International Journal of Current Advanced Research
ISSN: O: 2319-6475, ISSN: P: 2319-6505, Impact Factor: SJIF: 5.995
Available Online at www.journalijcar.org
Volume 6; Issue 8; August 2017; Page No. 5058-5063
DOI: http://dx.doi.org/10.24327/ijcar.2017.5063.0645

Research Article

ANALYSIS AND CONTROL OF SEMI-ACTIVE SUSPENSION SYSTEM FOR A QUARTER CAR MODEL

Sakshi Bansal* and Nathi Ram Chauhan

Department of Mechanical and Automation Engineering, Indira Gandhi Delhi Technical University for Women,
Delhi-110006 (India)

ARTICLE INFO

Article History:

Received 13th May, 2017
Received in revised form 11th
June, 2017 Accepted 25th July, 2017
Published online 28th August, 2017

Key words:

Semi-active suspension system,
SIMULINK, ANFIS

ABSTRACT

The objective of this paper is to analyze and control of semi-active suspension system for a quarter car model. The model of system is developed in SIMULINK. The performance characteristic of semi-active system is analysed in terms of ride comfort and its road holding ability. These characteristics are determined in terms of body acceleration, relative tyre force and relative wheel deflection by using different control strategies like PID, Neural Network and ANFIS. The results obtained by each controller is compared and analysed. The results indicate that the semi-active suspension system provides balance between ride comfort and road holding. ANFIS control provides better ride comfort as compared to Neural Network and PID.

INTRODUCTION

A suspension system is a crucial part of all the automobiles which consist of three elements broadly. Firstly, an elastic element, usually it is a coil spring its role is to deliver a force which is proportional and opposite of the elongation in the suspension. It mainly deals with the entire static load in the system. Secondly, a damping element, it is commonly called as shock absorber, its function is to provide a force which is dissipative in nature also proportional and opposite of the elongation speed. Unlike elastic element it has negligible role in carrying static load, it is crucial when dealing with the dynamic behavior of the system. Lastly, mechanical elements called link, its purpose is to link sprung mass with the unsprung mass of the system, that is, and it is responsible for the suspension kinematics. Thus, an automotive suspension system has various functions to perform which helps in comfort driving from driver and passenger perspective [1, 2].

1. Vehicle posture should be maintained properly, when vehicle is subjected to various internal and external forces.
2. Vibration caused by road roughness input should be isolated, as it is the major disturbance for the vehicle.
3. Good road handling must be assured.
4. Suspension stroke must be optimized; it must be neither excessive nor lacking in response to any disturbance.

It is because of the conflicting nature of the suspension system. If the suspension damping co-efficient is kept low, it provides low body acceleration, that is, more ride comfort but large tire displacement, that is, less road holding capacity, on the other hand if the suspension damping coefficient is kept high, and it provides small tire displacement, that is, good road holding condition and stability but large body acceleration. So, to reduce the effects of this conflicting nature led to the development of active and semi-active suspensions. Active suspensions use force actuators and Semi Active use rheological fluid dampers or Electrohydraulic damper. Only dissipation of energy takes place, if passive semi-active suspension system damper is used, but an active suspension system can generate a force in any direction without considering the direction of relative velocity across it. A good control strategy can help to remove this conflicting nature of the suspension system of either achieving comfort or maintaining stability. But active suspension system is very expensive for commercial use because of their large power requirements and complexity in manufacturing and controlling. So, most of the car manufacturers prefer semi-active damper, because of their ability of changing damping characteristics by providing only a small external power source. Semi active suspension system is more reliable with less complexity in operation also is more cost effective than active suspension system. So, they are becoming more and more popular for commercial vehicle.

