

Assess The Level of Smooth and Stable of The Suspension When Convert From Mechanical Suspension To Air Suspension

Huu Huy Nguyen¹, Thanh Lanh Le¹, Nam Thoi Le¹

¹ Dong Nai Technology University, Viet Nam

Email address: nguyenhuuhuy@dnctu.edu.vn, lethanhlanh@dnctu.edu.vn, lenamthoi09@gmail.com

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Abstract: This report illustrates the result of calculation of the level of smooth and stable of the bus when converting suspension from mechanical suspension to air suspension. The mechanical vibrations of the automobile in moving process includes: amplitude, frequency, acceleration, These factors may affect the safety of goods and the human state in the bus. This result also shows the great strengths of air suspension than mechanical suspension so that the requirement of smooth level in movement is guaranteed which is a good condition to rise the safety of goods in the bus, maintain human health, reduce physical fatigue and psychological tiredness of drivers and passengers.

Keywords: Mechanical suspension, Air suspension, Frequency, Smooth, Stable

1. Introduction

In the country and in the world, there have been many studies related to the testing and application of air suspension systems in improving vehicle smoothness and stability. Author Ho Xuan Truong with the topic "Calculating and simulating the stability of the vehicle with air suspension system", the author has concluded that the air suspension system is capable of overcoming the limitations of the conventional suspension system. Another study by Zhengchao. Xie [Zhengchao. Xie, A Noise-Insensitive Semi-Active Air Suspension for Heavy-Duty Vehicles with an Integrated Fuzzy - Wheelbase Preview Control, University of Macau, 2013, 12.] mentioned the problem of using air suspension on vehicles with large loads, it reduces the vibrations from the road surface and adjusts the height of the vehicle. Based on the obtained research results, we boldly proceed to convert the bus's suspension system from mechanical to gas. For the purpose of serving public passengers and people with disabilities, we first lowered the floor, using the pneumatic door lifting system in the rear door in combination with the use of a pneumatic suspension system, so we offer a reliable product line.

2. Suspension Strength Test and Stability

Test Calculation

2.1. About durability and softness

2.1.1 About durability

Due to lowering the floor, it is necessary to recalculate the durability and stability of the vehicle [1,2,4,7]

Input parameters:

- Mass distribution on axles (front/rear) at no load (kg):
3900 / 7450

- Mass distributed to the axle (front/rear) at full load (kg):
6000 / 10000

- Mass of axle (front/rear) (kg): 390 / 650

- Suspension mass (front/rear) (kg): 440 / 710

Calculation results table:

Mass placed on suspension (kg)	Front suspension	Rear suspension
When the car is not loaded	2770	6130
When the car is full	5170	8640
Number of gours	02	04

Through the calculation of the load distribution on the axles of the passenger car (city) TRACOMECO HM CNG B75, we see that the mass placed on the axles is smaller than the allowable capacity of the bridge announced by the chassi car designer. Therefore, we do not need to calculate the durability test of the suspension system [1-2].

2.1.2. About the smoothness of the car

a. Calculation of independent oscillations of the front and rear suspension:

Oscillation frequency n :

$$n = \frac{300}{\sqrt{f}} \text{ (times/minute)}$$

In there: f : deflection (cm)

b. Calculating the frequency of link oscillation

Due to the change in values such as the coordinates of the center of gravity of the car, the values of The mass is suspended, so it is necessary to re-evaluate the smoothness parameters of the car designed according to the link vibration frequency:

$$\Omega_{1,2}^2 = \frac{(\omega_1^2 + \omega_2^2) \pm \sqrt{(\omega_1^2 - \omega_2^2)^2 + 4 \cdot \mu_1 \cdot \mu_2 \cdot \omega_1^2 \cdot \omega_2^2}}{2 \cdot (1 - \mu_1 \cdot \mu_2)}$$

(rad/s) (1)

Table of results of calculation of oscillation frequency:

TABLE OF CALCULATION RESULTS		
No load	Front suspension	Rear suspension
n_1, n_2 (times/minute)	88,08	84,35
Ω_1, Ω_2 (times/minute)	89,54	74,84
Full load	Front suspension	Rear suspension
n_1, n_2 (times/minute)	82,26	79,75
Ω_1, Ω_2 (times/minute)	79,01	66,07

Conclusion:

- Satisfy the smooth condition of the car : $[n_1, n_2] \leq 150$ times/minute. $60 \text{ times/minute} \leq [\Omega_1, \Omega_2] \leq 90 \text{ times/minute}$.

