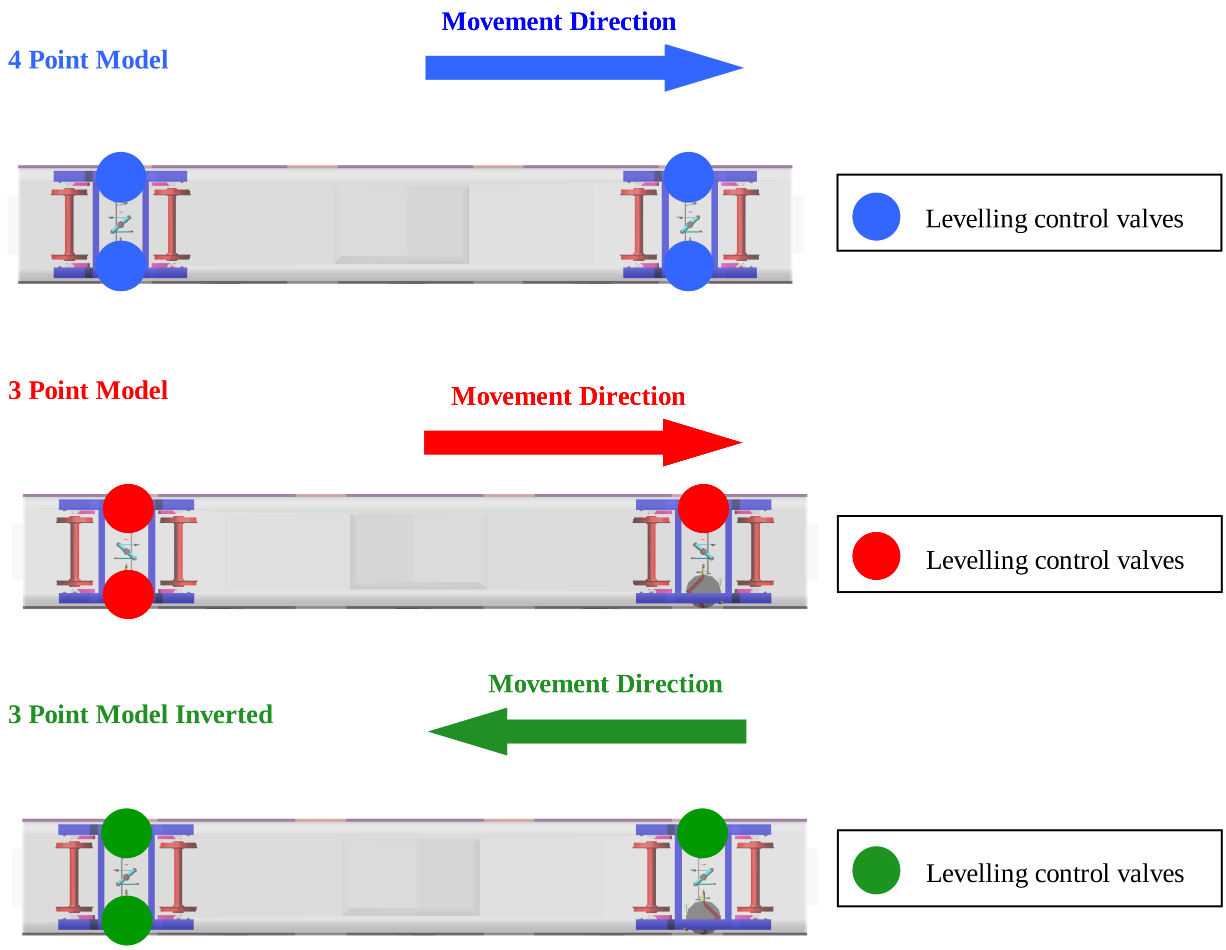

Figure 3: Scheme of control levelling valves of air suspension for 4 point and 3 point configurations

A thermodynamic model of air springs was developed in the MSC.Adams/Rail, using the Krettek air spring model, which is based on the energy and mass balance. The control leveling valve was modeled using the calibration curve of flow versus angle of the valve and the pneumatic circuit of the air suspension, taking into account the losses due to the geometry of the pipeline of the pneumatic circuit.

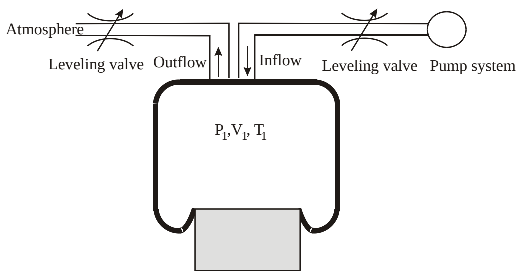

Figure 4. Scheme of an air spring system

The work process into the elastic chamber depends upon the speed of compression and expansion of the air. A rapid process (rapid spring deflection) is an adiabatic process, resulting in a high pressure and stiffness. On the other hand, slow deflection results in an isothermal process and low pressure and stiffness.