Related Work

Passive suspension systems are non-controlled suspension system, which are having a fixed damping coefficient, which

---

Corresponding author:* **Sakshi Bansal
Department of Mechanical and Automation Engineering,
Indira Gandhi Delhi Technical University for Women,
Delhi-110006 (India)

could provide either the road comfort if high damping coefficient dampers are used or the road holding condition if low damping coefficient dampers are used. So, to overcome this conflicting problem, Hrovart [2] in 1997, published a survey on electronically controlled suspension system, which could vary damping coefficient on the basis of road obstacles and thus can fulfill the objective of both ride comfort and road holding. The effect on performance of these electronically controlled suspension system was explained theoretically. Electronically controlled suspension system is further classified as active suspension system and semi-active suspension system based on their use of energy to actuate the damper. Semi-active suspension system uses relatively small amount of energy as compared to active suspension system to actuate the damper to change its damping coefficient. Later, in 2009, Wang *et al.*[3] compared the semi-active suspension system with passive suspension system, although he has used different system which is railway vehicle, rather than a car model, but vertical acceleration was observed to be low in case of semi-active suspension system, thus semi-active suspension system is better irrespective of system. Speltaa *et al.*[4] did a new analytical study by changing both spring stiffness and damping coefficient of the semi-active suspension system with a variable damping and stiffness and checked the performance of system in terms of comfort and again found it to be better than passive system. Eltantawie [5] in 2012, used decentralized neuro-fuzzy controller to analyse the ride comfort and stability of the vehicle. simulink was used to estimate ride comfort in terms of acceleration and again the results were compared with the passive suspension system. Again in 2015, Hrovart *et al.* [6] provided a insight to the active and semi-active suspension system by discussing various results on basis of hardware implementation of this suspension system. Deshpande *et al.*[7] in 2016, provided the additional performance parameters to observe the nature of suspension system other than body acceleration, that is, relative suspension deflection and relative tyre force, however simulation was carried out on active suspension system, but not on semi-active suspension system.

In current paper, a new semi-active suspension system is modeled in simulink with an additional equation which will provide variable damping force and also, the performance is evaluated in terms of new parameters that is relative suspension deflection and relative tyre force apart from the body acceleration and also, the comparative analysis of semi-active suspension performance is done by using different control strategies like PID, neural network and ANFIS.

METHODOLOGY

Block Diagram

For the suspension system, thus, the interest lies only in knowing the damping force (F_d), which will directly affects the passenger comfort, so, the output is damping force from the mechanical system, and the input is damping actuation (L), which is received by the electric system, after being sensed by the sensor, and another input is deflection speed (x*), as it will determine the damping force.

Here, J is the physical signal, which is used as a signal to operate the valve of the damper. It is generally current for electric system. Thus, this block diagram as shown in Figure 1, explains, how actually the system will work, when passive damper will be replaced by hydraulic or rheological damper.

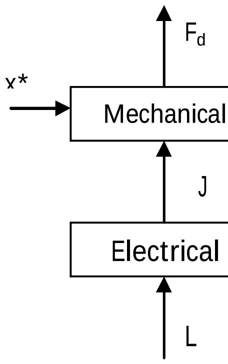

Fig 1 Block Diagram

Mathematical Modeling

Figure 2 is depicting the model of a semi active suspension system of quarter car. Here, damper c_s and spring k_s are coupling the unsprung mass and the sprung mass together, where sprung mass is mass of the chassis (or mass above suspension system) and unsprung mass is the mass of the wheel and tyre and the links connecting the chassis to the wheel. Damper chosen is magnetorheological. Also, the tyre is considered equivalent to spring k_t.

Disturbances are also assumed to be zero in this model, as it has main effect during braking and steering conditions, it can be calculated in separate problem statement and can be coupled with these results [3].

