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Study of stability of the vehicle body during rotation with the air suspension

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Abstract

This article deals with the problem of controlling the stiffness of the air suspension system to help stabilize the body when the vehicle is moving around. Through the simulation of the change of the suspension stiffness parameter using Matlab simulink software, this paper has shown the impact of external force on the change of air suspension stiffness through simulation graphs. Based on the specifications of the Thaco Mobihome vehicle, simulation results have shown that there is a control to change the air suspension stiffness to help the vehicle move more stably and safely in the horizontal direction when the vehicle is moving around. From the results of this study, it has also been shown that the application of air suspension system for passenger cars will completely improve the level of stability and safety for passengers.

Keywords: Stiffness of The Air Suspension; Air Suspension; Rotational Stability; Horizontal Stability

1. Introduction

When the vehicle is in revolving motion, many different forces will affect it, in which the effect of the inertia force when the vehicle is turning at high speed has a great influence on the balance stability in the vehicle's motion. When the horizontal force of inertia occurs, the load distribution on the inner and outer wheels will change differently. This change causes the left and right suspension to be deformed differently, and leads to the body tilting horizontally and easily causing the vehicle to roll over. The effect of inertia force on the vehicle is also affected by the vehicle's weight distribution, tire size and contact area, and the vehicle's center of gravity height. [1-3]

In addition, when a vehicle is in revolving motion, the centrifugal force is also a major factor affecting the balance of the vehicle. Centrifugal force is an inertial force generated by the vehicle's movement. When the vehicle is turning at high speed, the centrifugal force will pull the vehicle to the outside of the turn, and the force is proportional to the square of the vehicle's speed. This force will cause the vehicle to tilt, and if the centrifugal force is greater than the friction force between the tires and the ground, the vehicle will roll over [4-5].

In addition, the effect of centrifugal force on the vehicle can also be affected by the vehicle's weight and the radius of the turn. When the vehicle's weight is large and the radius of the turn is small, the centrifugal force will be greater, which will make the vehicle more prone to rollover. The speed of the vehicle also has a great influence on the centrifugal force. To fix this problem, the stiffness factor of the left and right suspension system will be changed differently according to the load acting on the wheel. This paper will study and simulate the control of changing the stiffness of the air suspension system when the vehicle is moving around to increase the stability of the vehicle [6-7].

The stiffness factor will be adjusted depending on the speed and load of the vehicle, which will be obtained from a sensor measuring the wheel load. To adjust the stiffness, the air pressure from the setting valve of the air spring will be controlled using a control algorithm. The control algorithm will calculate the necessary stiffness for the left and right

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suspension systems according to the wheel load and speed, and will adjust the air pressure to the air spring accordingly. The control algorithm will utilize PID control to adjust the air pressure to the air springs. The PID control will take the wheel load and speed as inputs, calculate the necessary stiffness for the left and right suspension system, and adjust the air pressure accordingly. The control algorithm will also take into account the effect of the road surface on the vehicle's stability. The algorithm will be tuned to adjust the stiffness of the suspension system in order to maintain the stability of the vehicle while driving [8-9]. This method of controlling the stiffness of the air suspension system can improve the stability of the vehicle while driving, and is expected to reduce the risk of accidents due to poor vehicle stability [10].

2. Theoretical Basis

2.1. Mathematic model

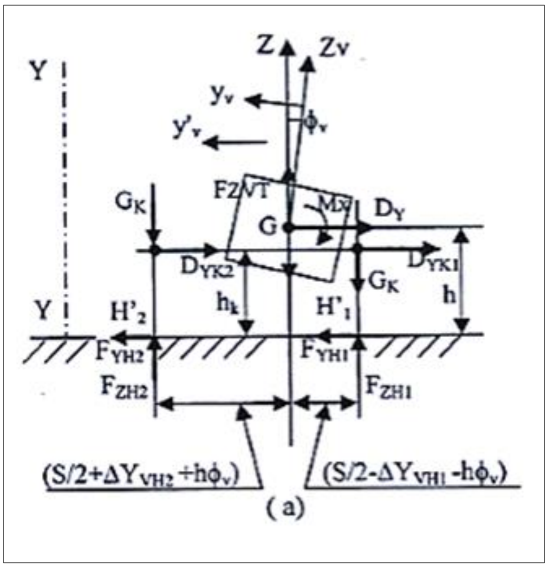

Figure 1 The model uses the calculation of the horizontal tilt angle of the vehicle [11]

