RIDE COMFORT ANALYSIS OF QUARTER CAR MODEL ACTIVE SUSPENSION SYSTEM SUBJECTED TO DIFFERENT ROAD EXCITATIONS WITH NONLINEAR PARAMETERS

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ABSTRACT

Ride comfort is a key issue in design and manufacture of modern automobiles. It is necessary to design finer suspension system in order to improve the quality of vehicles. Most real-world phenomena exhibit nonlinear behavior.This paper addresses the ride comfort analysis of quarter car model active suspension system. The analyses uses different standard road inputs with and without consideration of nonlinear behaviour of suspension spring. In this study the equations of motion are derived for quarter car model active suspension system. Theactive suspension system is proposed based on the Proportional Integral Derivative (PID) control technique for the enhancement of its ride comfort. The ride comfort analysis of the system has been determined by computer simulation using MATLAB/Simulink.

Keywords : Active Suspension,MATLAB/Simulink, Nonlinear, PID, Ride Comfort.

I INTRODUCTION

A car suspension system is the mechanism that physically separates the car body from the wheels of the car. Suspension system is one of the important part of the vehicle. Therefore, it is quite necessary to design finer suspension system in order to improve the quality of vehicles. Since the disturbances from the road may include uncomfortable shake and noise in the vehicle body, it is important to study the vibrations of the vehicle.

Suspension consists of the system of springs, shock absorbers and linkages that connects a vehicle to its wheels. The main function of vehicle suspension system is to minimize the vertical acceleration transmitted to the passenger which directly provides road comfort. Traditionally automotive suspension designs have been compromise between the three conflicting criteria’s namely road handling, load carrying, and passenger comfort. There are mainly three types of suspension system; passive, semi-active and active suspension system.

Traditional suspension consists springs and dampers are referred to as passive suspension, then if the suspension is externally controlled it is known as a semi active or active suspension [1].

Most real-world phenomena exhibit nonlinear behavior. There are many situations in which assuming linear behavior for physical system might provide satisfactory results. On other hand, there are circumstances or phenomena that require a nonlinear solution. A nonlinear structural behavior may arise because of geometric and material nonlinearities, as well as change in the boundary conditions and structural integrity. A nonlinear spring has a nonlinear relationship between displacement and force. A graph of force vs. displacement for a nonlinear spring will be more complicated than a straight line, with a changing slope. As nonlinear springs have different load-deflection characteristics than the linear spring, there will be difference in the amplitude of main mass obtained by theoretical and experimental methods [2].

Ride comfort is a key issue in design and manufacture of modern automobiles. Design of advanced suspension systems is one of the requirements, which provide a comfortable ride by absorbing the road disturbances as well as maintain the vehicle stability. A good amount of research activities has been directed to improve the ride comfort especially over the last decade[3].

The objective of this study is to determine ride comfort of quarter car model active suspension system for different road excitation by using MATLAB/Simulink with nonlinear parameters.

II MODELING OF ACTIVE SUSPENSION SYSTEM

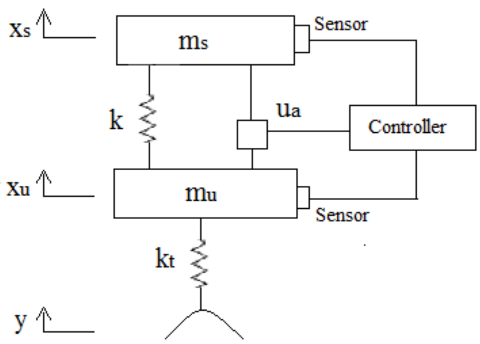

Fig.1. Quarter Car Model Active Suspension System

Quarter car model is used for suspension system analysis and design for its simplicity and yet ability to capture many important parameters. In Fig. 1, quarter car model active suspension system is shown. The sprung mass is denoted by 'm_s'and unsprung mass is by 'm_u'. Instead of damper, the force actuator is used in active suspension system. The tire is assumed to have only the spring feature and is in contact with the road terrain at the other end.

