International Journal of Current Engineering and Technology E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

Control and Simulation of Semi-Active Suspension System using PID Controller for Automobiles under LABVIEW Simulink

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Received 15 Aug 2017, Accepted 01 Oct 2017, Available online 08 Oct 2017, **Vol.7, No.5 (Sept/Oct 2017)**

Abstract

This paper aims at finding differences by investigating the results of the semi-active suspension of a quarter of a car and comparing its results with negative feedback performance results by using the LabVIEW simulation system. We will compare the practical and theoretical results of each system (passive suspension system and Semi-active suspension system). For the dynamic system used is a linear system which features the basic performance of the suspension system such as acceleration of the body, displacement of wheels, suspension flights, displacement of wheels. The main task of the suspension design is to provide the comfort of the ride and provide the long life of the vehicle and others. These factors can be measured by the performance of wheel deflection and body displacement. The inputs used are two types of road features. After conducting tests and practical and theoretical tests, the suggested semi-active suspension is better than passive suspension through the performance of body displacement and the displacement wheel.

Keywords*: passive suspension Semi-Active suspension, Quarter car Model, LabVIEW Simulink, step and random road disturbance*

1. Introduction

Suspension systems are the most important parts of the vehicle. They are a number of types Suspension systems are mainly classified into three main types: passive suspension, semi-active suspension and active suspension. These systems have been classified into these sections depending on operating mode to improve ride comfort, Minimize road damage, vehicle safety and overall performance.

The passive suspension system is the oldest of the systems and usually consists of dampers to monitor road shocks as well as springs with fixed parameters. All these parts are not subject to external control and directly-Appleyard *et al*. (1997) and Sun *et al*. (2009). Since the passive attachment system is made up of specific parts that are not subject to external control, it is used for specific operating conditions. On the contrary, active suspension systems have a wide range of operating conditions where they can adapt to all exterior conditions as well as all kinds of road based on external power controlled by a direct controller so the active suspension system has been studied since the 1960s, various approaches Have been proposed Harvat *et al*. (1997). The main drawback that has been made without the use of active suspension in practice is that active suspension requires a large power supply. Since 1970, designers have been waiting for semi-active suspension because it consumes far less energy than the active suspension and performs the same desired performance.

The reasons for the trend towards semi-active suspension provide some types of inhibitors that can be controlled during practical practices. Examples of these are magneto-rheological (MR) dampers and electrorheological (ER) dampers Semi-active suspension systems are the most widely used in engineering study and design, and many researchers have been looking at a type of semi-active suspension system, control with MR dampers for multiple researchers Yao *et al*. (2002) and Lai *et al*. (2002). Many control strategies have been evaluated by applying them to practical practices. The most important strategies are H -infinity control- Choi *et al*. (2002) and model following sliding mode control - Yokoyama *et al*. (2001) and skyhook, groundhook and hybrid control-Ahmadian *et al*. (2000). In this research the PID controller will be used where it is used PID to provide precise control of the vehicle suspension system. The proposed console has significant advantages compared to the old passive suspension-Kumar *et al*. (2008) approach- Constantin. (2009) and Hanafi *et al*. (2010). Most of the research and designers

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develop simulations in the Simulink environment, and Simulink has the ability to use a controller with the Simulink. Different types of controllers can be manipulated because it has a versatile interface that makes it easy to control–Lai *et al*. (2002) and Herren *et al*.(2008). In this research it will work on the design and analysis of performance results of vehicle suspension through the application of Simulink with two degrees of freedom. The Simulink input is a fixed parameter for the suspension system as well as simulations and dynamic response with road disturbances. In addition, PID controller is used and the results are compared to improve the performance of the proposed suspension.

2. Modelling Systems

The basic laws of mechanics are used to find and implement mathematical modeling of the body of a vehicle for a quarter of a vehicle to the degree of two degrees of freedom to find equations of semi-active suspension and passive suspension system.

To find the correct mathematical modeling for any suspension system, consider the following observations: -

- Consider the suspension of the car quarter has more than one degree of freedom, for example two degrees of freedom and that the movement of the system is imposed linear or almost linear.
- In order to reduce the complexities of the system (the reactions of the violators resulting from different links, joints and the system of gear as well as flex in the body of the car) these forces are neglected because they are small forces and that their influence (forces) is the minimum because of low intensity.
- The tires have a hardness and damping properties. The damping properties can be neglected in some designs.