Which
The coordinates of the vehicle (Y_V, Z_V), The coordinates of the road (Y, Z).
D_Y : Centrifugal force (N).
G: Body weight (N).
h : The height of the center of gravity of the trunk compared to the road surface (m).
D_{YK1}, D_{YK2} : Centrifugal force components at the center of gravity of the wheels (N).
G_K : Weight of wheels (N).
F_{ZVT} : External force acting at the center of gravity of the vehicle (N).
F_{YH1}, F_{YH2}: The horizontal reactions act in the Y direction at $H'_{1,2}$ (N).
F_{ZH1}, F_{ZH2}: Vertical reaction in the Z direction at $H'_{1,2}$ (N).
ϕ_V : Horizontal tilt angle of the vehicle (rad).
M_X : Moment to rotate the tank around the X axis.
ΔZ_V : isplacements in the Z direction (m).
ΔY_V : Displacements in the Y direction (m).
S: the distance between the two wheels (m).

We have the relationship:

$$\begin{cases} F_{YH1} + F_{YH2} = D_Y + D_{YK1} + D_{YK2} \\ F_{ZH1} + F_{ZH2} = G + G_K - F_{ZVT} \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

Then the tilt angle ϕ_V and the height of the center of gravity are determined with approximate values as follows:

$$\phi_V \doteq \frac{\Delta z_{VS1} - \Delta z_{VS2}}{S} = \frac{D_Y\left(h_v^{(0)} + \lambda_y . \frac{S}{2}\right) + M_x}{\frac{1}{2} C.i^2.S^2 + C_z.i_Z^2.S^2 - G\left(h_v^{(0)} + \lambda_y . \frac{S}{2}\right)} \ldots\ldots\ldots\ldots (2.2)$$

From the system of suspension balance equations, we can also solve the change of load on the left and right suspension airbag of the vehicle:

$$\begin{cases} \Delta F_{z1}^{s} = \frac{(-1)}{i}\left[\left(D_Y + \frac{G}{S}.\phi_V\right)\left(\frac{h_V^{(0)}}{S} + \frac{\lambda_y}{2}\right) - C_Z.i_Z^2.S.\phi_V\right] \\ \Delta F_{z2}^{s} = \frac{(-1)}{i}\left[\left(-D_Y - \frac{G}{S}.\phi_V\right)\left(\frac{h_V^{(0)}}{S} + \frac{\lambda_y}{2}\right) + C_Z.i_Z^2.S.\phi_V\right] \end{cases} \text{..............(2.3)}$$

With the above simplifications [12], the displacement of the trunk at the left and right wheels when the vehicle is turning can be determined by the following formula:

$$\begin{cases} \Delta h_1 = \frac{1}{C.i^2}\left[\left(D_Y + \frac{G}{S}.\phi_V\right)\left(\frac{h_V^{(0)}}{S} + \frac{\lambda_y}{2}\right) - C_Z.i_Z^2.S.\phi_V\right] \\ \Delta h_2 = \frac{1}{C.i^2}\left[\left(-D_Y - \frac{G}{S}.\phi_V\right)\left(\frac{h_V^{(0)}}{S} + \frac{\lambda_y}{2}\right) + C_Z.i_Z^2.S.\phi_V\right] \end{cases} \text{..............(2.4)}$$

2.2. Air suspension elastic characteristics

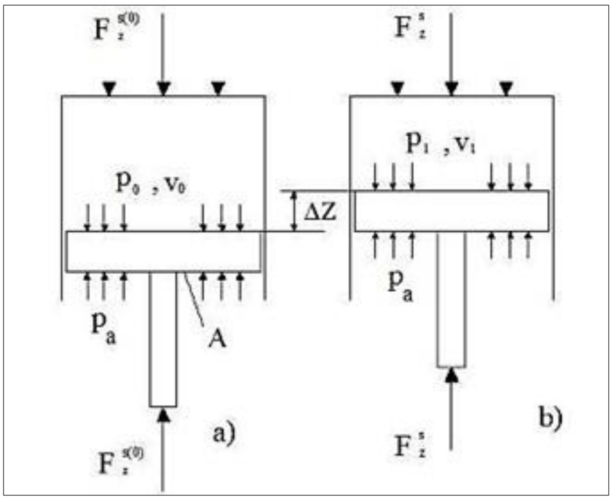

Figure 2 Pressure change in the air bags

In there:
F_z^s: Vertical load acting on the airbag(N).
$F_z^{s(0)}$: Vertical load in static state (N).
p_a: Atmospheric pressure (N/cm²).
p_0: Air pressure in the airbag in a stationary state (N/cm²).
p : Compressed air pressure in the air bag (N/cm²).
A : Airbag working surface area (cm²).