For this analysis the Hyundai Elantra Model is selected. The Suspension Parameters for Hyundai Elantra Model are, [4]

Sprung Mass: m_s: 236.12 kg

Unsprung Mass: m_u: 23.61 kg

Suspension Stiffness: k: 12394 N/m

Tyre Stiffness: k_t: 181818.88 N/m

Now, by applying Newton's Second Law of Motion for given system,

The equations of motion for the linear active suspension system are,

$$m_s\ddot{x}_s = -k(x_s - x_u) + u_a \tag{1}$$

$$m_u\ddot{x}_u = k(x_s - x_u) - k_t(x_u - y) - u_a \tag{2}$$

Where, y – Road displacement

x_s – Sprung mass displacement

x_u - Un-sprung mass displacement

u_a – Actuator force

The non-linear effects included in the spring force f_s are due to two parts. One is bump stop which restricts the wheel travel within the given range and prevents the tire from contacting the vehicle body. And the other is strut bushing which connects the strut with the body structure and reduces the harshness from the road input. This non-linear effect can be included in spring force f_s with non-linear characteristic versus suspension rattle space (x_s- x_u) from the measured data on SPMD (Suspension Parameter Measurement Device) is as shown in Fig.2.

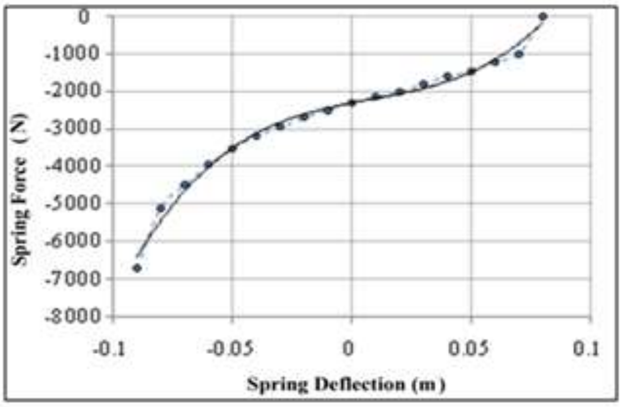

Fig.2. Non-linear Spring Force Property of Hyundai Elantra Model Suspension Spring

The spring force f_s is modelled as third order polynomial function

$$f_s = k_0 + k_1\Delta x + k_2\Delta x^2 + k_3\Delta x^3$$

Where the co-efficient are obtained from fitting the experimental data, which resulted in,

k_3 = 3170400 N/m^3, k_2= -73696N/m^2, k_1= 12394 N/m, k_0= -2316.4 N

(The SPMD data from the model Hyundai Elantra front suspension were used) [4]

Now, the equations of motion for active suspension system with nonlinear parameters are,

$$m_s\ddot{x}_s = [-k_0 - k_1(x_s - x_u) - k_2(x_s - x_u)^2 - k_3(x_s - x_u)^3] + u_a \tag{3}$$

$$m_u\ddot{x}_u = [k_0 + k_1(x_s - x_u) + k_2(x_s - x_u)^2 + k_3(x_s - x_u)^3] - k_t(x_u - y) - u_a \tag{4}$$

III ROAD EXCITATION

Vehicle is assumed to be travelling over a road with velocity of 50 km/hr, during this travel the excitation frequency is calculated as,

$$\omega = \frac{2\,\pi\,V}{\lambda}$$

$$\omega = \frac{2\,\pi \times 50\ \times 1000}{6 \times 3600} = 14.55\ \frac{rad}{sec} = 2.31\ \text{Hz}$$

For the ride comfort analysis of quarter car model active suspension system, three different road excitations are considered.

3.1 Bump Excitation

A single bump road input, y as described by (Jung-Shan Lin 1997), is used to simulate the road to verify the developed control system. The road input described by Eq. (5) is shown in Fig.3.

$$a\,(1 - \cos \omega t\,) \qquad 0.4 < t < 0.9 \tag{5}$$

In Eq. (5) of road disturbance, ‘a’ is set to 0.02 m to achieve a bump height of 4 cm.

