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Effect of Damping on Comfort Level of a Fully Independent Suspension System of An Automobile

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ABSTRACT: Suspension system is one of the most important systems of an automobile. One important function of the suspension system is to absorb the shocks caused by unevenness of the road. One of the present trends of an automobile is fully independent suspension system. The stiffness and damping of the suspension system play an important role in absorbing the shocks and there by provide comfort to the passengers. In this paper, an attempt is made to study the effect of damping on the comfort level. A damping of 1000 *N.s./m* is found to provide maximum comfort level always.

KEYWORDS: Fully independent suspension systems, Effect of damping, Comfort level

I. INTRODUCTION

The suspension system is one of the most important systems of an automobile. Its main purpose is not only to support the engine, its components, passengers, but also to isolate them from shocks arising due to roughness of the road. It has been a practice from the beginning to have a frame called *chassis* which is being supported through springs and dampers by the front and rear axles. This type of suspension system is called *Conventional Suspension System*. There is yet another type of suspension called *Independent Suspension*. In this type of suspension system, the body of the vehicle itself acts as the chassis. The axle of a wheel is hinged to the body and is held in position by springs and dampers which are placed in between axle and the body. The current trend in the automobile industry is to go for independent suspension system to all the four wheels. Such a suspension system is called fully independent suspension system.

The study of suspension systems has been a subject of interest for many researchers. Studies have been performed using simple models called *quarter car model* and *half car model*. These models are simple and yield quick results. However, they are not accurate because they cannot take into account all the possible motions of the body of the automobile.

Some of the early studies performed using quarter car model are due to Hedrick [1], Majjad [2] , Gobbi and Mastin [3]. Among the latest studies, Wei Gao et al. [5] studied dynamic behaviour of passively suspended vehicles running on rough roads. The road profile is considered to give random inputs to the suspension system. Considering nonlinear damping characteristics, Rajalingam and Rakheja [4] studied the dynamic behaviour of quarter car model. Wei Gao et al. [6] also studied the dynamic characteristics considering the mass, damping and tyre stiffness as random variables. Kamalakannan et al. [7] tried adaptive control by varying damping properties according to the road conditions. Thite [8] refined the quarter car model to include the effect of series stiffness. Wei Gao et al. [9] investigated dynamic response of cars due to road roughness treating it as random excitation.

Husiyno Akcay[10], Li-Xing Gao[11], Thite et al.[12], Roberto Barbosa[13] are among those who performed the studies using half car model.

Attempts are also being made to analyse the four wheeler, as it is. Such studies are called studies based on full car model. The results are more realistic because the possible motions of the main body are taken into account. Libin Li [14] performed computer simulation studies through multi body model. Pater Gaspar[15] proposed a method for identifying suspension parameters taking into account nonlinear nature of the components. Anil Shirahatt et al.[16]

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attempted to maximize the comfort level. Genetic algorithms have been employed to perform optimization to arrive at optimum values of suspension parameters. Hajkurami et al.[17] studied the frequency response of a full car model as a system of seven degrees of freedom. Balaraju and Venkatachalam analysed the dynamic behaviour of an automobile using full car model for both, fully conventional suspension systems[18] and fully independent suspension systems[19]. Aniruth et al.[20] analysed for optimum suspension parameters of semi independently suspended automobiles.

In this paper, an attempt is made to study the effect of the damping on the comfort level offered by a fully independent suspension system of an automobile.

II. FORMULATION

Figure 1 shows the arrangement of a fully independent suspension system. The mass $\boldsymbol{m}$ of the main body, is supported at its four corners. The front side suspension system characteristics are specified by the spring constant $\boldsymbol{k_2}$ and the damping constant $\boldsymbol{c_2}$. The rear side suspension system characteristics are denoted by the spring constant $\boldsymbol{k_3}$ and the damping constant $\boldsymbol{c_3}$. The mass $\boldsymbol{m_1}$ indicates mass of the tires. The tire characteristics are indicated by the spring constant $\boldsymbol{k_1}$ and the damping constant $\boldsymbol{c_1}$. The up and down motions of the tyres may be represented by the variables $\boldsymbol{x_i}$, $\boldsymbol{i}$ = 1 to 4. The up and down motions of the main mass may be indicated by the variable $\boldsymbol{x}$. The roll and pitch motions may be described by γ and λ. In total the entire system to describe by seven coordinates. The vertical displacements caused by the road roughness may be represented by the variables $\boldsymbol{y_i}$, $\boldsymbol{i}$ = 1 to 4, as shown in the Figure 1. Figure also shows the absolute linear displacements of the four corners of the main body through the variables $\boldsymbol{z_i}$, $\boldsymbol{i}$ = 1 to 4. Denoting the mass moments of inertia of the main body about roll and pitch axes, respectively, by $\boldsymbol{I_r}$ and $\boldsymbol{I_p}$, the equations of motions may be derived as

$$m_1\ddot{x}_1 + (k_1 + k_2)x_1 - k_2x + k_2B\gamma - k_2L_1\lambda + (c_1 + c_2)\dot{x}_1 - c_2\dot{x} + c_2B\dot{\gamma} - c_2L_1\dot{\lambda} = k_1y_1 + c_1\dot{y}_1 \quad (1a)$$

$$m_1\ddot{x}_2 + (k_1 + k_2)x_2 - k_2x - k_2B\gamma - k_2L_1\lambda + (c_1 + c_2)\dot{x}_2 - c_2\dot{x} - c_2B\dot{\gamma} - c_2L_1\dot{\lambda} = k_1y_2 + c_1\dot{y}_2 \quad (1b)$$

$$m_1\ddot{x}_3 + (k_1 + k_3)x_3 - k_3x + k_3B\gamma + k_3L_2\lambda + (c_1 + c_3)\dot{x}_3 - c_3\dot{x} + c_3B\dot{\gamma} + c_3L_2\dot{\lambda} = k_1y_3 + c_1\dot{y}_3 \quad (1c)$$

$$m_1\ddot{x}_4 + (k_1 + k_3)x_4 - k_3x - k_3B\gamma + k_3L_2\lambda + (c_1 + c_3)\dot{x}_4 - c_3\dot{x} - c_3B\dot{\gamma} + c_3L_2\dot{\lambda} = k_1y_4 + c_1\dot{y}_4 \quad (1d)$$

$$m\ddot{x} - k_2x_1 - k_2x_2 - k_3x_3 - k_3x_4 + 2(k_2 + k_3)x + 2(k_2L_1 - k_3L_2)\lambda - c_2\dot{x}_1 - c_2\dot{x}_2 - c_3\dot{x}_3 - c_3\dot{x}_4 + 2(c_2 + c_3)\dot{x} + 2(c_2L_1 - c_3L_2)\dot{\lambda} = 0 \quad (1e)$$

$$I_r\ddot{\gamma} + k_2Bx_1 - k_2Bx_2 + k_3Bx_3 - k_3Bx_4 + 2B^2(k_2 + k_3)\gamma + c_2B\dot{x}_1 - c_2B\dot{x}_2 + c_3B\dot{x}_3 - c_3B\dot{x}_4 + 2(c_2 + c_3)B^2\dot{\gamma} = 0 \quad (1f)$$

$$I_p\ddot{\lambda} - k_2L_1x_1 - k_2L_1x_2 + k_3L_2x_3 + k_3L_2x_4 + 2(k_2L_1 - k_3L_2)x + 2(k_2L_1^2 + k_3L_2^2)\lambda - c_2L_1\dot{x}_1 - c_2L_1\dot{x}_2 + c_3L_2\dot{x}_3 + c_3L_2\dot{x}_4 + 2(c_2L_1 - c_3L_2)\dot{x} + 2(c_2L_1^2 + c_3L_2^2)\dot{\lambda} = 0 \quad (1g)$$

The Equations (1) is forming a set of seven second order, linear, non homogeneous ordinary differential equations.

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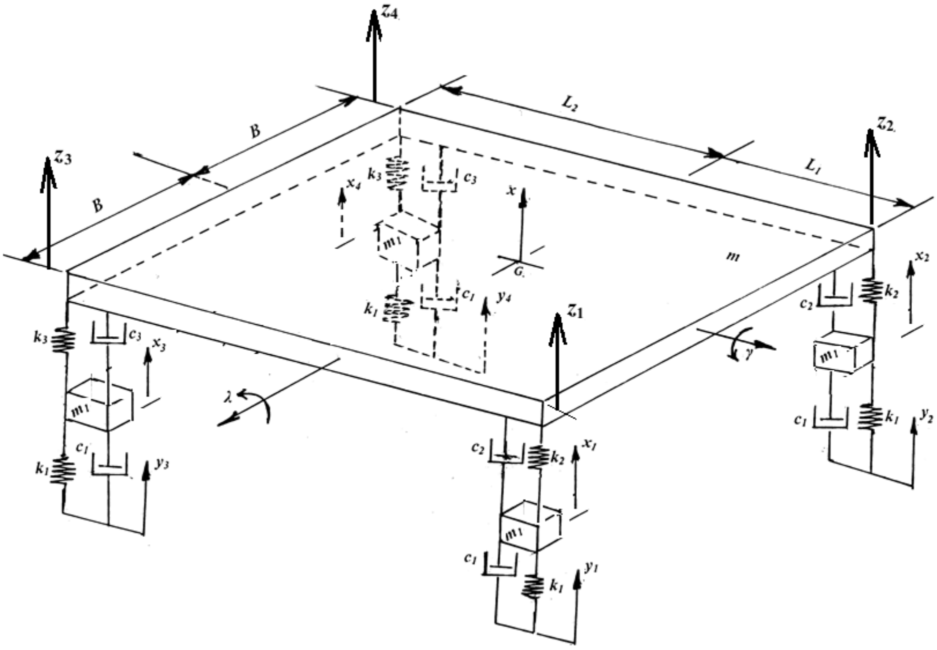

Figure 1 Schematic arrangement of full car model of fully independent suspension system

III. ANALYSIS OF THE SUSPENSION SYSTEM

In order to study the comfort level of the passengers, a quantity z^2 defined as the sum of the squares of vertical displacements at each corner of the vehicle, is considered. It may be expressed mathematically as

$$z^2 = \sum_{i=1}^{4} z_i^2 \tag{2}$$

where, the displacements z_i , i = 1 to 4 may be expressed as

$$z_1 = x - B\gamma + L_1\lambda \tag{3a}$$

$$z_2 = x + B\gamma + L_1\lambda \tag{3b}$$

$$z_3 = x - B\gamma - L_2\lambda \tag{3c}$$

$$z_4 = x + B\gamma - L_2\lambda \tag{3d}$$

As it is defined, z^2 is a positive definite quantity, and hence the minimum value is zero. This can happen only when z_i , i = 1 to 4 are all zeroes, which implies that all the four corners of the main body are having zero absolute displacements, implying that the main body is not moving at all. Therefore, the best comfort may be achieved when the value of z^2 is zero. However, this is an ideal situation. Therefore, one attempts to look for achieving a possible minimum value of z^2 .

Based on a practical road vehicle *Santro Xing*, numerical values are assigned to various parameters involved for the semi independent suspension system as follows.

m_1 = 40 *kg* $\qquad$ m = 1000 *kg*
I_r = 500 *kg.m*^{2} $\qquad$ I_p = 1000 *kg.m*^{2}

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$k_1 = 2\times10^5$ *N/m* $k_2 = 0.5\times10^5$ *N/m* $k_3 = 0.5\times10^5$ *N/m*
$c_1 = 1000$ *N.s/m* $L_1 = 1.0$ *m* $L_2 = 2.5$ *m* $B = 0.75$ *m*

In the present analysis the damping parameters c_2 and c_3 are taken same as, $c_2 = c_3 = c$. Some typical disturbances are chosen as listed in Table 1. The equations of motion expressed in Equation (1) are integrated for each of the disturbance chosen, for different values of c in the range 500 to 6000 *N.s/m*. For each value of c, the maximum value of z^2 is noted. Figure 2a shows the variation of $(z^2)_{max}$ with c, for the cases 1,2,3 and 4 of the Set 1 described in Table1. Similarly, Figure 2b shows the variation of $(z^2)_{max}$ with c for the cases 5,6,7 and 8 of the Set 2. These two Figures reveal that for a value of $c = 1000$ *N.s/m*, the values of $(z^2)_{max}$ are minimum. Therefore, $c_2 = c_3 = 1000$ *N.s/m* may be considered as optimum damping.

Table 1 Different disturbances chosen

Set 1: Displacement disturbances (all are in ***m***).

Case 1	$y_1(0) = 0.1$	$y_2(0) = 0$	$y_3(0) = 0$	$y_4(0) = 0$
Case 2	$y_1(0) = 0.1$	$y_2(0) = 0.2$	$y_3(0) = 0$	$y_4(0) = 0$
Case 3	$y_1(0) = 0.1$	$y_2(0) = 0$	$y_3(0) = 0.2$	$y_4(0) = 0$
Case 4	$y_1(0) = 0.1$	$y_2(0) = 0$	$y_3(0) = 0$	$y_4(0) = 0.2$

Set 2: Velocities disturbances (all are in ***m/s***).

Case 5	$\dot{y}_1(0) = 500$	$\dot{y}_2(0) = 0$	$\dot{y}_3(0) = 0$	$\dot{y}_4(0) = 0$
Case 6	$\dot{y}_1(0) = 500$	$\dot{y}_2(0) = 1000$	$\dot{y}_3(0) = 0$	$\dot{y}_4(0) = 0$
Case 7	$\dot{y}_1(0) = 500$	$\dot{y}_2(0) = 0$	$\dot{y}_3(0) = 1000$	$\dot{y}_4(0) = 0$
Case 8	$\dot{y}_1(0) = 500$	$\dot{y}_2(0) = 0$	$\dot{y}_3(0) = 0$	$\dot{y}_4(0) = 1000$

The existence of optimum value of damping may be explained as follows. When damping is nearly zero, the system would be an undamped system. Therefore, one can expect large amplitudes of forced vibrations. When damping is very large, it may be realised that the damper is providing a rigid connection of the main body to the axles. Hence, the entire disturbance is directly transferred to the main body. One should allow free movement of the plunger of the damper for pumping out the energy of the system effectively. Therefore, there must exist an optimum value of damping.

