Simulation and Analysis of Vehicle Suspension System for Different Road Profile

P.Senthil kumar\textsuperscript{1} K.Sivakumar\textsuperscript{2} R.Kalidas\textsuperscript{3}

\textsuperscript{1}Assistant professor, \textsuperscript{2}Professor & Head, \textsuperscript{3} Student

Department of Mechanical Engineering
Bannari Amman Institute of Technology, Erode, Tamilnadu, India
Corresponding Author: Email- bitsenthil@gmail.com

Abstract:

The objectives of this paper are to analysis of vehicle suspension system using quarter car model. Vehicle suspensions systems typically rated by its ability to provide good road handling and improve passenger comfort. Passive suspensions only offer compromise between these two conflicting criteria. In this study, investigation carried out to measure the performance of a spring mass damper system, under various conditions, through modeling, without having to subject the real system to these conditions. The results are obtained in simulation compared and interpreted with quarter car suspension test rig.

Keyword: passive suspension, quarter-car model

Introduction:

The performance of the suspension system is typically rated as to provide improved passenger comfort and avoid hitting it suspension travel limits. The main target of the suspension system is to isolate the car body from the road disturbances. According to Pollard and Simon [1], the ride comfort can be defined according to axis and angular acceleration of front and rear car body, therefore the numerical axis and angular acceleration must be minimise in order to attain higher ride comfort. In this paper, a simulation code was developed based on the MATLAB platform to analyse the system responses, namely displacement and acceleration of vehicle body and to suggest the optimised damping for the specific car data used for simulations. As the vehicle dynamics is concerned with controllability and stability of automobile, it is important in the design of a ground vehicle [2]. The modelling of the vehicle with the analysis of the dynamic response of the mathematical model has been examined in this paper. The simplest representation of a ground vehicle is a quarter-car model with a spring and a damper connecting the body to a single wheel, which is in turn connected to the ground via the tyre spring, see [3] and [4]. The quarter-car model is used only when the heave motion needs to be considered. It is a one wheel model (front and rear for studying the heave and pitch motions ([5], [6] and [7]). Secondly, the paper also focuses on optimisation of the damping coefficient of the suspension system for desired performance characteristics.
Passive suspension system:

The commercial vehicles today use passive suspension system to control the dynamics of a vehicle’s vertical motion as well as pitch and roll. Passive indicates that the suspension elements cannot supply energy to the suspension system. The passive suspension system controls the motion of the body and wheel by limiting their relative velocities to a rate that gives the desired ride characteristics. This is achieved by using some type of damping element placed between the body and the wheels of the vehicle, such as hydraulic shock absorber.

The Quarter Car Model

A quarter car model is a well-known model for simulating one-dimensional vehicle suspension performance. In its simplified form, the suspension consists of a spring of stiffness $K$ and a damper with damping coefficient $C$. The spring performs the role of supporting the static weight of the vehicle while the damper helps in dissipating the vibrational energy and limiting the input from the road that is transmitted to the vehicle (Ahmet Naci Mete, Sandip D Kulkarni, Michael Gerbracht, Noah Fehrenbacher). A simple representation of quarter car model is shown in Fig 1.

The values for the stiffness and damping coefficient have to be chosen to optimize vehicle performance under a certain range of vehicle load and road conditions. For a passive system with a highly uneven input, there is an inherent conflict between system stability and passenger comfort. For an extremely stiff suspension, the system will be highly stable, but acceleration of the sprung mass will be high, and the passenger comfort will be low. For a non-stiff suspension, passenger comfort will increase, but the vehicle becomes unstable.

From past research, active damper systems have proved to be very effective in improving the comfort and handling. However, when the vehicle is moving over a rough terrain the active systems do not have the reliability of a passive damper system. A failed active system can become dangerous if not coupled with a passive system.