The load acting on the airbag is determined by the formula:[3], [4]

$$F_z^s = (p - p_a).A \text{ [N] .... (2.5)}$$

When compressed, the piston moves a distance Δz. We have the volume of the compressed air chamber in the instantaneous state:

$$V = V_0 - A.\Delta z \ [cm^3] \text{ .... (2.6)}$$

Pneumatic pressure at variable load is determined:

$$p = \frac{F_z^s + p_a.A}{A} \left[\frac{N}{cm^2}\right] \text{ ....(2.7)}$$

In the working state with variable load F = F_z^s placed on the elastic chamber, the stiffness of the elastic chamber is determined:

$$C = \frac{n(F_z^S + p_a.A)A}{V} = \frac{n.p.A^2}{V} \quad \dots\dots\dots (2.8)$$

In there:
n : adiabatic coefficient of the gas.
C : airbag stiffness in working state.

2.3. Control to change the suspension stiffness so that the body of the vehicle is balanced when the vehicle is in rotation

The airbag pressure p when it is subjected to the applied vertical load Fz will be determined by the formula:

$$\begin{cases} p_1 = \frac{F_{Z1}^S + p_a.A_1}{A_1} \\ p_2 = \frac{F_{Z2}^S + p_a.A_2}{A_2} \end{cases} \quad \dots\dots\dots\dots\dots (2.9)$$

In there::

p_1, p_2 : Pressure of left and right airbag (*N/cm²*).

A_1, A_2: Average working area of left and right airbags (*cm²*).

Determine the amount of air (m) needed inside the air bags to be changed to ensure that the initial airbag volume factor remains unchanged (equilibrium factor). when there is a change in airbag pressure due to the changing load factor on the wheels. We have an equation of state for an ideal gas that shows the relationship between volume (V), pressure (p) and mass of gas (m) as follows [13-14]:

$$\begin{cases} m_1 = \frac{\mu.p_1.V_{(0)1}}{R.T} \\ m_2 = \frac{\mu.p_2.V_{(0)2}}{R.T} \end{cases} \quad \dots\dots\dots\dots\dots (2.10)$$

In there::
p_1, p_2 : Pressure of left and right airbag (atm).
$V_{(0)1}, V_{(0)2}$: average volume of left and right air bags in initial static state (l).
R : the constant of the gas (R = 0.082).
T : the absolute temperature ($T = 273+27$) (K).
m_1, m_2: the mass of air inside the left and right airbag (kg).
μ: molar mass of air ($\mu \approx 0.029$ *kg/mol*).

From this equation (210), we can calculate the amount of air inside the air bags of the left and right suspension systems. The change in the amount of air will be determined by the suspension system based on the displacement (or deformation) sensor of the suspension. From there an amount of air will be introduced into or out of the airbag in proportion to the deformation, so that the suspension can maintain its original volume.

2.4. Gas volume change

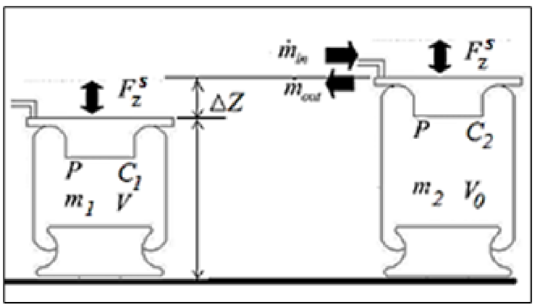

Figure 3 Change of gas mass when the load changes [8]

The fact that the volume (V) of the airbag is maintained constant but the pressure (p) of the airbag is changed, we have a change in the stiffness (C) of the left and right suspension elastomers. This hardness is determined by the formula [15]:

$$\begin{cases} C_1 = \frac{n(F_{Z1}^S + p_a.A_1)A_1}{V_{(0)1}} \\ C_2 = \frac{n(F_{Z2}^S + p_a.A_2)A_2}{V_{(0)2}} \end{cases} \quad \text{.................}(2.11)$$