2.2 Calculation of vehicle stability test.

2.2.1 Vehicle longitudinal stabilization.

Calculation to check the longitudinal stability of the car is to calculate the limit angle of the vehicle's longitudinal stability when going uphill and downhill:

- When the car is going uphill, the vertical stability limit for the car will be:

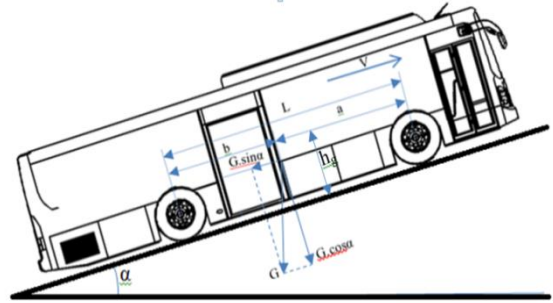


Figure 1: Calculation diagram of longitudinal stability when the car is going uphill

+ No load: $\alpha_{L0} = \arctg(b_0/h_{g0}). \quad (2)$

+ Full load: $\alpha_L = \arctg(b/h_g). \quad (3)$

- When the car goes down hill:

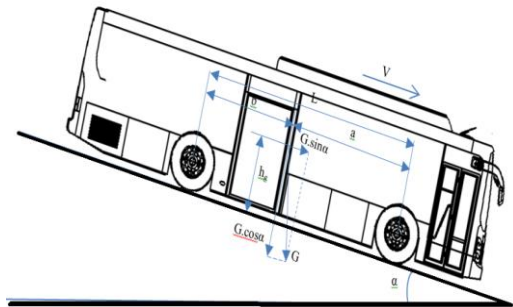


Figure 2: Calculation diagram of stability when the car goes downhill

+ No load: $\alpha_{X0} = \arctg(a_0/h_{g0}). \quad (4)$

+ Full load: $\alpha_X = \arctg(a/h_g). \quad (5)$

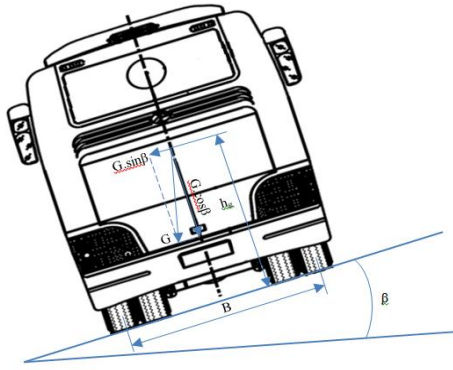


Figure 3: Calculation diagram of horizontal stability

2.2.2. Car horizontal stabilization.

The limiting horizontal tilt angle of the line □ is determined as follows:

+ No load: $\beta_0 = \arctg (B/2.h_{g0})$ (6)

+ Full load: $\beta = \arctg (B/2.h_g)$ (7)

2.2.3 Limit speed when turning with the smallest turning radius R_{min} .

The turning radius of the center of gravity when the car turns with the smallest turning radius at idling:

$$R_{tt0} = \sqrt{R_{min}^2 + b^2} \quad (8)$$

The turning radius of the center of gravity when the car turns with the smallest radius at full load.

$$R_{tt} = \sqrt{R_{min}^2 + b^2} \quad (9)$$

Limit speed when turning with the smallest turning radius R_{min} :

+ When the car is not loaded:

$$V_{gh0} = \sqrt{\frac{B.g.R_{tt0}}{2.h_{g0}}} \quad (10)$$

+ When the truck is full:

$$V_{gh} = \sqrt{\frac{B.g.R_{tt}}{2.h_g}} \quad (11)$$

Calculation results

	Car TRACOM ECO HM CNG B75	Parameter		
		α_L (degree)	α_X (degree)	β (degree)
1	No load	57.35	72,88	44,00
2	Full load	57,93	69,40	40,54

Conclusion:

The limit values of the vehicle's stability are in accordance with QCVN 10: 2011/BGTVT and actual road conditions, ensuring that the vehicle operates stably in all moving conditions.