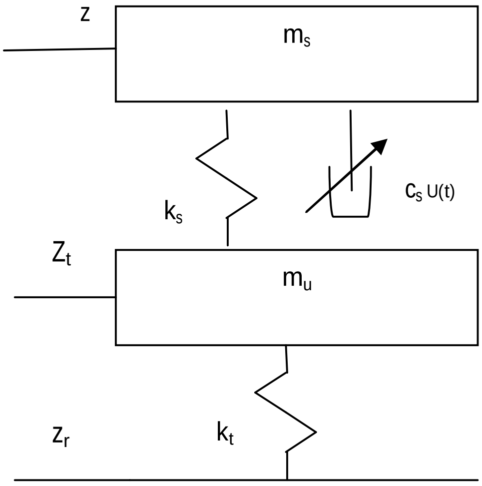

Fig 2 Semi-active suspension model

Dynamic equations for the above model [1] are,

$$m_s\ddot{z} = -k_s(z - z_t) - c_o(\dot{z} - \dot{\dot{z}}_t) \tag{1}$$

$$m_u\dot{z}_t = k_s(z - z_t) + c_s(\dot{z} - z_t - k_t(\dot{z}_t - z_r) \tag{2}$$

$$c_o = -\beta c_s + \beta c_i \tag{3}$$

Here, c_s and c_i are actual and requested coefficient of dampers, and β is controller damper actuator bandwidth.

But, these equations will provide the non-linear result, which is difficult to simulate also do not give the correct analysis, therefore Sergio *et al.* [1] in their paper used the linear time invariant (LTI) oriented method to change this system into linear system which can be used for designing and controlling purpose. The proposed equations of the linearized models are:-

$$m_s\ddot{z} = -k_s(z - z_t) - c_o(\dot{z} - \dot{z}_t) \dot{-} F_D \quad (4)$$

$$m_u\dot{z}_t = k_s(z - z_t) + c_s(\dot{z} - z_t) - k_t\dot{(}z_t - z_r) + F_D \quad (5)$$

$$F_D = -\beta F_D + \beta u \quad (6)$$

Here, F_D is the actual damping force and u is the requested damping force. u is requested by the damper when an obstacle is met on the road, this can be greater or smaller than the F_D depending on the intensity of the obstacle. The requested damping force, as given by u can be obtained by using additional controller like PID, neural network or adaptive neuro-fuzzy inference system.

State variables are used to develop the dynamic model of suspension system. State variable are:-

The tyre in the above equation is modelled as linear spring; its dynamic equation is denoted by $F_{t.}$

$$x_1 = z \quad (7)$$

$$x_2 = \dot{z} \quad (8)$$

$$x_3 = z_t \quad (9)$$

$$x_4 = \dot{z}_t \quad (10)$$

The tyre in the above equation is modelled as linear spring, its dynamic equation is denoted by $F_{t.}$

$$F_t = k_t(x_3 - z_r) \quad (11)$$

Performance Parameters

Performance parameters for analysing the semi-active suspension system are:-
1. Sprung mass acceleration to estimate ride comfort
2. Relative suspension deflection so that suspension deflection remains within space limit.
3. Relative tyre deflection to ensure road holding.

Relative suspension deflection (RSD) is the ratio of suspension deflection to rattle space limit.

$$RSD = (x_1 - x_3) / x_r \quad (12)$$

Relative tyre force (RTF) is ratio of tyre load under dynamic condition to static load of tyre.

$$RTF = F_t / (m_s + m_u)\, g \quad (13)$$

Table 1 Automotive Parameters (Reference Model) [1]

Value	Unit	Meaning
400	Kg	Sprung mass (m_s)
50	Kg	Unsprung mass ($m_{u)}$
30,000	N/m	Front suspension linearized stiffness(k_s)
20,000	N/m	Rear suspension linearized stiffness
1500	N/m/s	Front suspension linearized damping(c_s)
3000	N/m/s	Rear suspension linearized damping
200,000	N/m	Tire stiffness(k_t)
50	Rad/s	Suspension actuator bandwidth(b)
0.08	m	Rattle space limit(x_R)

Control Techniques

The control strategies that are used in analyzing the performance characteristics are discussed explaining how they are used to take the input signal and providing the output signal after comparing with the feedback signal.

Case 1: PID

A road input is provided to the PID controller, this PID controller is configured with semi-active suspension system, this system, provides a chassis deflection, as an feedback signal, now comparing this feedback with the road input, an error signal is send back to PID controller, which will tune the signal, so as minimize the chassis displacement, which will reduce the vertical body acceleration of the system in order to achieve ride comfort.