Mathematical Modelling of passive Suspension Systems

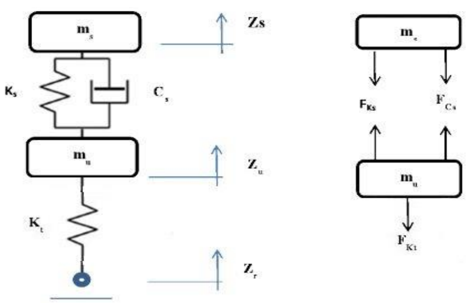

Fig.1 Quarter car passive suspension model

From Figure (1) The linear equations of the spring mass and the unspring mass can be derived as follows: -

Spring mass equation:

$$M_s\,\ddot{z}_s = -K_s\,(z_s - z_u) - C_s\,(\dot{z}_s - \dot{z}_u)^2 \qquad (1)$$

Unspring mass equation

$$M_u\,\ddot{z}_u = K_s\,(z_s - z_u) + C_s\,(\dot{z}_s - \dot{z}_u)^2 - K_t\,(z_s - z_r) \qquad (2)$$

Where:

M_s :Mass of vehicle's body (kg).
M_u: Mass of wheel (kg).
Fk_t : spring force of tire (N).
Fc_t : damping force of tire (N)
FK_s : linear force of coil springs (N).
K_s : stiffness of spring (N/m)
K_t : stiffness of tire (N/m).
C_s : damping coefficient of damper (N/m).
Z_s : displacement of vehicle's body(m).
Z_u : displacement of wheel (m).
Z_r : displacement of road profile (m).

After choosing State variables as,

$x_1\,(t) = [z_s(t) - z_u(t)]$
$x_2\,(t) = [\dot{z}_s(t) - \dot{z}_u(t)]$
$x_3\,(t) = \dot{z}_s\,(t)$
$x_4\,(t) = \dot{z}_u\,(t)$

We have from equation (1)

$$M_s\,\dot{x}_3\,(t) = -K_s\,x_1\,(t) - C_s\,[\,x_3\,(t) - x_4\,(t)\,]^2 \qquad (3)$$

we have from equation (2)

$$Mu\,\dot{x}4\,(t) = Ks\,x1\,(t) + Cs\,[\,x_3\,(t) - x_4\,(t)\,]^2 - K_t\,[\dot{z}_s\,(t) - \dot{z}_r\,(t)] \qquad (4)$$

The roughness of the road results in disturbances:

$W(t) = \dot{z}_r\,(t)$

Therefore,

$\dot{x}_1(t) = x_3\,(t) - x_4(t)$
$\dot{x}_2(t) = x_4\,(t) - w(t)$
$\dot{x}_3(t) = \frac{1}{Ms}\,[-K_s\,x_1\,(t) - C_s\,x_3\,(t) + C_s\,x_4\,(t)]$
$\dot{x}_4(t) = \frac{1}{Mu}[-K_s\,x_1\,(t) - K_t\,x_2(t) + C_s\,x_3\,(t) - C_s\,x_4\,(t)]$

State space equation can be written as form,

$\dot{x}(t) = A\,x\,(t) + Bw(t)$

$$\begin{bmatrix}\dot{x}1\\ \dot{x}2\\ \dot{x}3\\ \dot{x}4\end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 & -1\\ 0 & 0 & 0 & -1\\ \frac{-Ks}{Ms} & 0 & \frac{-Cs}{Ms} & \frac{Cs}{Ms}\\ \frac{Ks}{Mu} & \frac{-Kt}{Mu} & \frac{Cs}{Mu} & \frac{-Cs}{Mu}\end{bmatrix}\begin{bmatrix}x1\\ x2\\ x3\\ x4\end{bmatrix} + \begin{bmatrix}0\\ -1\\ 0\\ 0\end{bmatrix}$$

Where:

$$Bw = \begin{bmatrix}0\\ -1\\ 0\\ 0\end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \qquad D = [0; 0; 0; 0]$$

Mathematical Modelling of semi –active Suspension Systems

$$A = \begin{bmatrix} 0 & 0 & 1 & -1 \\ 0 & 0 & 1 & -1 \\ \frac{-Ks}{Ms} & 0 & \frac{-Cs}{Ms} & \frac{Cs}{Ms} \\ \frac{Ks}{Mu} & \frac{-Kt}{Mu} & \frac{Cs}{Mu} & \frac{-Cs}{Mu} \end{bmatrix}$$

