IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

Simulation of Semi Active Suspension of Half Car Model using Fuzzy Logic Controller

[1]Saurabh Aswale, [2]N. S. Nagmoti, [3]M. M. Khot
[1]Student, [2]Assistant Professor, [3]Assistant Professor
Mechanical Engineering Department
Walchand college of Engineering, Sangli, India

Abstract: Fuzzy logic controller is a multiple valued logic in which input space is mapped with output space with help of rules. In this study, semi-active suspension is developed using Fuzzy Logic. The proposed system is simulated using MATLAB/Simulink. A 4 degree of freedom half car model is formulated. Two road inputs are used to simulate the system. A Fuzzy Logic controller is designed to vary the damping coefficient of the system in real time. Body acceleration, tyre load variation and suspension deflection are assessed in the simulation. The results simulated with fuzzy logic controller are compared with the passive suspension. According to the comparison, it is noted that semi active system gives better results than the conventional system.

***Index Terms* - Semi-active Suspension, Fuzzy Logic Controller, Half Car Model, Mathematical Model.**

I. INTRODUCTION

A suspension system is used for providing comfort by absorbing road shocks and vibrations and to improve the road-holding ability of tires which is important for handling and of vehicle. The suspension has two main components, springs and dampers. Springs stores energy when there is a change in load which can be due to road bumps or inertial movement. The function of dampers is to dissipate the energy which is stored in the springs to avoid unwanted oscillations when the spring releases the stored energy.

While designing a suspension system, engineers have to take in account various functions of the system. It is a trade-off between the functions of the system. As if softer spring and less damping coefficient are selected the suspension will give better comfort by absorbing most of the vibrations but the vehicle handling will be affected as a soft suspension will allow more body movements and wheel hop. In the case of stiffer spring and more damping coefficient, the body movements can be controlled and tire-to-ground contact will be better but more vibrations will be transmitted to the body which makes the ride uncomfortable.

It is important to decide these parameters according to the specific application of the vehicle. To avoid drawbacks of the conventional suspension systems, active and semi-active suspensions have been developed.

Semi-active suspension: Semi-active suspension has construction similar to conventional suspension system but the damper is a variable damper in which damping coefficient can be varied. Generally, Magnetorheological (MR) dampers are used in such systems which allows seamless change of damping coefficient.

MATLAB/Simulink have been used in many studies for the design of semi-active suspension. The mathematical model is developed for the quarter car model. The system is simulated in MATLAB and a controller is designed to achieve good handling as well as comfort. Bingham model is used for simulating the behavior of MR damper which can be used in semi-active suspensions. [1][2]. In some studies, a magnetic actuator is used in place of an MR damper [3]. The PID controller is used in most of the control problems. For active suspension systems, a PID controller is used to controlling active force. Quarter car model is used for simulation [4]. This technique is also used for active suspension in rail car to improve stability, comfort and safety. A 2DoF suspension model is used [8].

Fuzzy logic controller is used for multi valued decision making. For active suspension, the fuzzy logic controller can be used to determine the active force. The mathematical model of quarter car using active suspension has been simulated in MATLAB/Simulink with different fuzzy rule sets and results show improvements in comfort and handling compared to the conventional system [5]. In another study, control problem is considered as disturbance rejection problem. Two control strategies are developed one for bump rejection and the other for load rejection using PID controller. The control strategies developed are applied to a quarter car model by integrating two control strategies. A PID controller, along with fuzzy control is employed. It is used to switch between bump isolation and inertial load rejection strategies. An electrodynamic servo valve and a hydraulic actuator are used [6]. In some studies, skyhook and ground hook concept are used for semi-active suspension design. For this, the Bouc-Wen model can be used as a simple analytical solution to model the dynamic response of a system utilizing MR dampers [7]. For semi-active suspension road, an estimation-based suspension hybrid control strategy is also developed. It aims to adaptively change control gains. It improves suspension performance [9]. A fuzzy logic controller can also be used for changing the damping coefficient in semi active suspension. The quarter car model is used for simulation using fuzzy logic control [11]. An Adaptive neuro-fuzzy inference system (ANFIS) with optimization is used in [12] for the nonlinear mathematical model. The ANFIS helps to take a look-ahead preview of the excitations resulting from road irregularities which is used to quickly mitigate the effect of the control system time delay on the damper response.