Case 2: Neural Network

In this case, the feedback signal is provided to the neural network, neural network trains the system on the basis of error signal obtained by comparing the road input signal to the feedback signal. After training the system, so as reduce the vertical chassis displacement, the results will be compared again, to check minimum error, and will continue, till we get minimum error signal. This will ultimately reduce the vertical body acceleration so as to improve the ride comfort.

Case 3: Adaptive Neuro-fuzzy Inference System

The control strategy is again replaced by the ANFIS; it is to obtain the benefit of both neural network and fuzzy logic. In this first fuzzy logic is used to extract the rules from the road input signal and vertical chassis displacement value. Now, neural network will train the results obtained by this fuzzy rule, and thus, the benefit of both neural and fuzzy are used to further reduce the vertical chassis displacement and provide further ride comfort by reducing vertical body acceleration.

RESULTS AND DISCUSSION

The various performance characteristics value that is obtained by using different control strategies is discussed along with the comparative analysis.

Input Parameters

Reference values for analysing the performance [7]
Suspension rattle space = 0.08 m

Road irregularity = considering bump peak of 25% higher than the suspension rattle space

Road irregularity peak = [0.08 + ((25/100) * 0.08)] = 0.1 m

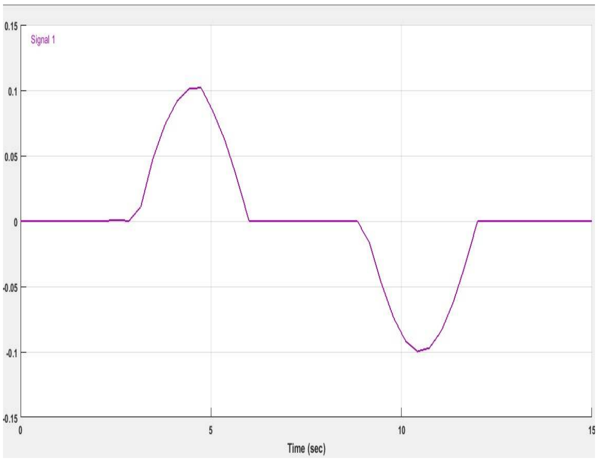

Fig 3 Input Road Profile

Fig. 3 shows the input road signal which is provided to the system. This signal is same as Deshpande [7] has used in modeling. This signal has a maximum peak of 25% greater than the rattle space available.

Semi-Active System Model In Simulink

By using (equation 4, equation 5, equation 6), analysis of system performance is done by evaluating the values body acceleration, relative suspension deflection and relative tyre force. To further improve the performance of the semi-active suspension system, controller is added, which will take the damping force requested by the MR damper as the reference force, and will provide the required force. Controller will automatically adjust the value of damping force required so as to provide maximum comfort and minimum tire deflection and hence minimum tyre force and overall pleasant ride.

Case 1: PID

Body Acceleration

Fig. 4 shows the response of the system, when semi-active suspension system is used with the PID controller. Here, the peak value of body acceleration is 0.8 m/s^2, the response on the road profile is similar to that of the passive system, and hence the system is assumed to behave properly.

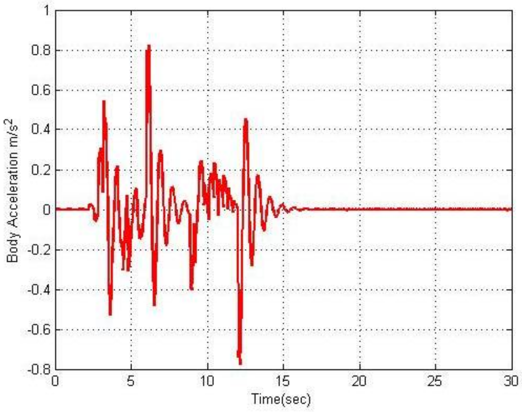

Fig 4 Body Acceleration Using PID

Relative Suspension Deflection

Fig. 5 shows relative suspension deflection is having its peak value at 0.6, which is less than one. Hence, the suspension travel is within the rattle space and makes the system suitable for evaluating the ride comfort.