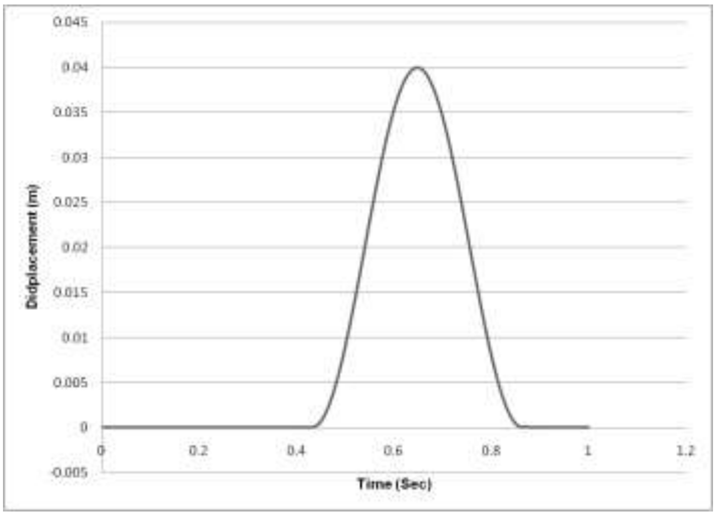

Fig.3. Road Profile for Bump Excitation

3.2 Step In Excitation

The Step InExcitation is represented by the Eq. (6),

$$y = \begin{cases} 0.00 & t < 0.43 \\ -0.04 & t \geq 0.43 \end{cases} \tag{6}$$

Here the height of the road disturbance is maintained at 4 cm. The road input described by Eq. (6) is shown in Fig. 4

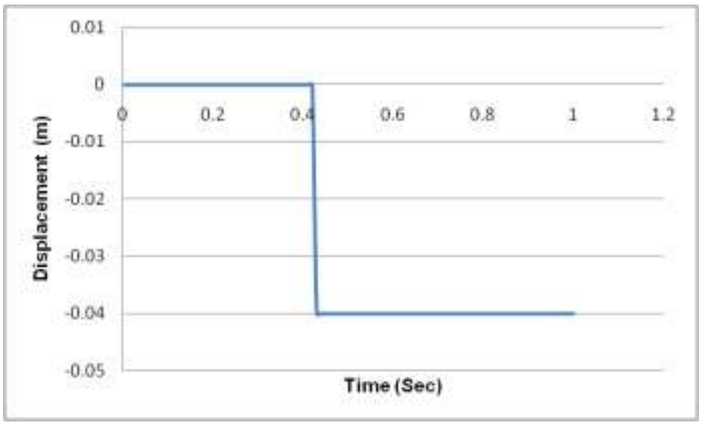

Fig.4. Road Profile for Step In Excitation

3.3 Rectangular Pulse Excitation

The Rectangular PulseExcitation is represented by the Eq. (7),

$$y = \begin{cases} 0.00 \longrightarrow 0.43 > t > 0.86 \\ 0.04 \longrightarrow 0.43 \leq t \leq 0.86 \end{cases} \quad (7)$$

Here also the height of the road disturbance is maintained at 4 cm. The road input described by Eq. (7) is shown in Fig. 5.

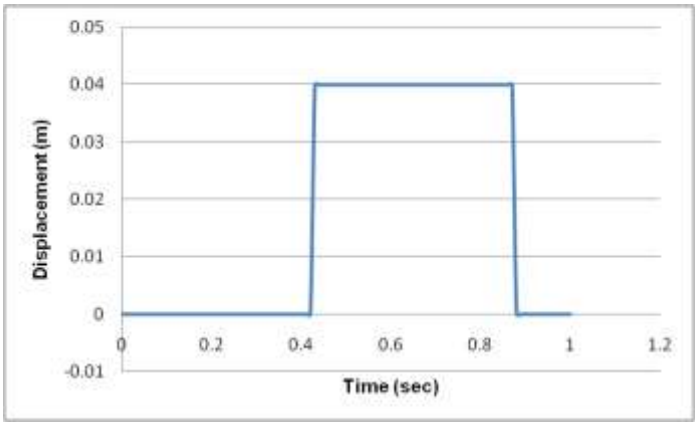

Fig.5. Road Profile for Rectangular Pulse Excitatio

IV SIMULATION AND RESULTS

Mathematical modeling is transformed to computersimulation model and MATLAB/Simulink is usedfor the simulation. PID controller is used for controlling the force. For every system, PID controller should be set itsvalue with respect to the system. For this reason,PID controller had to be tuned with system. In thisresearch, Ziegler-Nicols Method is used to tune PID controller. According to the continuouscycle method (Ziegler-Nichols Method) first thePID block was attached to the system by settingK_P=1, K_I=0, K_D=0.And then PID is tuned so that the response forthe disturbance is good [5].We tuned the PID controlleruntil the desired response was achieved.

Ride comfort analysis of quarter car model active suspension system for linear and nonlinear model is carried out in MATLAB/Simulink. For simulation the model variable-stepcontinuous solver ODE45 (Dormand-Prince) isused.

4.1 For Bump Excitation

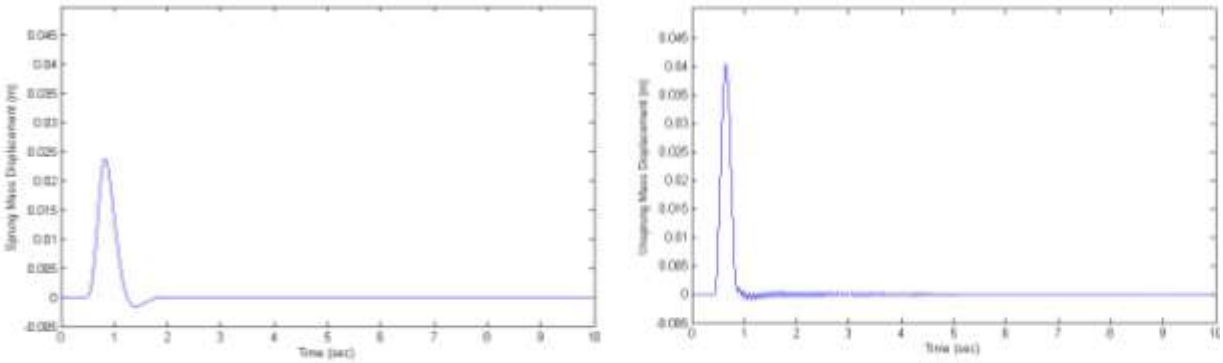

Fig.6. Sprung and Unsprung Mass Displacement of Linear Active Suspension System

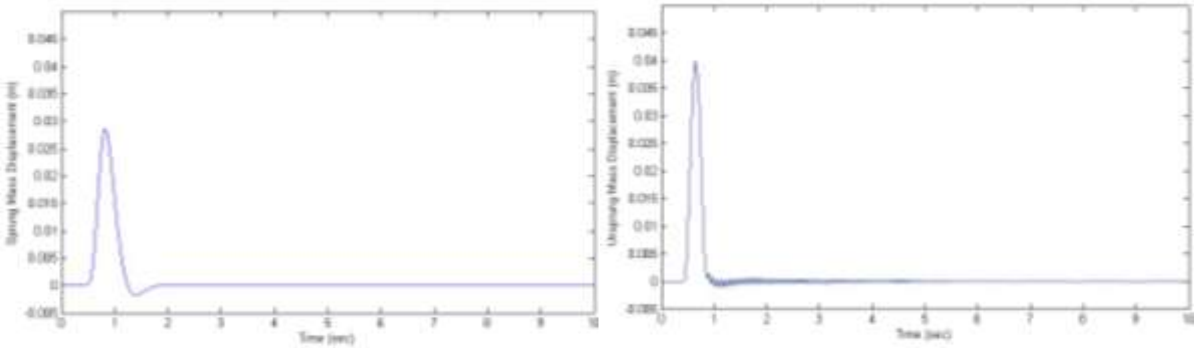

Fig.7. Sprung and Unsprung Mass Displacement of Nonlinear Active suspension System

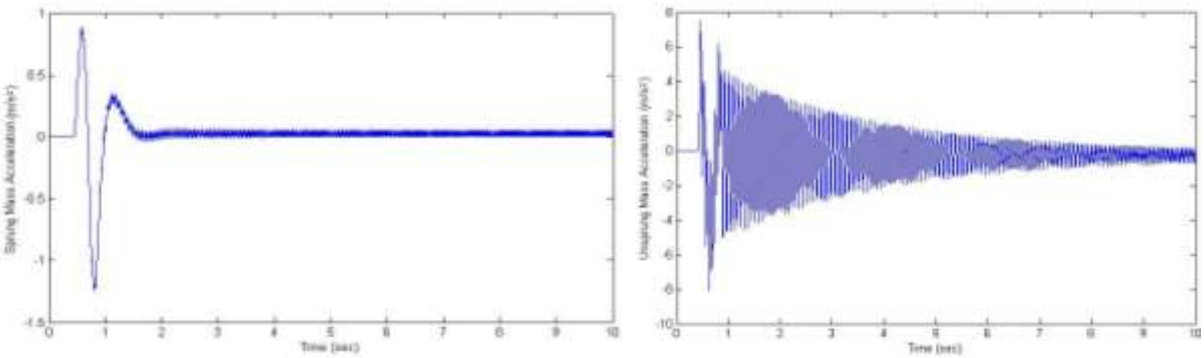

Fig.8. Sprung and UnsprungMass Acceleration of Linear Active Suspension System

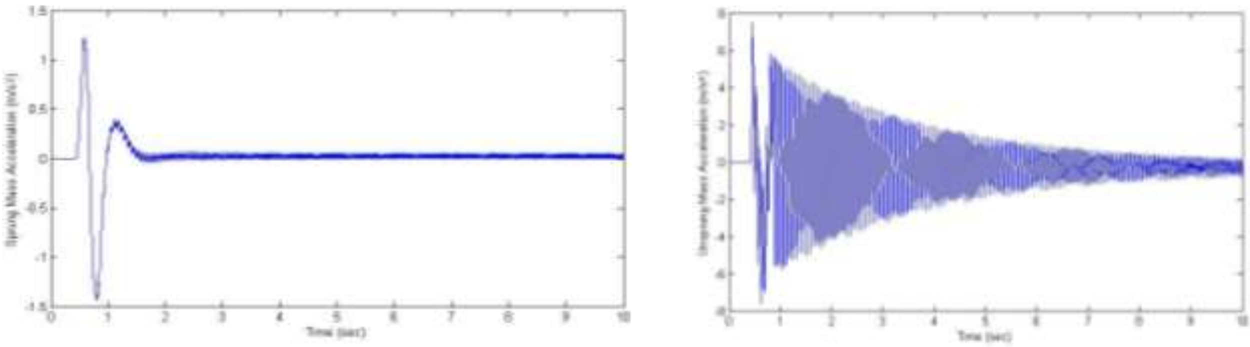

Fig.9. Sprung and Unsprung Mass Acceleration of Nonlinear Active Suspension System

4.2 For Step In Excitation

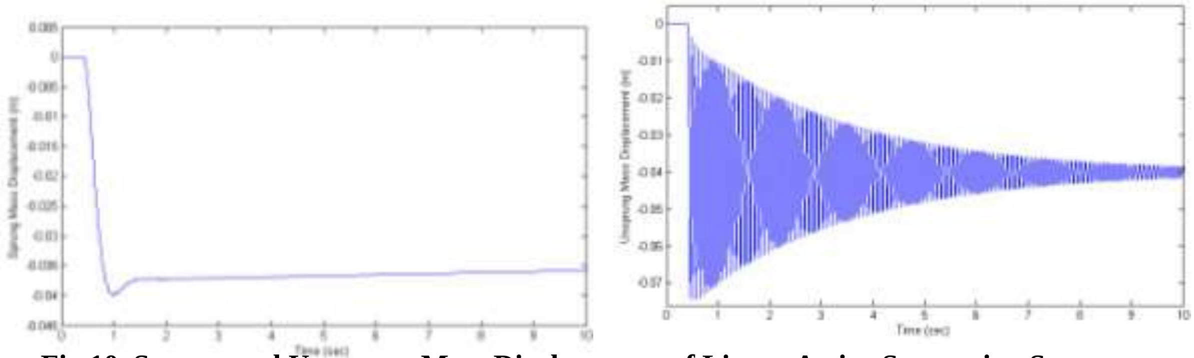

Fig.10. Sprung and Unsprung Mass Displacement of Linear Active Suspension System

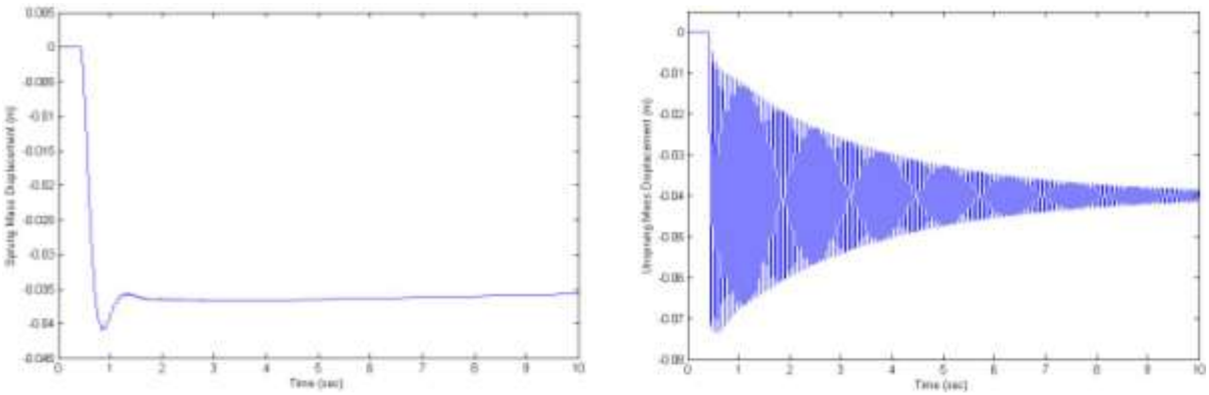

Fig.11. Sprung and Unsprung Mass Displacement of Nonlinear Active suspension System