3. Gentle Calculation

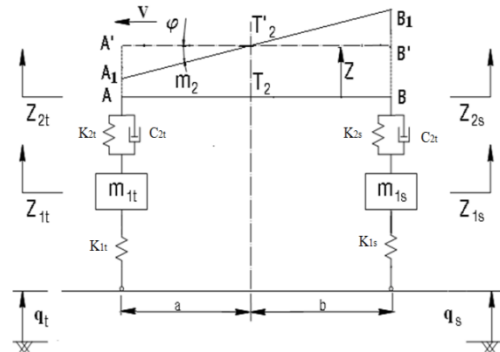


Figure 5: Calculation diagram of car vibration plane model

Considering the above figure calculation diagram, the suspended mass m_2 is placed at the center of gravity of the car moving up a segment Z from point T_2 to point T_2' , point A moves to point A_1 with distance Z_{2t} , point B moves Moving to point B_1 with a distance of Z_{2s} , the oscillating motion of the car is divided into two separate motions:

Vertical reciprocating motion Z is also known as bouncing motion, The rotation of the angle □ is called the vertical wobble [3-4]. These are the two most important types of oscillations in cars, with a small angle , we have the following geometric relationship:

$$Z_{2t} = Z - a.tg\varphi \approx Z - a.\varphi$$

$$Z_{2s} = Z - b.tg\varphi \approx Z - b.\varphi$$

We choose the extrapolated coordinates as follows:

$$q_1 = Z; \quad q_2 = \varphi; \quad q_3 = Z_{1t}; \quad q_4 = Z_{1s}$$

3.1. Equation of oscillation:

Mass Matrix :

$$M = \begin{bmatrix} m_2 & 0 & 0 & 0 \\ 0 & J_y & 0 & 0 \\ 0 & 0 & m_{1t} & 0 \\ 0 & 0 & 0 & m_{1s} \end{bmatrix}$$

Damping Matrix C : C=

$$C = \begin{bmatrix} C_{2t} + C_{2s} & C_{2s}.b - C_{2t}.a & -C_{2t} & -C_{2s} \\ C_{2s}.b - C_{2t}.a & C_{2t}.a^2 + C_{2s}.b^2 & C_{2t}.a & -C_{2s}.b \\ -C_{2t} & C_{2t}.a & C_{2t} & 0 \\ -C_{2s} & -C_{2s}.b & 0 & C_{2s} \end{bmatrix}$$

Hardness Matrix K:

K=

$$K = \begin{bmatrix} K_{2t} + K_{2s} & K_{2s}.b - K_{2t}.a & -K_{2t} & -K_{2s} \\ K_{2s}.b - K_{2t}.a & K_{2t}.a^2 + K_{2s}.b^2 & K_{2t}.a & -K_{2s}.b \\ -K_{2t} & K_{2t}.a & K_{1t} + K_{2t} & 0 \\ -K_{2s} & -K_{2s}.b & 0 & K_{1s} + K_{2s} \end{bmatrix}$$

3.2 System of differential equations of motion for a system of 4 degrees of freedom

$$\text{Matrix form: } M \ddot{x} + C \dot{x} + Kx = f \quad (12)$$

Exciting function vector:

$$f = \begin{bmatrix} 0 \\ 0 \\ \frac{1}{2} K_{1t}.q_0(1 - \cos\Omega t) \\ \frac{1}{2} K_{1s}.q_0\left(1 - \cos\Omega t - \frac{2\pi l}{L}\right) \end{bmatrix}$$