Relative Tyre Force

Fig. 6 shows the relative tyre force measured to be at its peak value at 0.81, which indicates that the dynamic tyre force is quite less than the static tyre force.

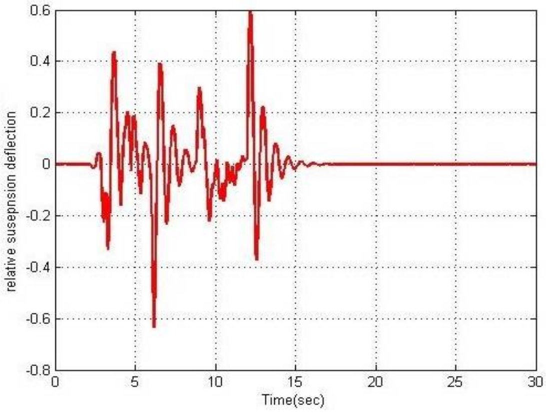

Fig 5 Relative Suspension Deflection Using PID

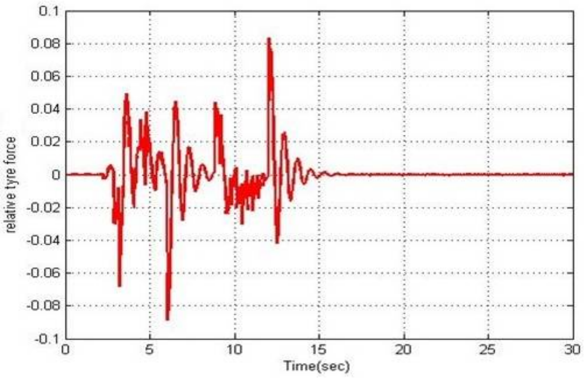

Fig 6 Relative Tyre Force Using PID

Case 2: Neural Network

Body Acceleration

Fig. 7 shows the response of the system, when semi-active suspension system is used with the neural network controller. Here, the peak value of body acceleration is 0.7 m/s^2. The response on the road profile is similar to that of the passive system, and the system is assumed to behave properly.

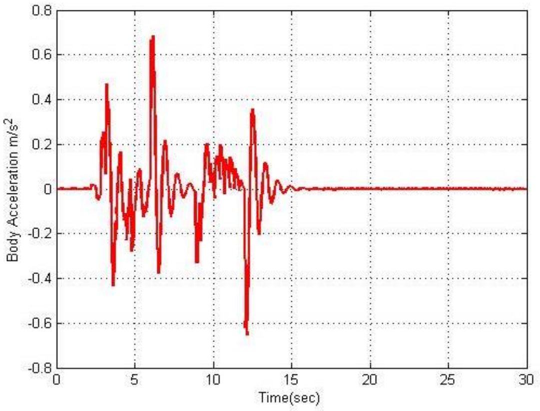

Fig 7 Body Acceleration Using NEURAL NETWORK

Relative Suspension Deflection

Fig. 8 shows relative suspension deflection is having its peak value at 0.65, which is less than one. Hence, the suspension travel is within the rattle space, thus it is making the system suitable for evaluating ride comfort.

Relative Tyre Force

Fig. 9 shows the relative tyre force measured to be at its peak value at 0.09, which indicates that dynamic tyre force is quite less than the static tyre force.