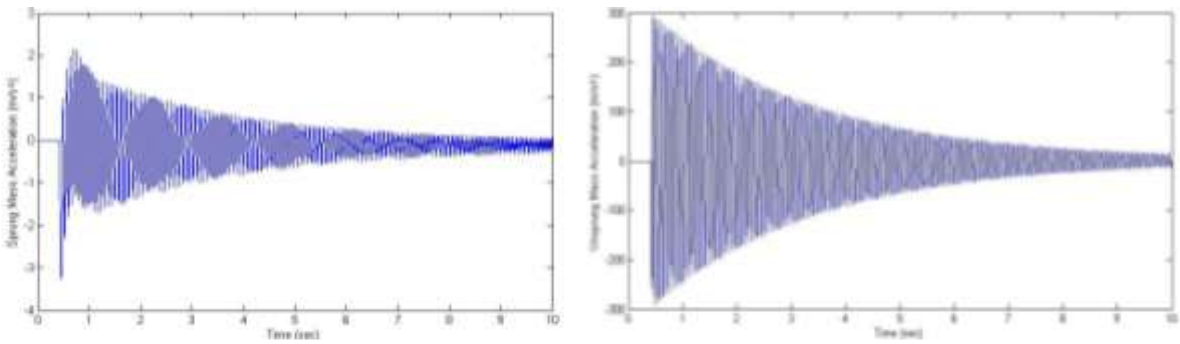

Fig.12. Sprung and Unsprung Mass Acceleration of Linear Active Suspension System

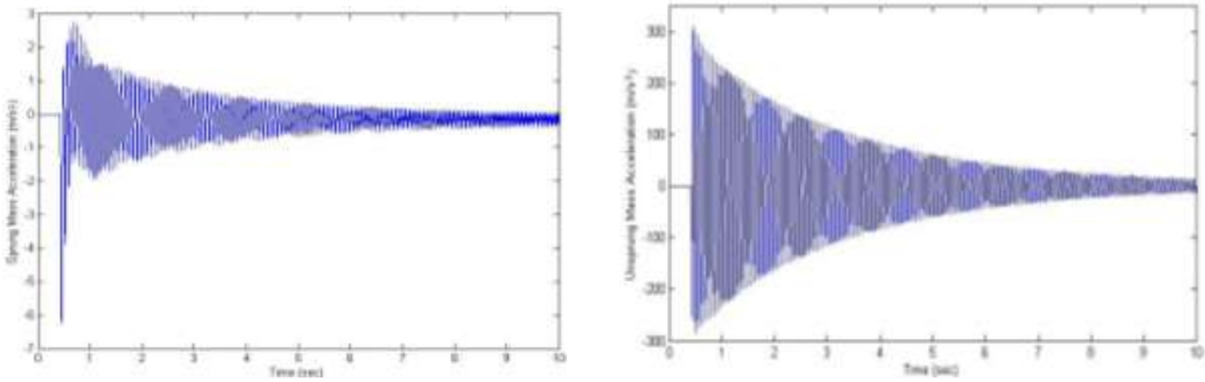

Fig.13. Sprung and Unsprung Mass Acceleration of Nonlinear Active Suspension System

4.3 For Rectangular Pulse Excitation

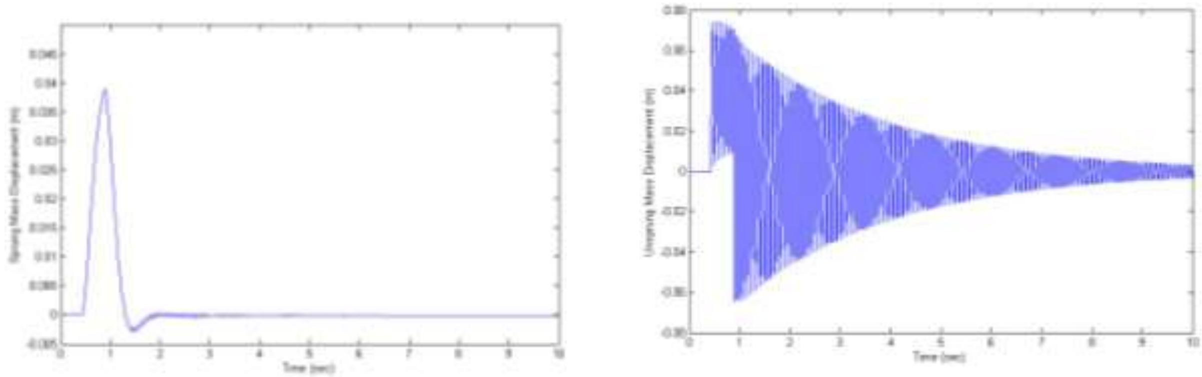

Fig.14. Sprung and Unsprung Mass Displacement of Linear Active Suspension System

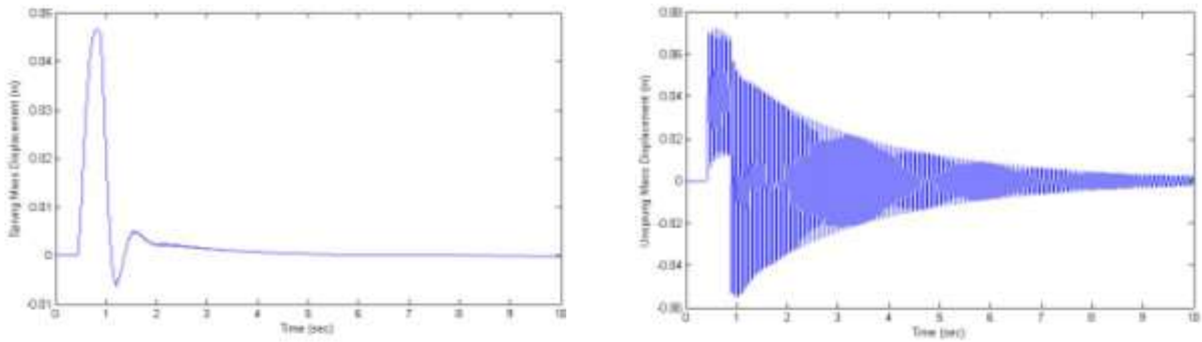

Fig.15. Sprung and Unsprung Mass Displacement of Nonlinear Active suspension System