The system of differential equations of motion of the car oscillation in the vertical plane is a system of 4 degrees of

freedom, written as follows:

$$\left\{ \begin{aligned} & \bullet m_2 \ddot{Z} + (C_{2t} + C_{2s}) \dot{Z} + (C_{2s}.b - C_{2t}.a) \dot{\varphi} - \\ & C_{2t} \dot{Z}_{1t} - C_{2s} \dot{Z}_{1s} + (K_{2t} + K_{2s})Z + \\ & (K_{2s}.b - K_{2t}.a)\varphi - K_{2t}.Z_{1t} - K_{2s}.Z_{1s} = 0 \\ & \bullet J_y \ddot{\varphi} + (C_{2s}.b - C_{2t}.a) \dot{Z} + \\ & (C_{2s}.b^2 + C_{2t}.a^2) \dot{\varphi} + C_{2t}.a \dot{Z}_{1t} - \\ & C_{2s}.b \dot{Z}_{1s} + (K_{2s}.b - K_{2t}.a)Z + \\ & (K_{2s}.b^2 + K_{2t}.a^2)\varphi + K_{2t}.a.Z_{1t} - \\ & K_{2s}.b.Z_{1s} = 0 \\ & \bullet m_{1t} \ddot{Z}_{1t} - C_{2t} \dot{Z} + C_{2t}.a \dot{\varphi} \\ & + C_{2t}.a \dot{\varphi} + C_{2t} \dot{Z}_{1t} - \\ & K_{2t}.Z + K_{2t}.a.\varphi + \\ & (K_{1t} + K_{2t}).Z_{1s} = \\ & \frac{1}{2} K_{1t}.q_0(1 - \cos\Omega t) \\ & \bullet m_{1s} \ddot{Z}_{1s} - C_{2s} \dot{Z} - C_{2s}.b \dot{\varphi} + C_{2s} \dot{Z}_{1s} - \\ & K_{2s}.Z - K_{2s}.b.\varphi + (K_{1s} + K_{2s}).Z_{1s} = \\ & \frac{1}{2} K_{1s}.q_0\left(1 - \cos\left(\Omega t - \frac{2\pi l}{L}\right)\right) \end{aligned} \right. \quad (13)$$

3.3 Evaluation of the vibration of the suspension system

To evaluate the smoothness of the suspension system, we choose two evaluation criteria the most important is the natural frequency of vibration with damping and acceleration weight r.m.s according to Vietnam Standard TCVN 6964-1:2001

3.3.1 Acceleration weight (r.m.s)

$$a_w = \left[\frac{1}{T} \int_0^T a_w^2(t) dt \right]^{\frac{1}{2}} \quad (14)$$

The algorithm of the program is to create a loop to calculate the sum when the index i runs from i = 0 to the end of the survey time..

S=0;

for i=1:length(time)

S=S+giatoc(i).^2*0.001;
end
S=sqrt(S/tf)

3.3.2 Calculate the natural frequency of oscillation

The natural frequency of the system is solved in the state when there is no external excitation, the damping resistance is zero [5]. The general equation of motion has the form:

$$M.\ddot{\vec{X}} + K\vec{X} = 0 \quad \text{hay} \quad M.\ddot{\vec{X}} = -K\vec{X} \quad (15)$$

$$\ddot{\vec{X}} = -\omega^2.\vec{X} \quad (16)$$

With ω is the natural frequency of oscillation of the system.

Substituting (17) into equation (16), we have the following relation: $K - \omega^2.M = 0$

$$\text{The above equation is rewritten: } \left| \frac{K}{M} - \lambda.E \right| = 0 \quad (17);$$

$$\text{Với } \lambda = \omega^2$$

This equation leads to solving the problem of eigenvalues and eigenvectors, using Matlab's eig function we write a program to calculate eigenfrequency as follows:

% Calculate natural frequency of oscillation without damping:

$$[V,D] = \text{eig}(K,M); \text{omegad0} = \text{sqrt}(D); \text{omegad0};$$

$$\text{TSR} = \text{omegad0}/(2*\pi);$$

When investigating an oscillating system with damping, not subject to external agitation, the oscillating system will be described by a non-periodic law, but the coordinates of the object still change cyclically [6-7]. Therefore, it is conventionally assumed that the system has an eigenfrequency, the frequency standard for smoothness in automobile oscillations is evaluated based on this natural frequency.

Call ω_{d0} is the natural frequency of vibration of the system without damping, is the natural frequency of vibration of the system with damping. We can give a dimensionless quantity that characterizes vibration quenching as the damping

$$\text{ratio: } \zeta = \frac{K}{K_0} \quad (18)$$

The natural frequency of a damped system is calculated through the natural frequency of an undamped system according to the formula:

$$\omega_{d1} = \omega_{d0} \sqrt{1 - \zeta_1^2} \quad (19)$$

By the calculation method as above, we conduct calculations for both mechanical and air suspension systems on 2 different types of pavement profiles (jump, half sinusoid) with loads from no load to full load to evaluate. smoothness for both systems. The calculation results are shown in the following diagram :

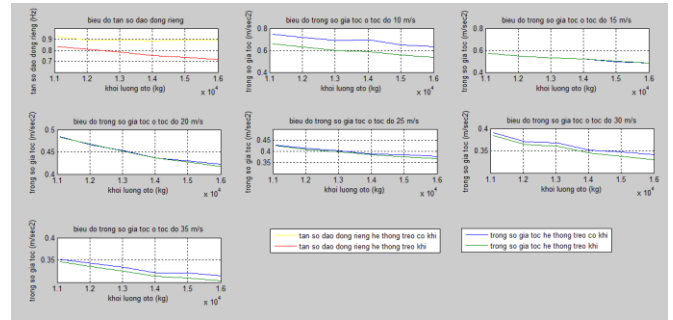


Figure 6: Histogram of natural frequency of vibration and acceleration weight with jump pavement profile

From the chart through the data table, we can see the natural frequency of the air suspension system significantly reduced, down 9.17% at idle and 18.17% at full load. This proves that the air suspension is quieter than the mechanical one by 18.17%.

Acceleration weight in medium load mode (about 2946 kg, about 45 people) and low speed (15m/s) is increased compared to mechanical suspension but not significantly (the highest increase is 0.78%) and is still within the allowable limit but it gradually stabilizes and decreases when the car reaches a speed of more than 20m/s. When the car is fully loaded, this value decreases, down to 8.63% compared to a mechanical suspension.

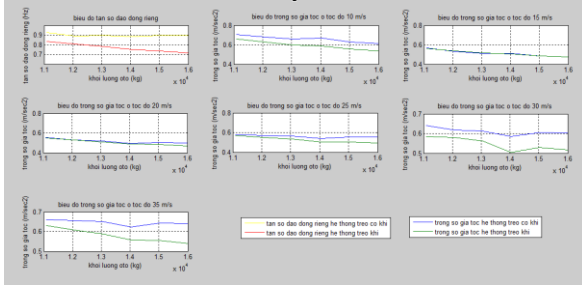


Figure 7: Histogram of natural frequency of vibration and acceleration weight with semi-sinusoidal pavement profile

system. This confirms that with cars with an air suspension system that makes the occupants feel more comfortable.

From the chart through the data table, we can see that the natural oscillation frequency of the air suspension system is significantly reduced, down by 9.17% in no-load mode and 18.17% at full load. This proves that the air suspension is quieter than the mechanical one by 18.17%.

Acceleration weight in medium load and low speed mode (15m/s) is increased compared to mechanical suspension system but not significantly (the highest increase is 0.31%) but it gradually stabilizes and decreases when the car reach a speed of nearly 20m/s. When the car is fully loaded, this value decreases compared to the mechanical suspension system (the highest reduction is 1.1%). This confirms that with cars with air suspension systems make the occupants feel more comfortable.

From the two comparative data tables above, it is clear that with the air suspension system, the car moves more smoothly, so it helps the occupants to feel more comfortable, especially on bad roads, full load, speed. high.

As we all know the roads in Vietnam are not very good, the bus is always overloaded during rush hour, with the bus using the air suspension system, it has met the necessary and increasingly important needs. high in public passenger transport.

Along with lowering the floor in combination with the use of an air suspension system, using an electromagnetic pneumatic control system, it is very simple to help disabled people get on

and off the vehicle.

The product with the above conversion direction has been assigned by the Vietnam Automobile Industry Corporation to the company Tracomco where I work, and the product has been licensed by the Vietnam Register for circulation [8-9].

Conclusion: Through calculation and evaluation, the option of converting the mechanical suspension system to the air suspension system is very feasible because it ensures safety and is especially quieter than the mechanical suspension system. The test result is that this product has been put into circulation on the market and is very satisfied by customers.

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