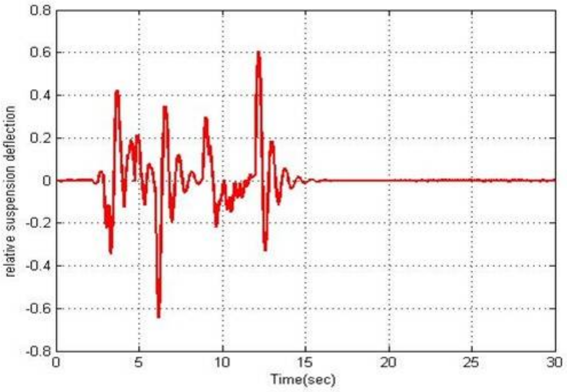

Fig 8 Relative Suspension Deflection Using NEURAL NETWORK

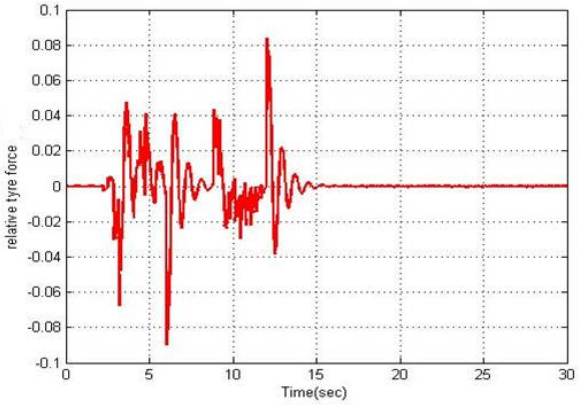

Fig 9 Relative Tyre Force Using NEURAL NETWORK

Case 3: Adaptive Neuro-fuzzy Inference System

Body Acceleration

Fig. 10 shows the response of the system, when semi-active suspension system is used with the neural network controller. Here, the peak value of body acceleration is 0.6 m/s^2. The response on the road profile is similar to that of the passive system, and hence the system is assumed to behave

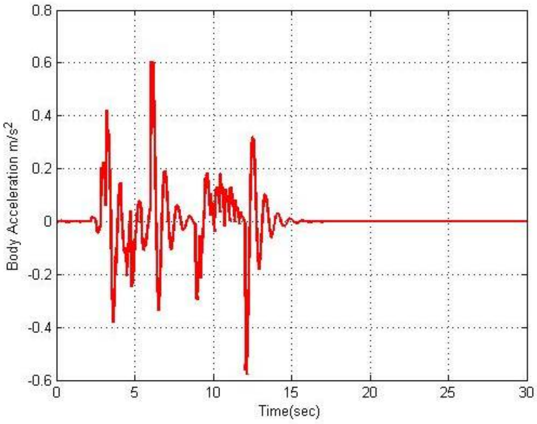

Fig. 10 Body Acceleration Using ANFIS

Relative Suspension Deflection

Fig. 11 shows relative suspension deflection is having its peak value at 0.14, which is less than one; hence the suspension travel is within the rattle space, thus making the system suitable for evaluating ride comfort.

Relative Tyre Force

Fig. 12 shows the relative tyre force measured to be at its peak value at 0.055, which indicates that dynamic tyre force is quite less than the static tyre force.

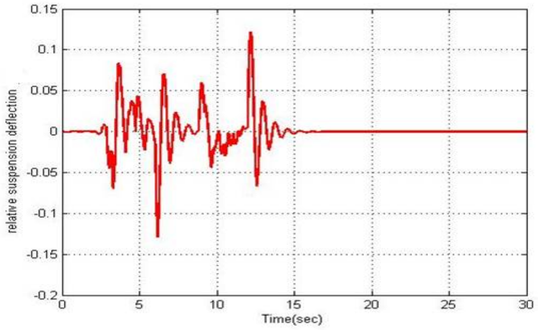

Fig 11 Relative Suspension Deflection Using ANFIS

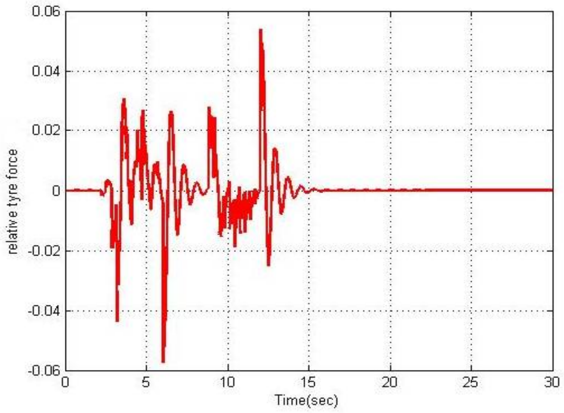

Fig 12 Relative Tyre Force Using ANFIS

Comparative Analysis Based On Results Obtained From Different Controllers

From the above analysis of the performance parameter, it is seen that the proposed model is working properly. The condition of relative suspension deflection is, it should be less than one, as it will deflect only in available rattle space. Each controller has adjusted its value of suspension deflection accordingly. Further in each model, it is seen that relative tyre force is very less, which indicates in each system, dynamic tyre force is much less than the static tyre force.