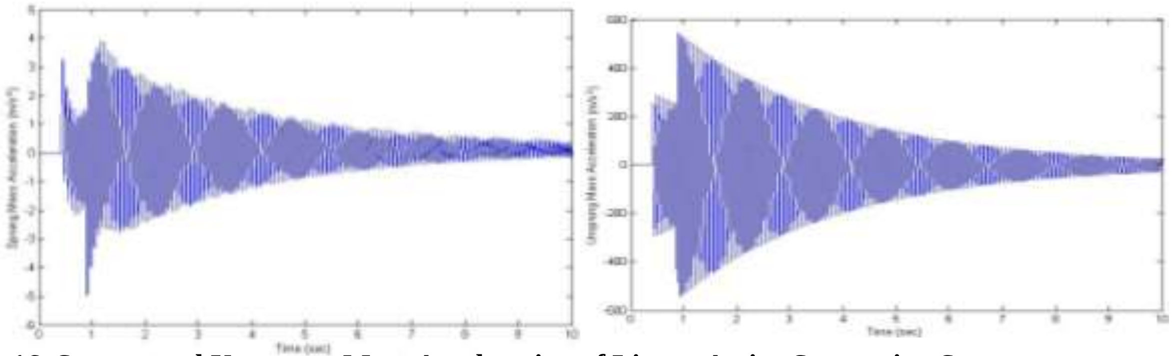

Fig.16. Sprung and Unsprung Mass Acceleration of Linear Active Suspension System

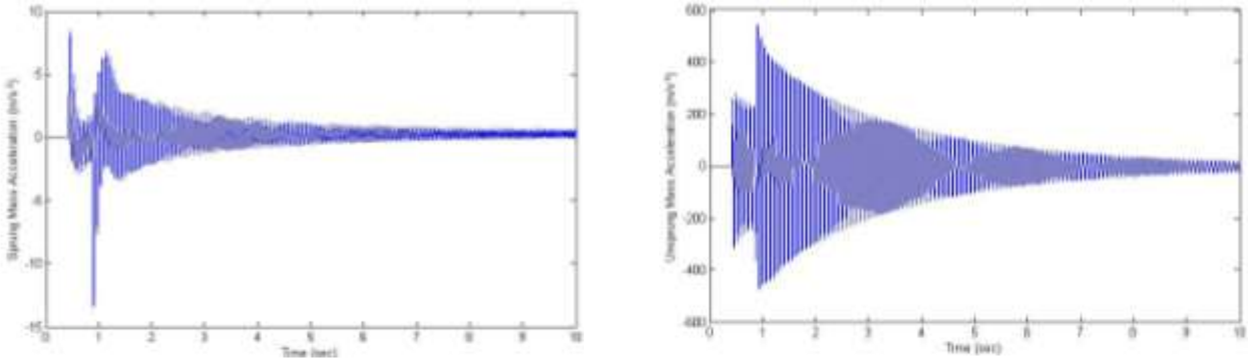

Fig.17. Sprung and Unsprung Mass Acceleration of Nonlinear Active Suspension System

V CONCLUSION

From the results obtained from simulation, it is seen that importance of consideration of nonlinear parameter. When graph of nonlinear active suspension system is compared to linear suspension system for different road excitations, it is clearly seen that the behaviour of nonlinear active suspension system tends to more actual behaviour of the system. Therefore nonlinear parameters are required to be considered in the analysis, in order to achieve the real time result.

From simulation results it is seen that active suspension system reduces the disturbance coming from road and reduces the acceleration of sprung mass and provide good ride comfort.

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