In this study, 4 degrees of freedom mathematical model for half-car suspension is developed. Simulation is carried out in MATLAB/Simulink. Semi-active suspension is designed for the half-car model. A fuzzy logic controller is used to determine the variable damping coefficient. The system is simulated in Simulink and using Co-Simulation to check ride comfort, handling and suspension deflection of the system. The results are compared with a passive suspension system which is also simulated in Simulink.

II. HALF CAR MODEL:

Unlike the quarter car model where only one wheel is analysed, the half-car model considers two wheels of one side. In this type of model, half of the weights of the entire car including that of passengers are considered for analysis purposes. The main advantages of this type of models are

1. Vehicle pitch/ roll motions can be simulated.

2. Left and right dampers and spring characteristics can be modelled differently which is also different on the actual vehicle.

3. Body motions and the center of gravity effect can be simulated. [12]

The figure given below shows a half car model. In which, z_b is body (sprung mass) displacement, z_{w1} and z_{w2} are wheel (unsprung mass) displacements on either side. z_{r1}, z_{r2} are road irregularities. m_s is the weight of sprung mass and $m_{u1,}\ m_{u2}$ are the unsprung masses. B is track width. k_{t1}, k_{t2} are the tyre stiffnesses, k_{s1}, k_{s2} are suspension spring stiffness. c_{p1}, c_{p2} are damping coefficients of suspension dampers. The damping of tyres is neglected.

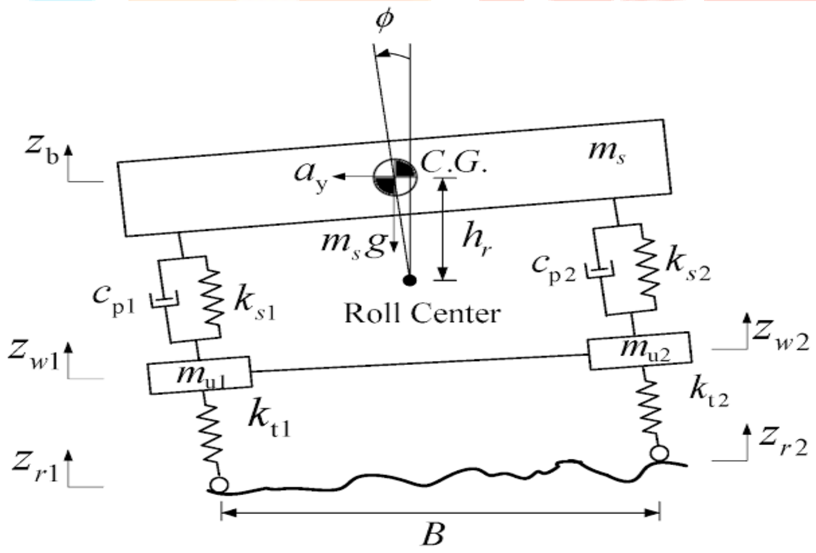

Figure 1. Half car rolling model [9]

Using Newton's laws of motion

$$\ddot{z_b}.m_s = F_{s1} + F_{s2} \quad (2.1)$$

$$\ddot{z_{w1}}.m_{u1} = -F_{s1} - k_{t1}(z_{w1} - z_{r1}) \quad (2.2)$$

$$\ddot{z_{w2}}.m_{u2} = - F_{s2} - k_{t1}(z_{w2} - z_{r2}) \quad (2.3)$$

$$(I_{xx} + m_s h_r)\, \ddot{\varphi} = m_s(a_y \cos\varphi + g \sin\varphi)h_r + \frac{B}{2}\ (F_{s1} - F_{s2}) \quad (2.4)$$

Where,

$$F_{s1} = - k_{s1}\ (z_b - z_{w1} - \frac{B}{2}\ \sin\varphi/2) - c_{p1}\ (\dot{zb} - \dot{z_{w2}}) \quad (2.5)$$

$$F_{s2} = - k_{s2}\ (z_b - z_{w2} + \frac{B}{2} \sin\varphi\ ) - c_{p2}\ (\dot{zb} - \dot{z_{w2}}) \quad (2.6)$$

$(I_{xx} + m_s h_r)$ is rolling inertia which depends on the inertia of the vehicle and height of the roll center.

