

# A Study on Performances of Passenger Vehicles with Suspension Systems

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## Abstract

When the passenger vehicle runs on an off-road, the vertical displacement occurs. This vertical displacement variation affects settling time and some oscillations for passengers on the vehicle. The passenger vehicle is simulated with a quarter car system. We measure the vertical peak displacement and settling time using the quarter simulation model using the road profile with semicircular bump stop. The active suspension system with specific feedback control has better performances for the settling time and the peak value of the transient response than the passive suspension system has.

**Keywords:** Active Suspension System, Passive Suspension System, Settling Time, The Vertical Displacement

## 1. Introduction

The design of the passenger vehicle<sup>1</sup> should satisfy the comfort and smooth adaptation on the road conditions. To satisfy these requirements, the suspension system plays an important role. The passive suspension system has springs and dampers. The active suspension system has actuators, springs and dampers. By linear state feedback, the passive suspension may be changed to active suspension system. The eigenvalues of the feedback system can be assigned at desired positions in the complex  $z$  plane. Modelling of suspension system includes the quarter car, half car<sup>2</sup> and full car modelling<sup>3</sup>. By analyzing the quarter model, the vertical displacement may be determined. Analysis of half car modelling gives us the pitch and vertical displacement. For full car modelling, the rolling, pitching, and vertical displacement can be measured. In this paper, the vertical displacement can be measured by analyzing the quarter car. The passenger vehicle has either a passive suspension system or an active suspension system. The active suspension may be obtained by

the linear state feedback controller. The investigation of the vertical transient is considered for the passenger vehicle for the passive suspension system and the active suspension system. The road profile is a bump stop road and the flat road is followed. Settling time is lower for the active suspension system compared with that for the passive suspension system. The peak value for the vertical transient on the bump stop road is lower for the active suspension system compared with that for the passive suspension system.

## 2. Quarter Car Model and Equations

### 2.1 The Quarter Car Model

The quarter car model is depicted in Figure 1 and some values for the quarter car models are tabulated in Table 1. The state variables of dynamic equations are  $x_1 = x$ ,  $x_2 = y$ ,  $x_3 = z$ ,  $x_4, x_5 = x_2$

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$$\begin{aligned}
 & \frac{-(k_1 + k_2)}{m_1} & \frac{k_2}{m_1} & \frac{(h_1 + h_2)}{m_2} \\
 & \frac{h_2}{m_2} & \frac{k_2}{m_2} & \frac{(k_2 + k_3)}{m_2} & \frac{k_3}{m_2} & \frac{h_2}{m_2} & \frac{(h_1 + h_2)}{m_2} \\
 & \frac{h_2}{m_2} & \frac{k_3}{m_2} & \frac{k_3}{m_2} & \frac{h_3}{m_2} & \frac{h_3}{m_2}
 \end{aligned}$$

$$B = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ \frac{k_1}{m_1} & \frac{b_1}{m_1} & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \frac{-1}{m_2} \end{bmatrix}, \quad c = [0 \ 1 \ 0 \ 0 \ 0], \quad u = \begin{bmatrix} \gamma \\ \dot{\gamma} \\ f \end{bmatrix}, \quad x = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \end{bmatrix}$$

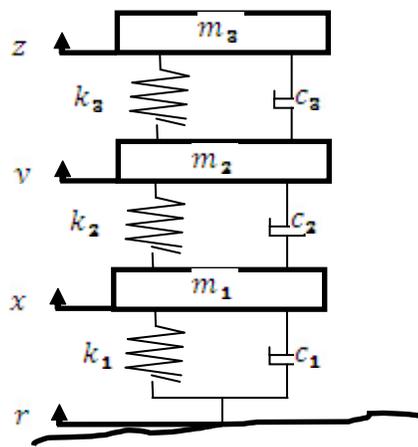


Figure 1. Quarter car model including arms.

Table 1. The parameters of the quarter car model

Parameters	Fixed values
passengers effective mass ( $m_3$ )	25 kg
passengers vertical stiffness ( $k_3$ )	19000 N/m
passengers damping coefficient ( $c_3$ )	1000 N.s/m
body mass ( $m_2$ )	500 kg
body stiffness ( $k_2$ )	16000 N/m
body damping coefficient ( $c_2$ )	1000 N.s/m
wheel mass ( $m_1$ )	205 kg
wheel stiffness ( $k_1$ )	10000 N/m
wheel damping coefficient ( $c_1$ )	2000 N.s/m