IV. CONCLUDING REMARKS

The work presented in this paper and significant conclusions that may be drawn based on the present work may be summarized as follows.

(i) A full car model of fully independent suspension system is studied for optimum damping parameters.
(ii) For the purpose of study, the values of various other parameters are taken which correspond to a real practical automobile.
(iii) A quantity z^2 is defined to indicate the comfort level for the passengers.
(iv) The damping of the shock absorber is varied from 500 to 6000 *N.s/m* in steps of 500 *N.s/m*. For each damping value the time response is observed for some typical disturbances and the maximum value of z^2 is noted.
(v) The reason for the existence of an optimum value of damping is discussed.
(vi) A damping value of 1000 *N.s/m* is found to offer the lowest value for $(z^2)_{max}$ for all the disturbances.

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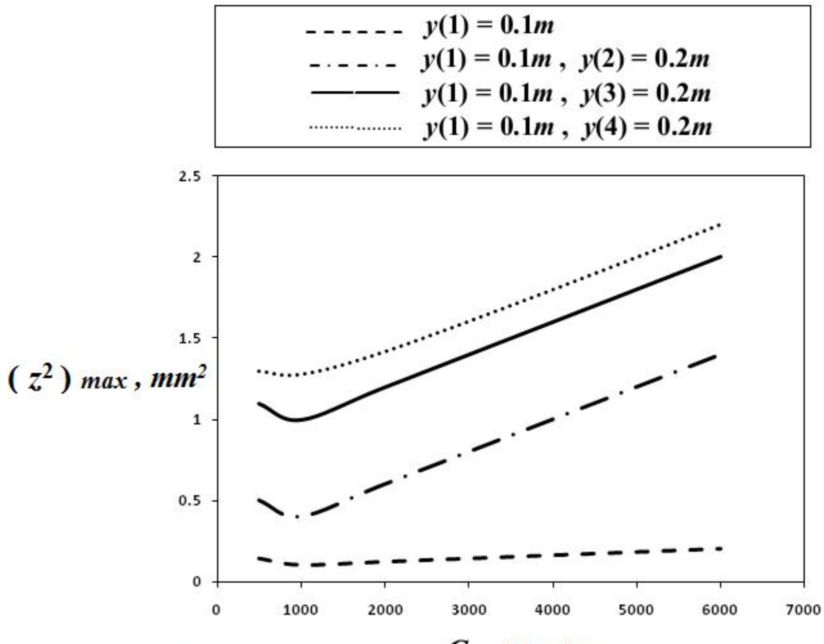
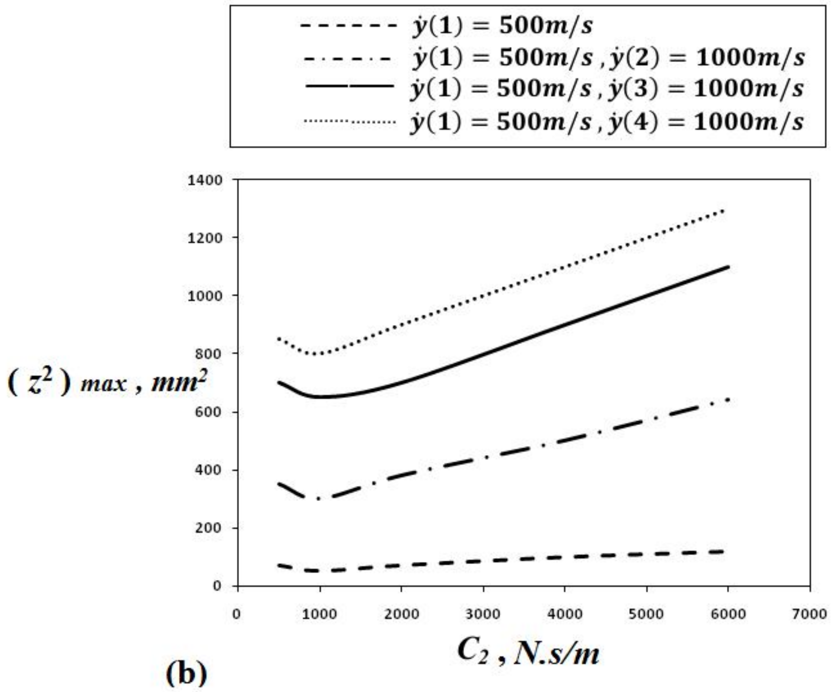


(a)



(b)

Figure 2 Effect of damping on $(z^2)_{max}$ for fully independent suspension system

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