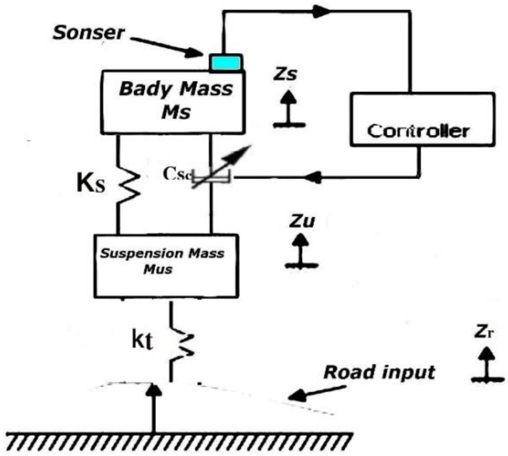

Fig 2 Quarter car semi active suspension model

From Figure (2) The linear equations of the spring mass and the unspring mass can be derived as follows:

Spring mass equation:

$$M_s \ddot{z}_s = -Ks \ (z_s - z_u) - Cs_c \ (\dot{z}_s - \dot{z}_u)^2 \quad (5)$$

Unspring mass equation:

$$M_u \ddot{z}_u = Ks \ (z_s - z_u) + Cs_c \ (\dot{z}_s - \dot{z}_u)^2 - K_t \ (z_s - z_r) \ (t) \quad (6)$$

Where:

Cs_c : damping coefficient of damper controller PID (N/m).

After choosing State variables as,

$x_1 (t) = [z_s(t) - z_u(t)]$
$x_2 (t) = [\dot{z}_s(t) - \dot{z}_u(t)]$
$x_3 (t) = \dot{z}_s (t)$
$x_4 (t) = \dot{z}_u (t)$

We have from equation (1)

$$M_s \dot{x}_3 (t) = -K_s \ X_1 (t) - Cs_c [x_3 (t) - x_4 (t)]^2 \quad (7)$$

We have from equation (2)

$$M_u \dot{x}_4 (t) = K_s x_1 (t) + C_{sc} [x_3 (t) - x_4 (t)]^2 - K_t [\dot{z}_s (t) - \dot{z}_r (t)] \quad (8)$$

Therefore,

$\dot{x}_1(t) = x_3 (t) - x_4(t)$
$\dot{x}_2(t) = x_4 (t) - w(t)$
$\dot{x}_3(t) = \frac{1}{Ms} [-K_s x_1 (t) - Cs_c x_3 (t) + C_{sc} x_4 (t)]$

$$M_s \ddot{z}_s = -Ks \ (z_s - z_u) - Cs_c \ (\dot{z}_s - \dot{z}_u)^2 \quad (5)$$

unspring mass equation:

$$M_u \ddot{z}_u = Ks \ (z_s - z_u) + Cs_c \ (\dot{z}_s - \dot{z}_u)^2 - K_t \ (z_s - z_r) \ (t) \quad (6)$$

Where:

Cs_c : damping coefficient of damper controller PID (N/m).

After choosing State variables as,

$x_1 (t) = [z_s(t) - z_u(t)]$
$x_2 (t) = [\dot{z}_s(t) - \dot{z}_u(t)]$
$x_3 (t) = \dot{z}_s (t)$
$x_4 (t) = \dot{z}_u (t)$

We have from equation (1)

$$M_s \dot{x}_3 (t) = -K_s \ X_1 (t) - Cs_c [x_3 (t) - x_4 (t)]^2 \quad (7)$$

We have from equation (2)

$$M_u \dot{x}_4 (t) = K_s x_1 (t) + C_{sc} [x_3 (t) - x_4 (t)]^2 - K_t [\dot{z}_s (t) - \dot{z}_r (t)] \quad (8)$$

Therefore,

$\dot{x}_1(t) = x_3 (t) - x_4(t)$
$\dot{x}_2(t) = x_4 (t) - w(t)$
$\dot{x}_3(t) = \frac{1}{Ms} [-K_s x_1 (t) - Cs_c x_3 (t) + C_{sc} x_4 (t)]$

$\dot{x}_4(t) = \frac{1}{Mu}[-K_s x_1 (t) - K_t x_2(t) + Cs_c x_3 (t) - Cs_c x_4 (t)]$

State space equation can be written as form,

$\dot{x}(t) = A x (t) + Bw(t)$

$$\begin{bmatrix} \dot{x}1 \\ \dot{x}2 \\ \dot{x}3 \\ \dot{x}4 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 & -1 \\ 0 & 0 & 1 & -1 \\ \frac{-Ks}{Ms} & 0 & \frac{-Cs}{Ms} & \frac{Cs}{Ms} \\ \frac{Ks}{Mu} & \frac{-Kt}{Mu} & \frac{Cs}{Mu} & \frac{-Cs}{Mu} \end{bmatrix} \begin{bmatrix} x1 \\ x2 \\ x3 \\ x4 \end{bmatrix} + \begin{bmatrix} 0 \\ -1 \\ 0 \\ 0 \end{bmatrix} W$$

Where:

$$A = \begin{bmatrix} 0 & 0 & 1 & -1 \\ 0 & 0 & 1 & -1 \\ \frac{-Ks}{Ms} & 0 & \frac{-Cs}{Ms} & \frac{Cs}{Ms} \\ \frac{Ks}{Mu} & \frac{-Kt}{Mu} & \frac{Cs}{Mu} & \frac{-Cs}{Mu} \end{bmatrix}, \ Bw = \begin{bmatrix} 0 \\ -1 \\ 0 \\ 0 \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, D = [0; 0; 0; 0]$$

3. Simulation under LabVIEW simulink

All suspension systems need a simulation system in order to get a dynamic response. Most of the previous research uses the simulation system Matlab Simulink, but in this research we will use the simulation system by LabVIEW Simulink program because of its extensive uses in the fields of electrical and mechanical and the potential of a wide range of control operations, including PID controller and other control add to that the objectives of using the LabVIEW program for the lack of use of previous research and the trend towards the use of the program Matlab.

LabVIEW programming has great capabilities in the practical and theoretical fields where most of the control operations of the automatic report and other control units are carried out by the program of LabVIEW for the provision of all the required design of the control units.

3.1. Simulation for passive suspension system

Simulink was designed and developed for the passive suspension system according to equations (1) and (2). Figure (3) represents a simulation of the passive suspension system: -

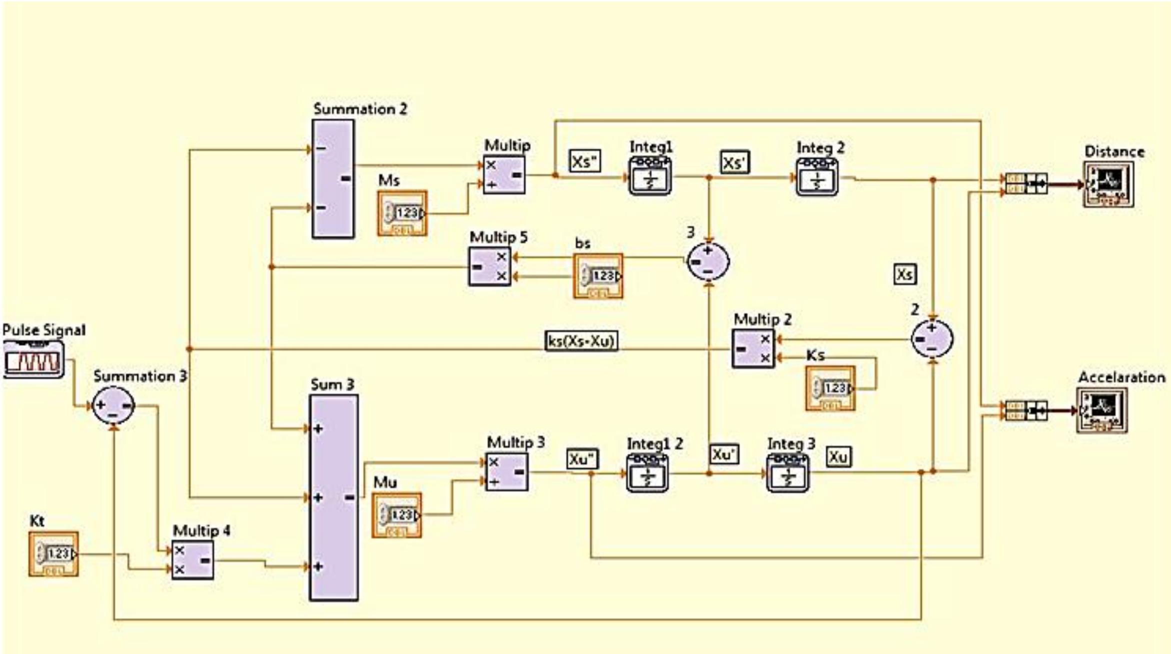

Fig 3 Simulink for passive suspension model

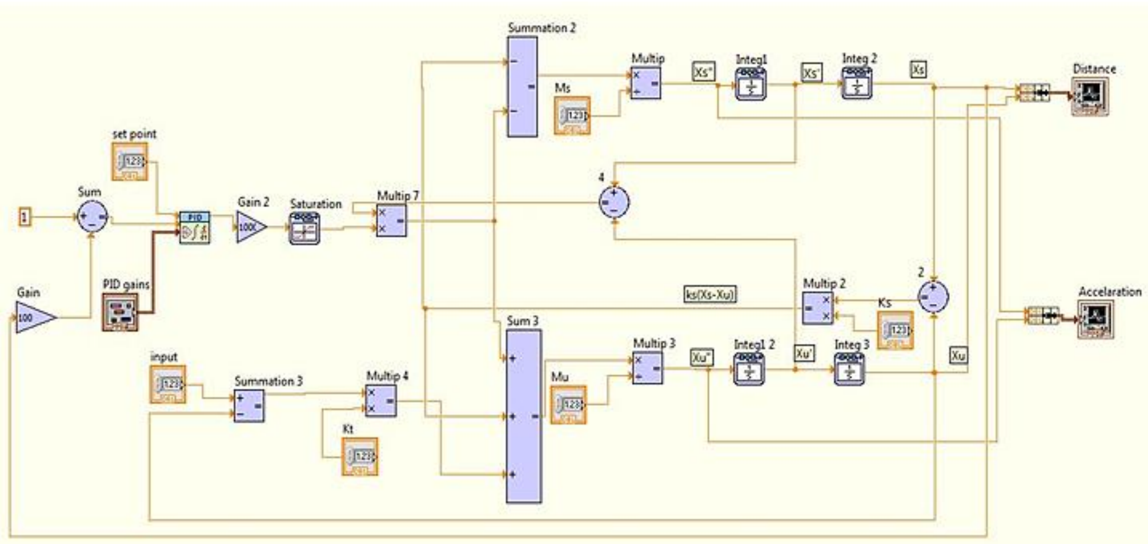

Fig 4 Simulation of semi active suspension system controller in LabVIEW Simulink

3.2. Simulation for semi-active suspension system

Simulink was designed and developed for the semi-active suspension system according to equations (5) and (6). Figure (4) represents a simulation of the semi active suspension system.

Table 1 Parameters used in system simulation

S.N	Parameter	Symbol	Qualities
1	Coefficient of suspension spring	Ks	16900 N/m
2	Damping coefficient of the dampers	Cs	1140 N.s/m
3	Mass of vehicle body	Ms	290 Kg
4	Mass of the tire and suspension	Mu	70 Kg
5	Coefficient of tire material	Kt	179000 N/m

4. Result and discussion

(PID) is a Proportional Integral derivative and as a feedback loop controller for the proposed system, and in order to reach the desired output set from the point where an error signal is fed to the closed loop of the control unit mentioned. In order to stabilize the time and reduce the excessive use of the following values (PID):

Table 1 Parameters used in system simulation

K_p	K_i	K_d
3.563	2.255	0.534

The values mentioned above are taken from the gains obtained by the multiple experiments to reach the best results in terms of the peak overshoot, Settling Time (Sec) of adjustment by the Simulink, while the modern car industry uses a number of different types of control with different values to get the specifications that the manufacturer wants Obtained. Two types of input (input step) are used for Simulink software for LabVIEW to get results.