Body acceleration	: $\ddot{z}_b$
Suspension Travel (Left)	: z_b - z_{w1}
Suspension Travel (Right)	: z_b - z_{w2}
Tyre load variation (Left)	: $k_{t1}(z_{w1} - z_{r1})$
Tyre load variation (Right)	: $k_{t1}(z_{w2} - z_{r2})$

III. ROAD INPUT:

Sinusoidal road inputs are generally used for the simulation of suspension models as we can simulate the system for various frequencies and amplitudes. Different inputs are used for each wheel to ensure there is a rolling motion when the vehicle goes over the bumps.

Road input at Left wheel: $Z_{r1} = \; a\sin(w\pi t) \qquad for\;\; 0 < t < 2$ (3.1)

Amplitude(a) = 0.2

Road frequency (w) = 3.2 rad/ sec

Road input at Right wheel: $Z_{r2} = \; a\sin(w\pi t) \qquad for\;\; 0 < t < 2$ (3.2)

Amplitude(a) = 0.2

Road frequency (w) = 2 rad/ sec

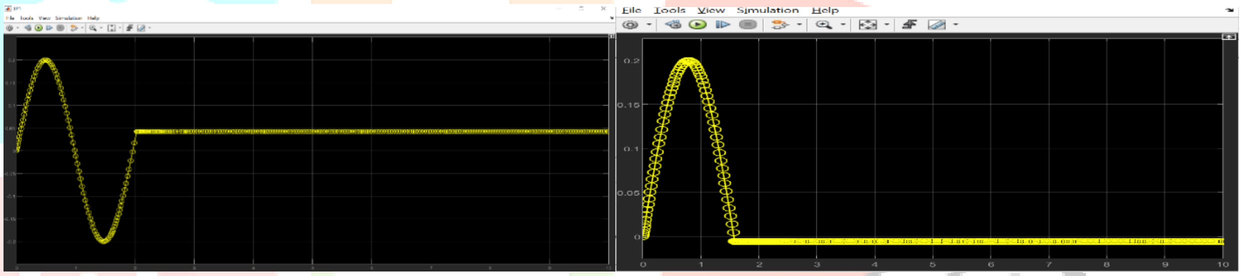

Figure 2. Road Inputs for left and right wheels

IV. FUZZY LOGIC

Conventional Boolean logic uses “True or False” approach (1 for true and 0 for false). Fuzzy logic is based on ‘Degree of truth. Fuzzy logic is a form of many-valued logic in which the truth values of variables may be any real number between 0 and 1 including both. It is used where values are not completely true or false. It doesn’t require mathematical model as it is based on set of rules, hence it is easier to understand and implement.

Membership functions, fuzzy sets, linguistic variables, fuzzy rules are the main aspects of fuzzy logic. Membership functions express degree of truth for given value of variables. There are many types of Membership Functions but the main are triangular trapezoidal and Gaussian membership functions.

For this study five membership functions are used for two inputs:

HN - High Negative
LN - Low Negative
Z - Zero
LP - Low Positive
HP - High Positive

For output, membership functions are taken as 1 to 5, 1 being the lowest, and 5 is the highest damping coefficient.