![Fig. 1 Mathematical model of quarter car model](image-url)
SYSTEM MODELLING:

Designing a passive suspension system for a car turns out to be an interesting design problem. When the suspension system is designed, a 1/4 car model (one of the four wheels) is used to simplify the problem to a one dimensional spring-damper system. The Force acting on the quarter car model is represented in Fig. 2

![Quarter car model with Free Body Diagram](image)

**Fig. 2 Quarter car model with Free Body Diagram**

- $m_1$ is the sprung mass of quarter vehicle,
- $m_2$ is the unsprung mass of the quarter vehicle,
- $k_1$ is the spring constant of suspension system,
- $k_2$ is the spring constant of tire,
- $C_r$ is the damping coefficient of tire,
- $C_s$ is the damping coefficient of suspension,
- $x_1$ is the displacement of the vehicle body,
- $x_2$ is the displacement of the suspension system,
- $x_r$ is the displacement of the road disturbance.

From the picture above and Newton's law, we can obtain the dynamic equations as the following:
Parameters of Quarter Car Model for Simple Passenger Car:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of seat $M_s$</td>
<td>90 kg</td>
</tr>
<tr>
<td>Mass of sprung $M_v$</td>
<td>250 kg</td>
</tr>
<tr>
<td>Mass of unsprung $M_t$</td>
<td>40 kg</td>
</tr>
<tr>
<td>Damping ratio of sprung mass $b_v$</td>
<td>2000 Ns/m</td>
</tr>
<tr>
<td>Damping ratio of unsprung mass $b_s$</td>
<td>3000 Ns/m</td>
</tr>
<tr>
<td>Stiffness of unsprung mass</td>
<td>125000 N/m</td>
</tr>
<tr>
<td>Stiffness of sprung mass</td>
<td>28000 N/m</td>
</tr>
<tr>
<td>Stiffness of seat mass</td>
<td>8000 N/m</td>
</tr>
</tbody>
</table>

The SIMULINK model of quarter car suspension for different road profile can be represented as follow:

![Simulink model of Quarter car](image)

**Fig. 3 Simulink model of Quarter car**

**Road Profile**

A sinusoidal shape of the road profile as shown in Fig. consisting of depressions of depth $a = 0.10$ m & 0.06 m, frequency of 7Hz is used for analysis (Baumal et al., 1998).

As a function of time, the road conditions are given by

\[
\text{Out} = \begin{cases} 
(1 \sin 7t) & , 0 \leq t \leq 0.75 \\
0 & , \text{otherwise} 
\end{cases}
\]
RESULT AND DISCUSSION

Simulation based on the mathematical model for quarter car by using MATLAB/SIMULINK software will be performed. Performances of the suspension system in terms of ride quality and car handling will be observed, where road disturbance is assumed as the input for the system. Parameters that will be observed are the suspension travel, wheel deflection, and the car body acceleration for quarter car. The aim is to achieve small amplitude value for suspension travel, wheel deflection, and the car body acceleration. The steady state for each part also should be fast.

Two type of road disturbance is assumed as the input for the system. The road profile 1 is assumed to be a single bump of height \(a = 0.10\) m. The suspension travel limit for the given profile measured as 0.05 m. The corresponding suspension acceleration and wheel travel are represented in Fig. 5. The road profile 2 is assumed to be a single bump of height \(a = 0.06\) m. The suspension travel limit for the given profile measured as 0.03 m. The corresponding suspension acceleration and wheel travel are represented in Fig. 6.

Fig. 4 Road profile for height (i) \(a = 0.05\) m; (ii) \(a = 0.03\) m.
Fig 5 Analysis of quarter car suspension for road profile 1

Fig 6 Analysis of quarter car suspension for road profile 2
CONCLUSION:

The following conclusions were made for the work presented here:

- Quarter car models can successfully be used to analyse the suspension system responses to different road inputs but accuracy of the results obtained will depend on how accurately and effectively the system parameters have been measured (Eg. sprung mass, unsprung mass, stiffness and damping).
- Using the models analysed in this work, the system responses with different road excitations can be obtained.
- With different set of sprung mass, un sprung and stiffness etc, the suitable damping value can be obtained.

Reference:


