Effects of Air Suspension Design Parameters of a Heavy Truck on Road Surface Friendliness

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Abstract - *The suspension system plays an important role in improving vehicle ride comfort as well as reducing the loads acting on the road surface, a quarter vehicle model with air suspension system of a heavy truck is established under random road excitation. The design initial parameters of air suspension system such as the initial effective volume and initial pressure in air are respectively analyzed to evaluate their effects on dynamic load coefficient (DLC). The obtained results indicate that the design initial parameters of air suspension system have a significant effect on road surface friendliness. The study results are the theoretical basis for the design and control of the air suspension system.*

***Key Words*:** Heavy truck, air suspension system, initial pressure, initial effective volume, road surface friendliness.

1. INTRODUCTION

Nowadays, the air suspension system is not only popularly used in passenger cars but also popular in heavy-duty trucks. Research in the field of air suspension systems is an interesting topic for researchers and designers in terms of improving system comfort. The design parameters of the suspension system such as the stiffness and damping coefficients were analyzed for their effects on vehicle ride comfort and road surface friendliness based on a three-dimensional vehicle-pavement coupled model with 14 degrees of freedom[1]. A dynamic model of the air suspension system is proposed to optimize the design parameters of the air suspension system[2] and then the optimal design parameters for the air suspension systems was found out in the direction of improving the smoothness of the road surface using genetic algorithm (GA)[3]. A 2-DOF quarter mathematical model with air suspension system was recommended for comparison with classic air spring and dynamic air spring and then a parametric analysis is conducted to investigate the influences of the air spring model parameters on the vehicle dynamics[4]. A 3D dynamic model with 14 degrees of freedom was developed with the dynamic models of the traditional and new air suspension systems to compare the performance of the air suspension systems for reducing the negative impacts on the road surface when vehicle moves on the different road conditions[5]. An air suspension system with damping multi-mode switching damper was recommended with a new damper with four discrete damping modes for vehicle semi-active air suspension. And then the air suspension system with the new damper was posed challenging hybrid control problem[6]. The auxiliary chambers and pipes were required in addition to air springs to investigate the effects of bellows and those of heat transfer on spring constant and damping factor[7]. The road surfaces and vehicle speeds were selected to analyze their effects on vehicle ride comfort and road surface friendliness based on a 2-DOFs quarter-vehicle dynamic model with an air suspension system[8]. The objective of this paper is based on a quarter-vehicle dynamic model with an air suspension system proposed based on the reference [8] to consider and evaluate the effects of the design initial parameters of air suspension system on the value of dynamic load coefficient (DLC).

2. QUARTER -VEHICLE DYNAMIC MODEL WITH AIR SPRING SUSPENSION

A 2-DOFs quarter-vehicle dynamic model with an air suspension for a heavy truck is established based on the reference[8], as shown in Fig-1.

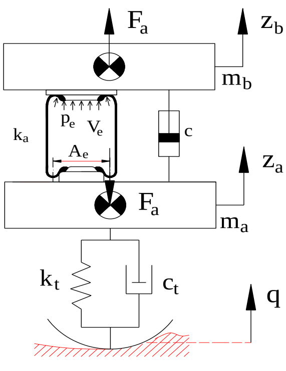

Fig-1: Quarter-vehicle dynamic model with air suspension system[8]

Interpretation of the symbol in Fig-1, m_a, and m_s are unsprung mass and sprung mass of vehicle, respectively; k_t and c_t are the stiffness and damping coefficients of tire, respectively; k_a and c are the stiffness coefficient of air bag and damping coefficient of a hydraulic damper, respectively; z_a and z_b are the vertical displacements of

$$\dot{q}(t)+2\pi f_0 q(t)=2\pi n_0\sqrt{G_q(n_0)v(t)}w(t) \tag{11}$$

unsprung mass and sprung mass, respectively; p_e is the absolute pressure in the air chamber, p_a is the atmospheric pressure, and A_e is the effective area, V_e and A_e are the effective volume and area, q is the excitation of road surface roughness.