In there:
C_1, C_2: Stiffness of left and right suspension airbags (*N/cm*)
$V_{(0)1}$, $V_{(0)2}$: Initial average volume of left and right air bags (*cm³).*

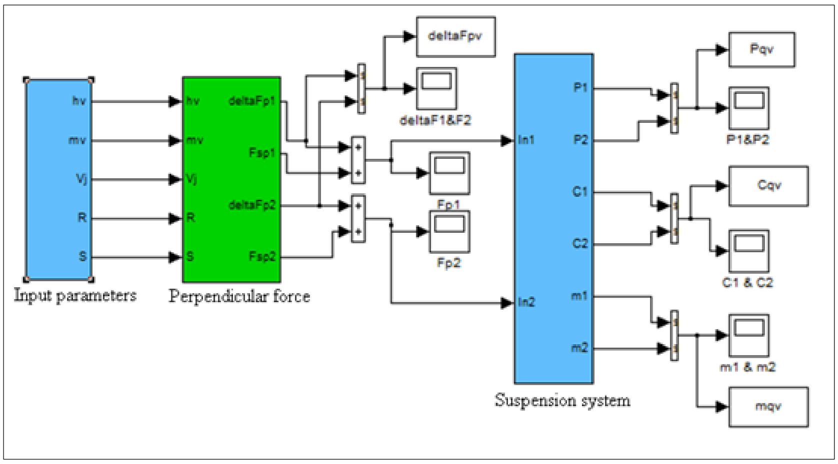

Figure 4 The model simulates the vehicle stability and the air suspension system when the vehicle turns around

3. Simulation Results in Rotation Motion

3.1. Simulation of vehicle stability with air suspension in circular motion with constant radius.

When the vehicle turns around with a constant turning radius (R is a constant) with a velocity (V). Centrifugal force will appear at the center of gravity of the vehicle and this force tends to cause the vehicle to tilt sideways. At this time, there will be a change in the load on the left and right side airbags. This change is described as the following graph (Figure 5).

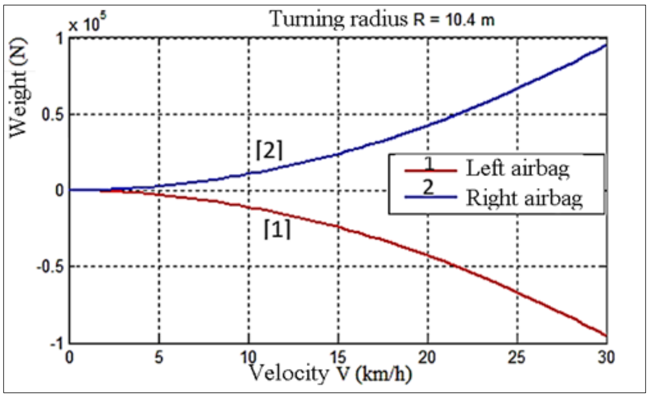

Figure 5 Load change when the vehicle turns to the left

With the change of load on the left and right air bags, the pressure inside the bags will also change. We have a simulation graph of the pressure change of the air bags (Figure 6).

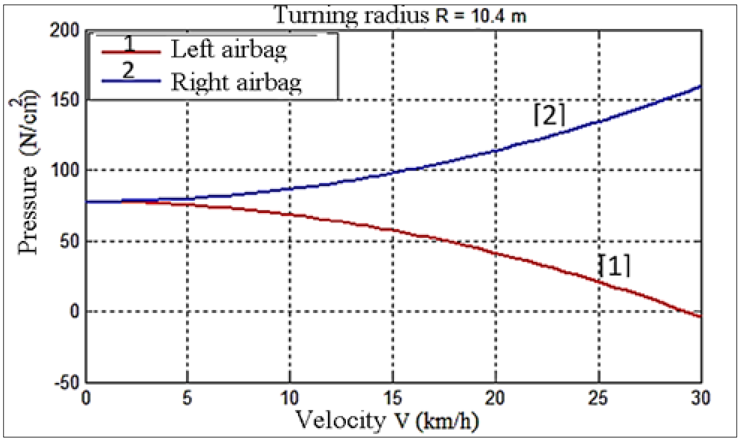

Figure 6 Pressure change when the car turns to the left

According to the elastic characteristics of the air suspension system, when there is a change in pressure inside a constant airbag volume, it will lead to a change in airbag stiffness (Figure 7).