Table 2 Body acceleration comparisons

S.No.	Controllers	Body acceleration (m/s^2)
1.	PID	0.8
2.	NEURAL	0.7
3.	ANFIS	0.6

Comparison of body acceleration is shown in Table 2, it is seen that, ANFIS is giving an experience of least body acceleration, thus making a ride more comfort for the passenger as compared to the suspension system, which is getting external power source by PID controller and Neural Network. The choice of controller also depends on the use and cost efficiency of the suspension system, external power source can be preferred by any control strategy as each controller provides very less acceleration, but when precision is required as in case of sports vehicles, the controller which provides least body acceleration should be preferred.

CONCLUSION

The semi-active suspension modelling was done in simulink using linearized equations of variable damping force. Semi-active suspension system is controlled by PI, neural network and ANFIS and analysed for performance parameters that is relative suspension deflection, relative tyre force and body acceleration. It is seen that relative suspension deflection, is always less than 1, in all the cases of PID controller, Neural Network and ANFIS, which indicates that suspension will always travel in its rattle space without providing any physical damage to the system. Relative tyre force is very less than one, in every case, which ensures that dynamic force on tyre will not overtake the static tyre force on the tyre. Body acceleration is less in all the cases but with the change of control techniques. It was also observed that the body acceleration showed a drastic change in its value with least acceleration, observed in case of ANFIS i.e, 0.6 m/s^2 and most in case of PID i.e.0.8 m/s^2 .

References

1. S.M. Savaresi, C. Poussot-Vassal, C. Spelta, O. Sename and L. Dugard, “Semi-Active Suspension Control for Vehicles”, 1st ed. UK: Sciencedirect, 2010
2. D.Hrovat, ‘Survey of Advanced Suspension Developments and Related Optimal Control Applications”, Pregamon, Automatica Vol.33,No. 10,pp. 1781-18171, 1997
3. D. H. Wang a & W. H. Liao, Semi-active suspension systems for railway vehicles using magnetorheological dampers , “*International Journal of Vehicle Mechanics and Mobility*”, Vol. 47, No. 12, pp. 1439-1471, 2009
4. Cristiano Speltaa, Fabio Previdia, Sergio M. Savaresib, Paolo Bolzernb, Maurizio Cutinic, Carlo Bisagliac and Simone A. Bertinottic, “Performance analysis of semi-active suspension with control of variable damping and stiffness”, *International Journal of Vehicle Mechanics and Mobility Vehicle System Dynamics* Vol. 49, Nos. 1-2, pp. 237-256, 2011
5. M.A.Eltantawie, “Decentralized Neuro-Fuzzy Control for Half-Car With Semi-Active Suspension System”, *International Journal of Automotive Technology*, 2012
6. H. Eric Tsenga & Davor Hrovata, “State of the art survey: active and semi-active suspension control” Vehicle System Dynamics, 2015
7. Vaijayanti S. Deshpande, Pramod D. Shendge, and Shrivijay B. Phadke, “Nonlinear Control for Dual Objective Active Suspension Systems”, IEEE Transactions On Intelligent Transportation System, 2017

How to cite this article:

Sakshi Bansal and Nathi Ram Chauhan (2017) 'Analysis and Control of Semi-Active Suspension System for a Quarter Car Model ', *International Journal of Current Advanced Research*, 06(08), pp. 5058-5063.
DOI: http://dx.doi.org/10.24327/ijcar.2017.5063.0645

****