The equations of motion: From the quarter vehicle dynamic model in Fig-1, the motion equations of unspung and sprung masses using Newton's second law are written as follows

$$m_a\ddot{z}_a = k_{air}(z_a - z_b) + c(\dot{z}_a - \dot{z}_b) - k_t(z_a - q) - c_t(\dot{z}_a - \dot{q}) \quad (1)$$

$$m_b\ddot{z}_b = -k_{air}(z_a - z_b) - c(\dot{z}_a - \dot{z}_b) \quad (2)$$

The stiffness characteristic of the air bad: The absolute pressure of the air spring and the force of the elastic element are given as below

$$F_a = (p_e - p_a)A_e \quad (3)$$

where, p_a is pressure atmosphere.

Differentiating Eq.(3) and then substituting Eq.(4) into it yields the air spring nonlinear elastic stiffness:

$$k_a = \frac{dF_a}{dz} = \frac{dp_e}{dz}A_e + (p_e - p_a)\frac{dA_e}{dz} \quad (4)$$

If the air condition change determined that it is polytrophic, the following equation is valid:

$$p_e V_e^n = const \quad (5)$$

Differentiating Equation (3) with respect to z yields:

$$V_e^n \frac{dp_e}{dz} + np_e V_e^{n-1}\frac{dV_e}{dz} = 0 \Rightarrow \frac{dp_e}{dz} = -n\frac{p_e}{V_e}\frac{dV_e}{dz} = n\frac{p_e A_e}{V_e} \quad (6)$$

Combined with Eq.(6) and Eq.(4) the equivalent stiffness can be given as follows

$$k_a = \frac{dF_a}{dz} = n\frac{p_e A_e}{V_e} + (p_e - p_a)\frac{dA_e}{dz} \quad (7)$$

The effective area of air spring is simply a linear variable with the change of the height of air spring[10]. For any given moment, the effective area of air spring can be defined as

$$A_e = A_0 + \alpha(z_b - z_a) \quad (9)$$

where, where A_0 is the initial effective area of air spring, α is the change of the effective area with respect to ($z=z_b-z_a$), and z is the instantaneous height variation of air spring.

Apart from the effective area, the effective volume also changes at the same time[10]. The effective volume of air spring can be defined as:

$$V_e = V_0 - \beta(z_b - z_a) \quad (10)$$

Where, V_0 is the initial effective volume of air spring and β is the change of the effective volume with respect to z.

Road surface excitation [11], [12]: The random road surface roughness of random white noise is selected as excitation source waveform for vehicle suspension, the random road profile is produced by filtering the white noise using the following mathematical model of the road roughness

where, $G_q(n_0)$ is the road roughness coefficient which is defined for typical road classes from A to F according to ISO 8068(1995) [9], n_0 is a reference spatial frequency which is equal to 0.1 m; v(t) is the speed of vehicle; f_0 is a minimal boundary frequency with a value of 0.0628 Hz; n_0 is a reference spatial frequency which is equal to 0.1 m; w(t) is a white noise signal.

3. DYNAMIC LOAD COEFFICIENT

To analyze the effects of the design initial parameters of air suspension system on road surface friendliness, the DLC is selected as an indicator in this study. The dynamic load coefficient DLC[13] is defined as the ratio of a ratio of the root mean square(r.m.s) of the vertical dynamic tire force over static load.

$$DLC = \frac{F_{t,rms}}{F_s} \quad (12)$$

where, $F_{t,rms}$ and F_s are the r.m.s of the vertical dynamic and the static tire force, respectively

4. RESULTS AND DISCUSSION

MATLAB/Simulink software is used to solve the differential equations of motion with a set of parameters of a heavy truck by the reference [8] when vehicle moves on the ISO class A road surface at v=72km/h with fully loaded. The vertical dynamic tire load acting on road surface with three initial pressure conditions (Case 1: $0.5xp_0$, Case 2 $1,0xp_0$, an Case 3: $1.5xp_0$, where p_0 is the initial pressure of the original air spring) is shown in Fig-2.

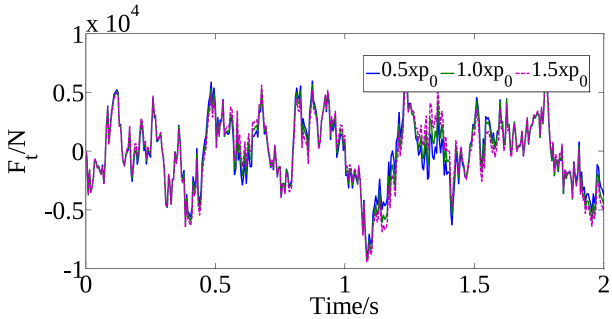

Fig-2: Time domain acceleration of response vehicle body with three initial pressure conditions

From the results of Fig. 2, we could determine the value of the dynamic load coefficients (DLC) through Eq.(12) with three cases as DLC= 0.0750, DLC= 0.0776 and DLC= 0.0836. The results show that p_0 value increases then DLC value increases which leads to the unfavorable road surface friendly.