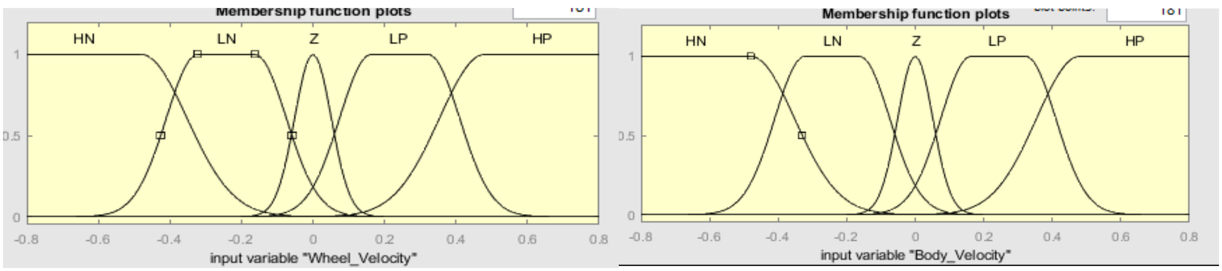

Figure 3. Membership functions

The point of fuzzy logic is to map an input space to an output space. It is defined by set of rules which are 'if-then' statements. The fuzzy logic controller is designed in the form of a circuit which can vary damping coefficient of variable damper according to the fuzzy rule set. Sprung mass velocity and relative velocity from sensors is given to the controller as a feedback and required damping coefficient is calculated according the rules. The rule is stated for example, "If wheel velocity is 'NB' and Body velocity is 'PB' then Damping coefficient is '1'(lowest)"

The rules can be shown as a chart:

Table 1. Fuzzy Logic Rue Table

5 MF FUZZY RULE SET		Wheel Velocity				
		NB	NS	Z	PS	PB
Body Velocity	NB	5	4	1	1	1
	NS	4	4	2	2	1
	Z	1	3	2	3	1
	PS	1	2	2	3	4
	PB	1	1	1	3	5

The controller is designed in MATLAB. The relation between inputs and outputs is defined using rules and can be seen as the surface graph shown in the figure 5. The graph shows how input space is mapped with the output space. As shown in the graph, there are different values of damping coefficient as wheel velocity and body velocity changes.

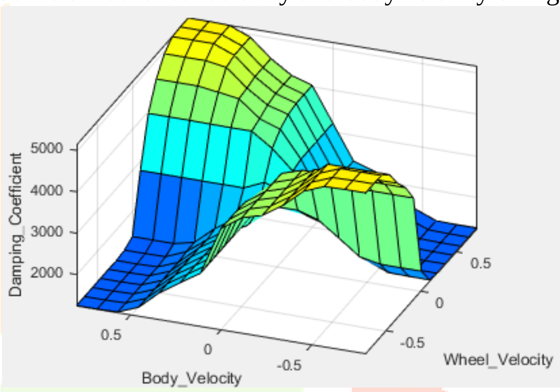

Figure 4. 3D Surface Graph

IV. RESULTS AND DISCUSSION

The use of the suspension is to control body acceleration, suspension deflection, and dynamic tire load variation. The performance of suspension is improved if the values of these parameters are minimized. The half-car model is simulated using Simulink with a passive system and a semi-active system using fuzzy logic control. The graphs of parameters are plotted to compare both systems. Comparison is done by using RMS values. Minimum the RMS value better the system will be. The graphs below show the comparison. Yellow graph shows passive suspension parameters and blue graph shows parameters for semi active suspension. As we can see in the graphs, system with semi active suspension settles more quickly.