In practice, air spring operates in a process between adiabatic and isothermal. This process is called polytropic process and it is closer to an adiabatic process.

The thermodynamics equations that describe the behaviour of the elastic chamber is based on the energy and mass balance.

The ideal gas law gives:

$$P_1 V_1 = mRT_1 \tag{1}$$

Differentiating with respect to time:

$$\dot{P}_1 V_1 + P_1 \dot{V}_1 = \dot{m}RT_1 + mR\dot{T}_1 \tag{2}$$

Isolating the term $\dot{P}_1$, the rate of change of pressure in the above equation, we can write:

$$\dot{P}_1 = \frac{\dot{m}RT_1}{V_1} + \frac{P_1 \dot{T}_1}{T_1} - \frac{P_1 \dot{V}_1}{V_1} \tag{3}$$

Writing the equation of energy conservation we obtain:

$$\partial W = -\partial U + \partial Q \tag{4}$$

Where W is the total energy, U is the internal energy and Q is the heat exchange. Each term in equation (4) can be written as:

$$\partial W = P_1 \dot{V}_1 \tag{5}$$

$$\partial U = \dot{m}c_v T_1 + mc_v \dot{T}_1 \tag{6}$$

$$\partial Q = \dot{m}c_p T_2 + K_h A(T_{env} - T_1) \tag{7}$$

The term $K_h A(T_{env} - T_1)$ is the heat exchange with the environment. Substituting equations (5), (6) and (7) into equation (3) and isolating the term $\dot{T}_1$:

$$\dot{T}_1 = \frac{T_1(k-1)}{P_1 V_1}\left[-P_1 \dot{V}_1 - \dot{m}c_v T_1 + \dot{m}c_p T_2 - K_h A(T_1 - T_{env})\right] \tag{8}$$

The air spring force is the pressure times the effective area. This can be written as:

$$F_{air} = P_1 A_e \tag{9}$$

Supposing a laminar flow, it can be shown that the air mass flow through the pipe into chamber is:

$$\dot{m} = \rho(T_1, P_1) C_d A_p \sqrt{\frac{2}{\rho(T_1, P_1)}(P_{feed} - P_1)} \tag{10}$$

The air mass ouflow from the chamber is given by:

$$\dot{m} = \rho(T_1, P_1) C_d A_p \sqrt{\frac{2}{\rho(T_1, P_1)}(P_1 - P_{atm})} \tag{11}$$

At high temperatures and pressures the air density is not linear. The following equation gives the air density based on temperature and pressure:

$$\rho(T_1, P_1) = 1.2929\left(\frac{27313}{T_1}\right)\left(\frac{P_1 - 0.38783e}{760}\right) \tag{12}$$

3. DYNAMIC ANALYSES

Analyses were performed with two velocities, 20 Km/h and 70 Km/h and with different turning radius and super elevation of the track. Table 2 shows the maneuver conditions for the analysis.

In the Table 2 Maneuver 1 was the physical condition of the track, Maneuver 2 was the proposed modification of the track in order to decrease the L/V coefficient and increase the safety condition at low velocities. Maneuver 3 was performed in order to evaluate the 4-point and 3-point configuration at higher speed (70 Km/h).

	Maneuver 1	Maneuver 2	Maneuver 3
Superelevation (mm)	190.0	160.0	50.0
Transition (m)	50.0	80.0	50.0
Curve lenght (m)	100.0	210.0	400.0
Miminum curve radius (m)	217.0	217.0	400.0
Operation velocity (Km/h)	20.0	20.0	70.0

Table 2: Maneuver parameters for dynamic analysis

The L/V coefficients for the outside wheel at the leading truck for maneuvers shown in Table 2 can be seen in Figure 5. The lowest L/V coefficient was obtained in the 3-point configuration with the front truck with one control valve. But in the 3-point configuration when the two-point truck is the leading truck the L/V coefficient increases significantly (green line in the graphics).

For higher velocities (70Km/h) the L/V of the 3-point configuration with the leading truck with two valves was the best configuration, with the lowest L/V coefficient.