The initial effective area values of air spring from $0.5xp_0$ value to $2.5xp_0$ are investigated its effects on DLC value when vehicle moves on ISO class B road surface at vehicle v=72 km/h. The DLC value with variable initial pressure of air spring is shown in Fig-3. From the result of Fig- 3 we see that the p_0 value increases, DLC value increases which leads to reduce road surface friendly.

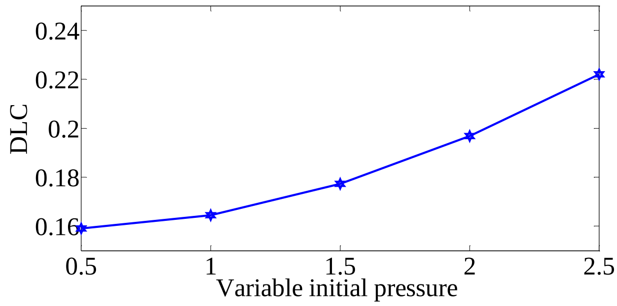

Fig-3: The DLC value with variable initial pressure of air spring

The vertical dynamic tire load acting on road surface with three initial effective volume conditions (Case 1: $10^{-3}xV_0$; Case 2 $1xV_0$ and Case 3: $10xV_0$, where V_0 is the initial effective volume of the original air spring) is shown in Fig-4 when vehicle moves on the ISO class B road surface at v=72km/h with fully loaded. From the results of Fig. 4, we could determine the value of the dynamic load coefficients (DLC) through Eq.(12) with three cases as DLC= 0.1655, DLC= 0.1644 and DLC= 0.1645. The results show that V_0 value reduces then DLC value increases and V_0 value increases, the DLC value is almost unchanged.

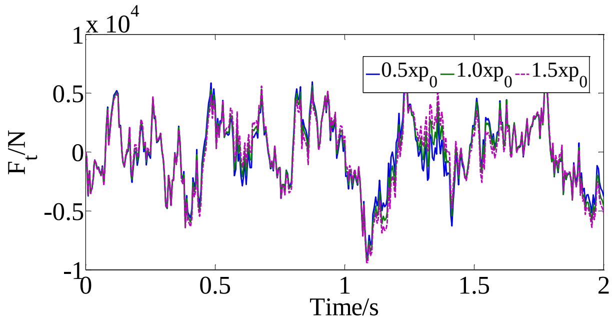

Fig-4: Time domain acceleration of response vehicle body with three initial effective volume conditions

The initial effective volume values of air spring from 10^{-4} xV_0 value to $1xV_0$ are investigated its effects on DLC value when vehicle moves on ISO class B road surface at vehicle v=72 km/h. The DLC value with variable initial effective volume of air spring is shown in Fig-4. From the result of Fig- 4 we see that the V_0 value increases, DLC value increases, then it increases slowly which leads to a negligible effect on road surface friendly.

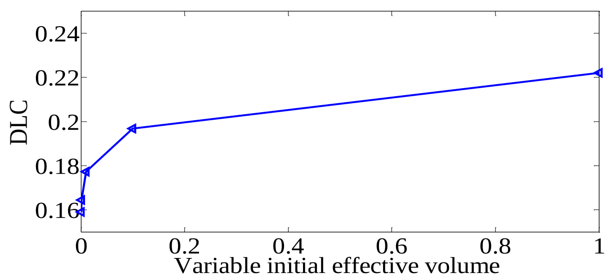

Fig-4: The DLC value with variable initial effective volume of air spring

5. CONCLUSIONS

In this study, a quarter-vehicle dynamic model with an air suspension system is established under random road excitation to evaluate the effects of the design initial parameters of air suspension system on the value of dynamic load coefficient (DLC). The major conclusions that can be drawn from the analysis can be summarized as follows: (1) The p_0 value increases, DLC value increases which leads to reduce road surface friendly and (2) the V_0 value increases, DLC value increases, then it increases slowly which leads to a negligible effect on road surface friendly. In addition, the study results are the theoretical basis for the design and control of the air suspension system.

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