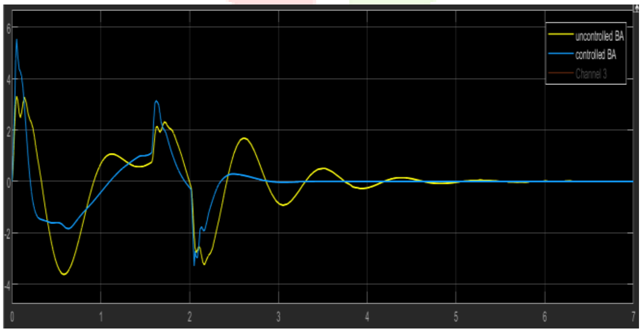

Figure 5.1. Body Acceleration

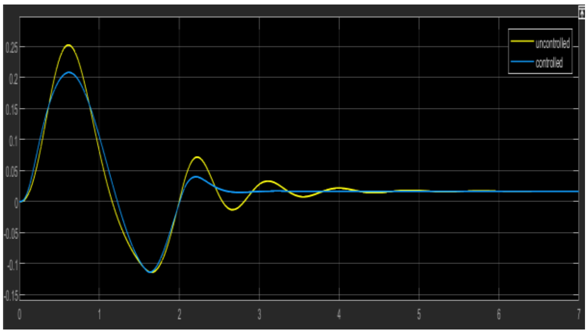

Figure 5.2 Body Displacement

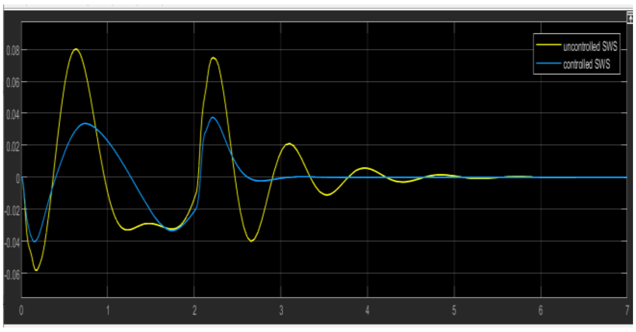

Figure 5.3 SWS (left side)

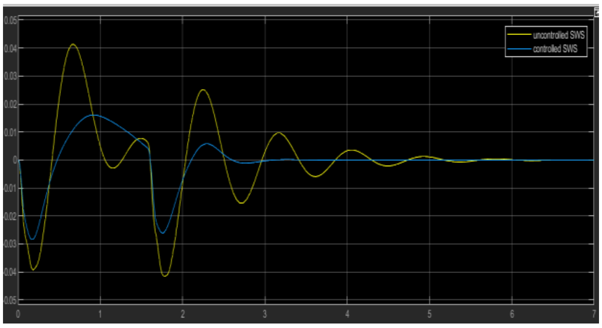

Figure 5.4 SWS (Right side)

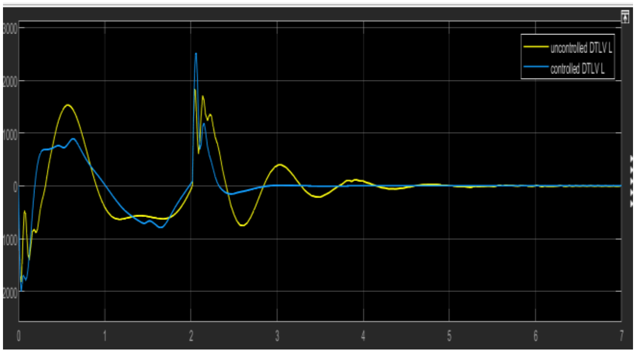

Figure 5.5 DTLV (left side)

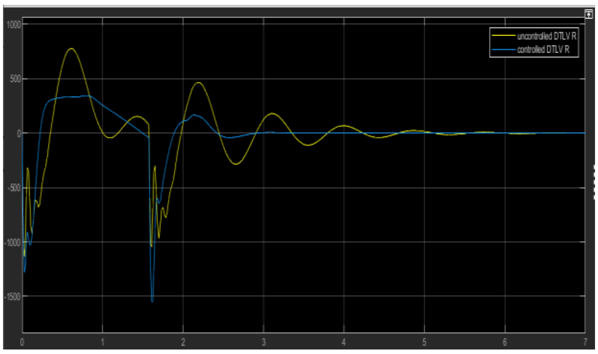

Figure 5.6 DTLV (Right side)

The results show that there is improvement can be achieved by the use of semi-active suspension. The suspension deflection is considerably less so we can say it is a more stable system and will cause less wear to the components. It is more comfortable as well as improves the handling of the vehicle.

Table 2. RMS Values

Parameters	Passive	Semi Active	% improvement
Body Acceleration(m/s^2)	1.57	1.282	18.34
Body Displacement(cm)	8.53	7.87	7.73
Suspension Deflection (Left) (cm)	3.15	1.83	41.9
Suspension Deflection (Right) (cm)	1.70	1.035	39.41
DTLV (Left) (N)	689.1	613	11.03
DTLV (Right) (N)	397	337	15.11

CONCLUSIONS

In this paper, various advancements in semi active and active suspension technology are discussed. A new method is proposed using fuzzy logic. A half car suspension model is formulated using Newtons law. A new control strategy is developed using Fuzzy logic controller. Fuzzy logic can be used in control problems having multiple variables. It is easy to understand and implement. Simulation of the system is done using MATLAB/Simulink. Graphs of Body acceleration, displacement, suspension deflection and tyre load variation are obtained by the simulation. The conventional system is compared with newly developed semi active system on graphs and RMS values of above parameters.