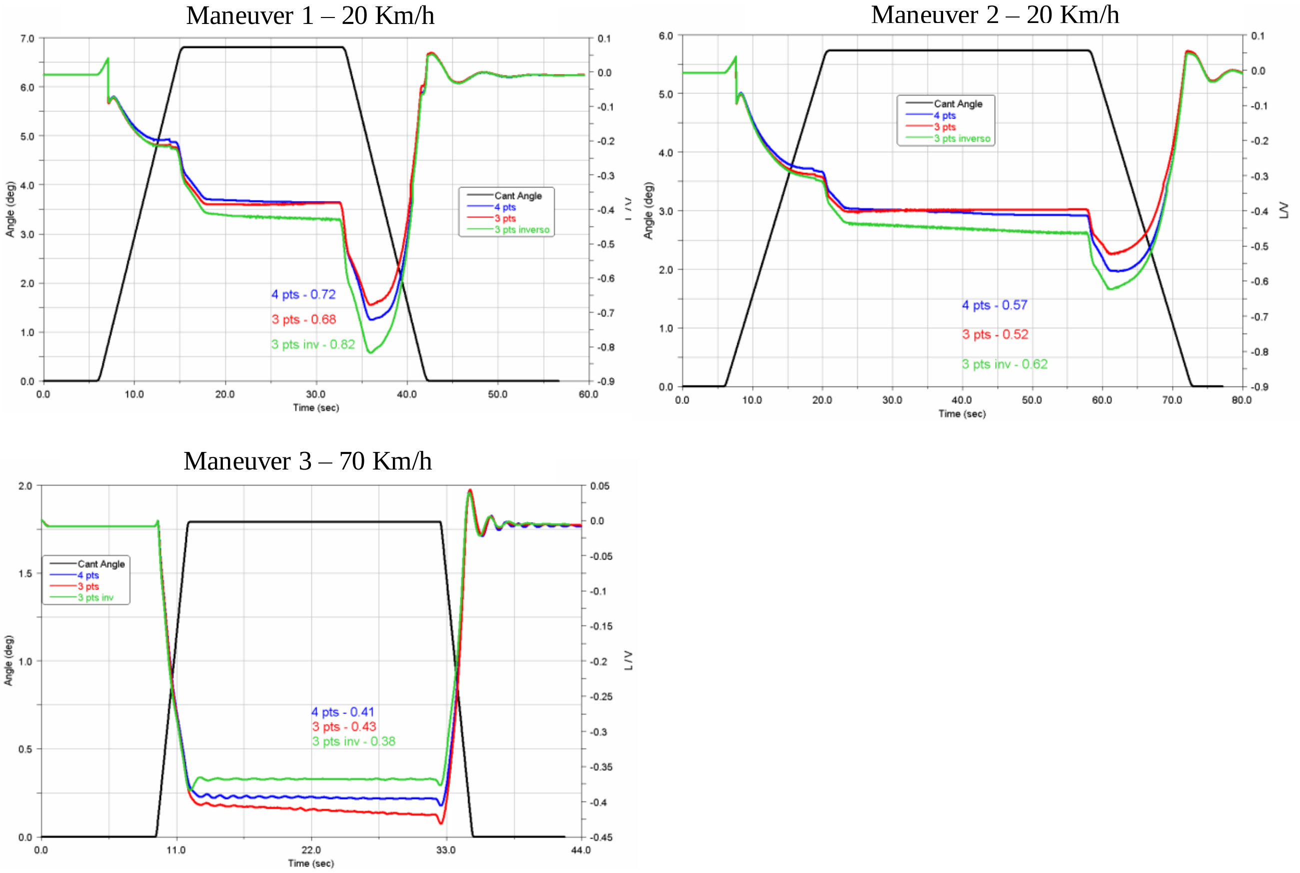

Figure 5. L/V coefficients of the maneuvers – blue – 4-point, red – 3-point with leading truck with one valve, green – 3-point with leading truck with two-valves.

Table 3 shows a summary of the highest value of the L/V coefficients obtained in each maneuver. As can be seen in Table 3 there is not a best configuration for all conditions of speed. The 4-point configuration has an intermediate performance in both low and high speeds.

	Maneuver 1 20 Km/h	Maneuver 2 20 Km/h	Maneuver 3 70 Km/h
4 point	**0.72**	**0.57**	**0.41**
3 point	**0.68**	**0.52**	**0.43**
3 point inverted	**0.82**	**0.62**	**0.38**

Table 3:Summary of L/V coefficients of the maneuvers

4. CONCLUSIONS

The results have shown that at low velocities the three-point configuration has a better performance than four-point configuration, but only in one direction, when the single point truck is the leading truck. In the three-point configuration when the truck with single point is in the rear (with two-point truck in the leading truck) the three-point has a poor performance at the low speed velocity .

In the case of high velocities the 3-point configuration with the leading truck with two valves showed the best performance. Analyzing the data the conclusion is that the 4-point configuration has the intermediate performance for all the velocity conditions.

As a suggestion for future work is the development of a switch system for the 3-point configuration, changing the leading truck control leveling system based on the direction of movement and velocity, changing the one and two valves configuration according to the direction of the movement and velocity of the rail passenger car. In this case we could reach the best performance for all velocities.

Acknowledgements

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