4.1 System responses under (Z_r =.1) input

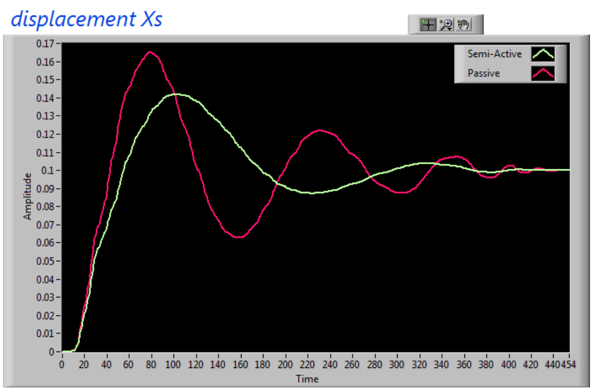

Fig 5 Time response of vehicle body postion

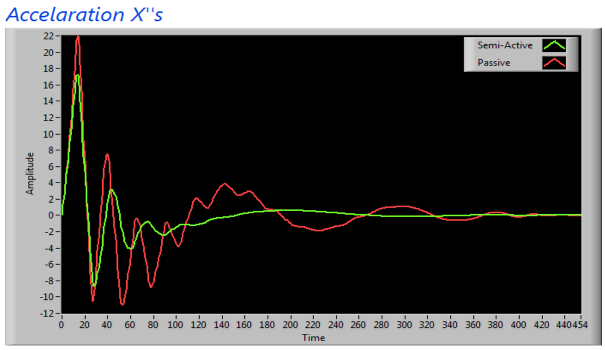

Fig 6 Time response of vehicle body acceleration

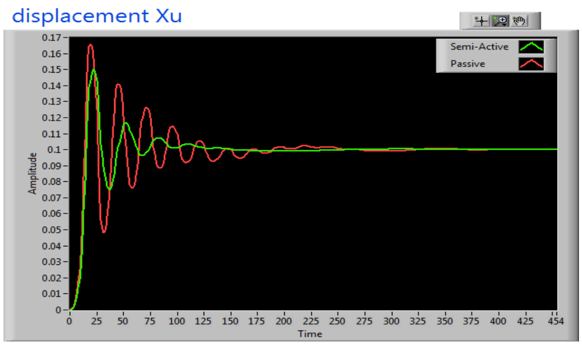

Fig 7 Time response of wheel and tire position

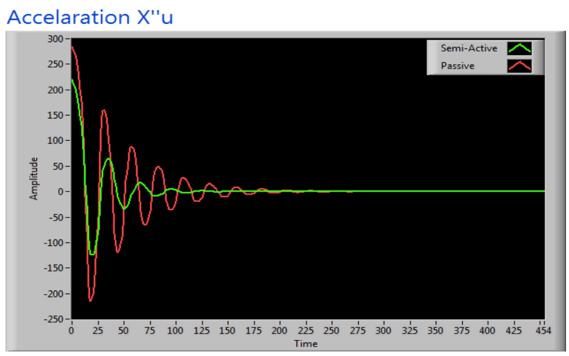

Fig 6 Time response of vehicle wheel acceleration

Table 3 Performances Evaluation and compare results

Types	Settling Time(Sec)		
	Passive	**Semi-active**	**Improvement**
Body Acceleration	420	300	19%
Body position	420	380	10%
Wheel Acceleration	225	175	22%
Wheel position	250	175	30%

Table 3 Performances Evaluation and compare results

Types	Peak overshoot		
	Passive	**Semi-active**	**Improvement**
Body Acceleration	22	17	22%
Body Position	0.165	0.14	15%
Wheel Acceleration	290	225	22%
Wheel Position	.0165	0.149	10%

4.2 System responses under sawtooth input

The main input used for this type of disturbance is a 10 mm amplitude and the frequency is 10Hz as shown below :-