The results show that there is improvement can be achieved by the use of semi-active suspension. The suspension deflection is considerably less so we can say it is a more stable system and will cause less wear to the components over passive suspension. It is more comfortable as well as improves the handling of the vehicle.

REFERENCES

[1] Ankita R. Bhise, Rutuja G. Desai, Mr. R. N. Yerrawar, Dr. A.C. Mitra, Dr. R. R. Arakerimath, "Comparison Between Passive And Semi-Active Suspension System Using Matlab/Simulink" IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 13, Issue 4 Ver. I (Jul. - Aug. 2016), PP 01-06

[2] Mr. Amit A. Hingane, Prof. S. H. Sawant, Prof. S. P. Chavan, Prof. A. P. Shah, Random Road Excitation Using MATLAB/Simulink" IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), ISSN: 2278-1684, PP: 01-06

[3] Dr. J. Jancirani, K. Prabu, J. Jeevamalar, "Development of an Actively Controlled Vehicle Suspension for Passenger Vehicles", IEEE-International Conference On Advances In Engineering, Science And Management (ICAESM -2012) March 30, 31, 2012

[4] K. Dhananjay Rao, "Modeling, Simulation and Control of Semi Active Suspension System for Automobiles under MATLAB Simulink using PID Controller", Third International Conference on Advances in Control and Optimization of Dynamical Systems March 13-15, 2014. Kanpur, India. [5] A. Shehata, H. Metered and Walid A.H. Oraby, "Vibration Control of Active Vehicle Suspension System Using Fuzzy Logic Controller" Conference paper, September 2014 DOI: 10.1007/978-3-319-09918-7_35

[6] Mohammad H. AbuShaban, Mahir B. Sabra, Iyad A. Abuhadrous, "A New Control Strategy For Active Suspensions Using Modified Fuzzy And PID Controllers" The 4th International Engineering Conference- Towards Engineering of 21st Century.

[7] Y. K. Wen, "Method for Random Vibration of Hysteretic Systems," ASCE Journal of the Engineering Mechanics Division, vol. 102, no.2, pp.249- 2 263,

[8] Daniyan, I. A. and Mpofu, K. and Osadare D. F., "Design And Simulation Of A Controller For An Active Suspension System Of A Rail Car" Publisher: Cogent OA; Journal: Cogent Engineering; DOI: http://dx.doi.org/10.1080/23311916.2018.1545409

[9] Yechen Qin, Mingming Dong, Reza Langari, Liang Gu, and Jifu Guan, "Adaptive Hybrid Control of Vehicle Semiactive Suspension Based on Road Profile Estimation" Hindawi Design, Modelling and Simulation of Semi Active Suspension for Solid Axle Vehicle Department of Mechanical Engineering, WCE Sangli. Page 26 Publishing Corporation Shock and Vibration Volume 2015, Article ID 636739, 13 pages http://dx.doi.org/10.1155/2015/636739

[10] Y. M. Sam and K. Hudha, "Modelling and Force Tracking Control of Hydraulic Actuator for an Active Suspension System" Modelling and Force Tracking Control of Hydraulic Actuator for an Active Suspension System" 0-7803-9514-X/06/2006 IEEE

[11] Bhanu Chander V, "Modelling and Analysis of Quarter Car Vehicle Suspension System Using Fuzzy Logic"

[12] Shehata Gad, A., El-Zoghby, H., Oraby, W., and Mohamed El-Demerdash, S., "Application of a Preview Control with an MR Damper Model Using Genetic Algorithm in Semi-Active Automobile Suspension," SAE Technical Paper 2019-01-5006, 2019, doi:10.4271/2019-01-5006.