Table 2. Performance comparison between two suspension systems

	Vertical displacement (peak value)[cm]	Stabilization time[sec]
Passive suspension	14.0	6.87
Active suspension	9.49	3.45

Table 3. Eigenvalue comparison between two suspension systems

Suspension Type	Eigenvalues
Passive suspension	$-21.0572 \pm 18.87j$
	$-7.43 \pm 9.23j$
	$-0.83 \pm 3.14j$
Active suspension	$-7.49 \pm 9.44j$
	$-3.53 \pm 3.67j$
	$-113.83, -2.77$

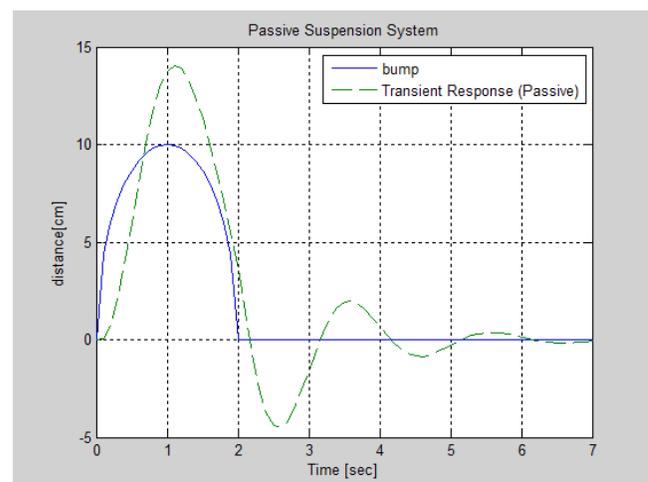
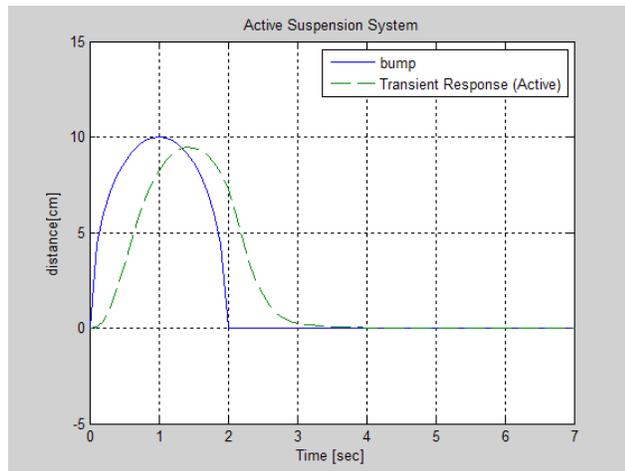


Figure 2. Transient responses for a given bump (passive suspension system).



**Figure 3.** Transient responses for a given bump (active suspension system).

In the above,  $r$  is a road profile,  $\dot{r}$  is a differentiation with respect to  $t$  and  $f$  is a force pressing the arm as shown in Figure 1.

## 2.2 Active Suspension System

For the active suspension system, the linear feedback vector and state vector are

$$k = [00000 \ -2000]$$

$$x = [x \ y \ z \ \dot{x} \ \dot{y} \ \dot{z}]'$$

and the value  $f = [001]'$   $kx$  is feedback into the force of the  $u$  vector in the state space representation.

## 2.3 Road Profile

The road with bump stop has a semicircle pattern whose radius is 10cm and then the flat road follows.

$$r(t) = 0.1\sqrt{1-(t-1)^2} \quad \text{if } 0 \leq t \leq 2 \quad \text{and if } 2 < t, r(t) = 0.$$

## 3. Results

The vertical displacements are obtained for the passive quarter car system and the active quarter car system. For the passive system, the peak to peak value of the vertical displacement is 14.0cm and for the active suspension system, the vertical displacement is 9.49cm. The settling time is defined as the first time when the value of the response  $r(t)$  falls into the band  $-0.01 \leq r(t) \leq 0.01$ . By analyzing the transient response, the settling time is 6.87 sec for the passive suspension system in Figure 2 and 3.45 sec for the active suspension system as shown in Figure 3. All the data are tabulated in Table 2. In Table 3, eigenvalues for the passive and active suspension system are tabulated.

## 4. Discussion

The investigation of the vertical transient is considered for the passenger vehicle for the passive suspension system and the active suspension system. The road profile is a bump stop road and the flat road is followed. The bump stop pattern is a semicircle pattern. Settling time is lower for the active suspension system compared with that for the passive suspension system. The peak value for the vertical transient on the bump stop road is lower for the active suspension system compared with that for the passive suspension system.

## 5. References

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