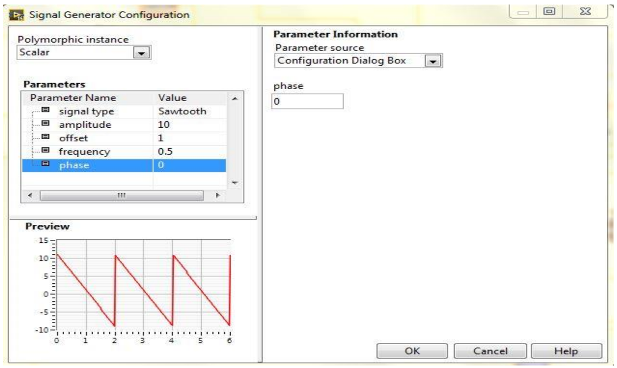

Fig 8 Signal generator configuration for square input

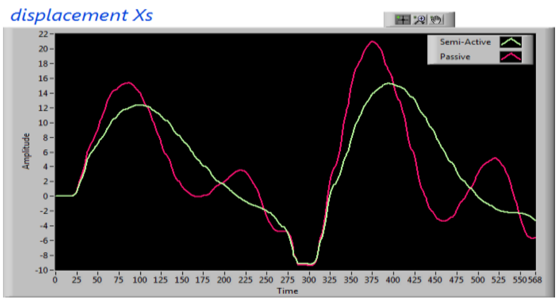

Fig 9 Time response of vehicle body position

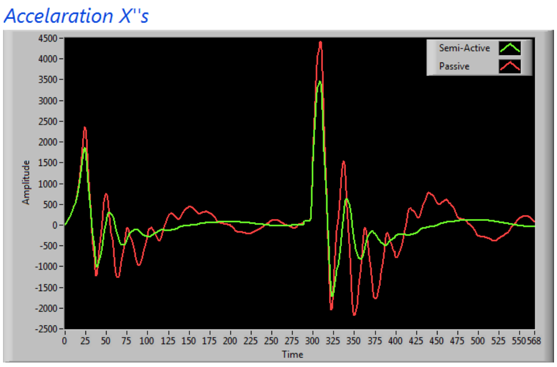

Fig 10 Time response of vehicle body acceleration

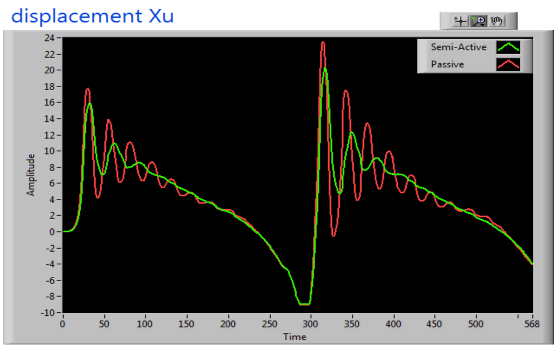

Fig 11 Time response of wheel and tire position

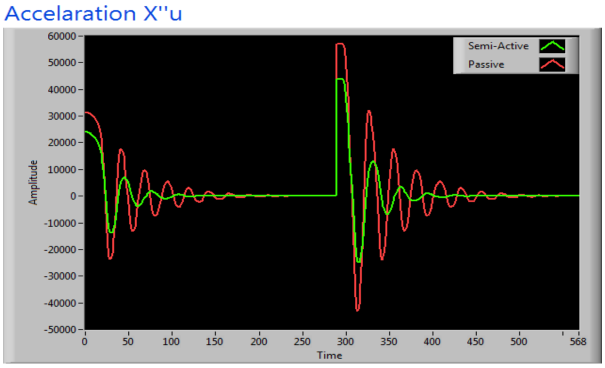

Fig 12 Time response of wheel and tire acceleration

Table 5 Performances Evaluation and compare results

Types	Settling Time(Sec)		
	Passive	**Semi-active**	**Improvement**
Body Acceleration	300	200	33%
Body position	---------	--------	-----------
Wheel Acceleration	500	400	20%
Wheel position	--------	----------	-----------

Table 6 Performances Evaluation and compare results

Types	Peak overshoot		
	Passive	**Semi-active**	**Improvement**
Body Acceleration	4400	3500	20%
Body Position	21	15	28.5%
Wheel Acceleration	55000	45000	18%
Wheel Position	23	20	13%

Conclusion

In this paper, a number of research works have been carried out to compare negative suspension and semi-active suspension. Their dynamic and observable characteristics are compared with the results. There is improved performance in reference to performance standards such as peak overshot time, settling time, wheel deflection, suspension deflection, wheel position the body accelerates. In turn the art of improving the performance of the vehicle will increase the condition and ensure stability and this raises the level of passenger comfort.

It has also been shown that the semi-active suspension system that uses the PID controller is superior to the passive suspension when exposed to any outside input (external stirring) in terms of wheel deflection, suspension deflection, body position response as well as body acceleration and wheel acceleration.

Therefore, the use of the semi-active suspension system is the best passive suspension system from the perspective of vehicle handling as well as ride comfort and safety.

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