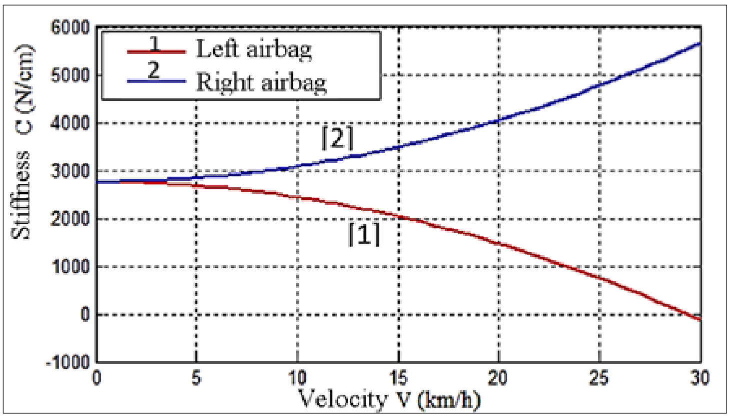

Figure 7 Average stiffness of the suspension airbag when the vehicle turns to the left (R = 10.4 m)

The graph shows that the average stiffness of the right airbags increases with the vehicle's rotational speed, which has the effect of reducing the body movements at the right wheels when the load increases. In contrast, the stiffness of the left airbags decreases as the revving speed increases, it helps the body not to move upward when the load acting on the airbag decreases.

3.2. Investigate changes in suspension airbag stiffness with different turning radius

When the vehicle turns left with different turning radius R (10.4 40 m), the simulation results show the average stiffness change of the left and right suspension airbags as follows: (Figure 8) and (Figure 9).

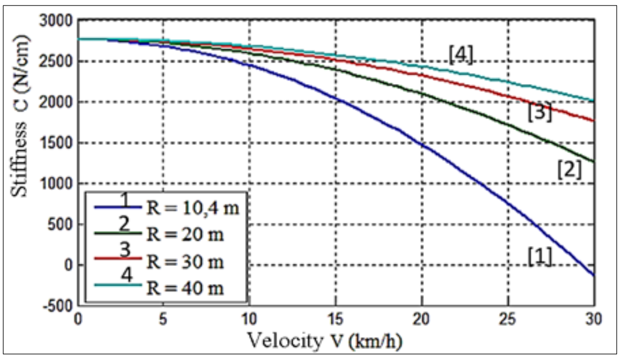

Figure 8 Average stiffness of the left-hand side airbag when the vehicle turns left

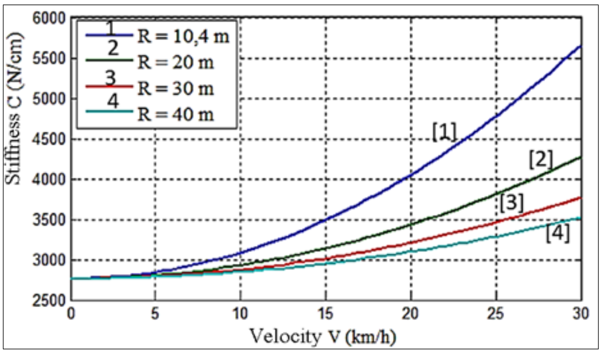

Figure 9 Average stiffness of the right suspension airbags when the vehicle turns left

We see: At the same revving speed (V = 30 km/h), the average stiffness on the left airbags will decrease more slowly, as the vehicle turns around with larger turning radii (Fig. 8). The average stiffness on the right side airbags will also increase more slowly, as the vehicle turns around with larger turning radii (Figure 9).

4. Conclusion

In addition, the steering system should also increase the steering angle to ensure that the car can make a smooth turn. In order to improve the stability of the car when turning, it is necessary to reduce the body roll and increase the grip of the tires. This can be achieved by optimizing the air suspension system parameters, such as reducing the body roll angle and increasing the damping force of the airbags. In addition, increasing the tire pressure and improving the tire tread pattern can also help to improve the stability of the car when turning.

In this study, the air suspension system will increase the stiffness of the air bags on the outside of the turn and decrease the stiffness on the inside of the turn. This will help to keep the vehicle balanced and reduce the amount of strain on the suspension components. Additionally, this will help the vehicle to remain stable and provide a smoother ride for the passengers.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

All authors contributed positively to the writing of this manuscript and there no conflict of interest as agreed to the content of this research.

Statement of informed consent

Informed consent was obtained from all individuals respondents included in the study

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