International Journal of Advance Research in Science and Engineering
Volume No.07, Issue No.05, May 2018
www.ijarse.com
IJARSE
ISSN: 2319-8354

Vibration Control of Car Suspension System Using PID, Fuzzy and Fuzzy PID Controllers

GAURAV KUMAR SINHA

RESEARCH SCHOLAR, ELECTRICAL DEPARTMENT, BIT SINDRI DHANBAD, (INDIA)

ABSTRACT

Optimal vehicle handling, good driving pleasure, best comfort for passengers, effective and efficient isolation of road noise and vibration in suspension systems has been a key research area .This paper presents the application of different controllers to control the vibration occurred in the car suspension system. When the suspension system is designed, a ¼ model of car is used to simplify the problem to a one dimensional mass spring- damper system. Its open-loop performance on the basis of time response is observed which depicts that the car suspension has oscillations with large settling time. To overcome this problem, closed-loop system is used. Despite continuous advancement in control theory, Proportional –Integral (PI), Proportional-Integral-Derivative (PID) IMC, FUZZY, Fuzzy PID Control method are the popular technique to control any process. In this paper, PID, Fuzzy and Fuzzy -PID controllers are used to control the vibrations to give smooth response of the Car suspension system and carry-out their comparison on the basis of time and frequency using Matlab environment.

Keywords: *Car suspension system, Dynamic modeling, PID controller, Fuzzy controller, Fuzzy - PID controller.*

1. INTRODUCTION

Increasing progress in automobile industry demands for Better riding capabilities and passenger comfort, to produce highly developed model. The aim of the advanced car suspension system is to provide smooth ride and maintain the control of the vehicle over cracks, uneven pavement of the road. Moreover, suspension system modeling has an important role for realistic control design of the suspension.

In passive suspension system, spring and diminishing element is placed between the wheel and the car body. They allow the forward compensation between the suspension stroke deviation and the driving comfort. According to the car structural feature, suspension stroke is limited for some specified values. Riding comfort reduces as suspension deviation reached these limited specified values.

In active suspension system, a hydraulic system which is controlled by feedback controller is placed between the wheel and the car body. Controlled suspension system allows forward compensation between the

IJARSE
ISSN: 2319-8354

performance criteria of suspension deviation and the riding comfort . Nowadays, different types of controllers are used to Control the car suspension system such as adaptive control, LQR, nonlinear control, H infinity, P, PI PID and Fuzzy controller . In this paper, PID, FUZZY and FUZZY -PID controllers are designed to control the vibration occurred in car suspension system using SIMULINK/MATLAB .

2. THE CAR SUSPENSION SYSTEM

Car Suspension is the system of springs, shock absorbers and linkages that connects a car to its wheels and allows relative motion between the two. Suspension system serves a dual purpose- contributing to the vehicle's road holding/handling and braking for safety purpose and pleasure driving, and keeping vehicle occupants comfortable and isolated from road noise, bumps, and vibrations, etc.

2.1 Modeling and System Analysis

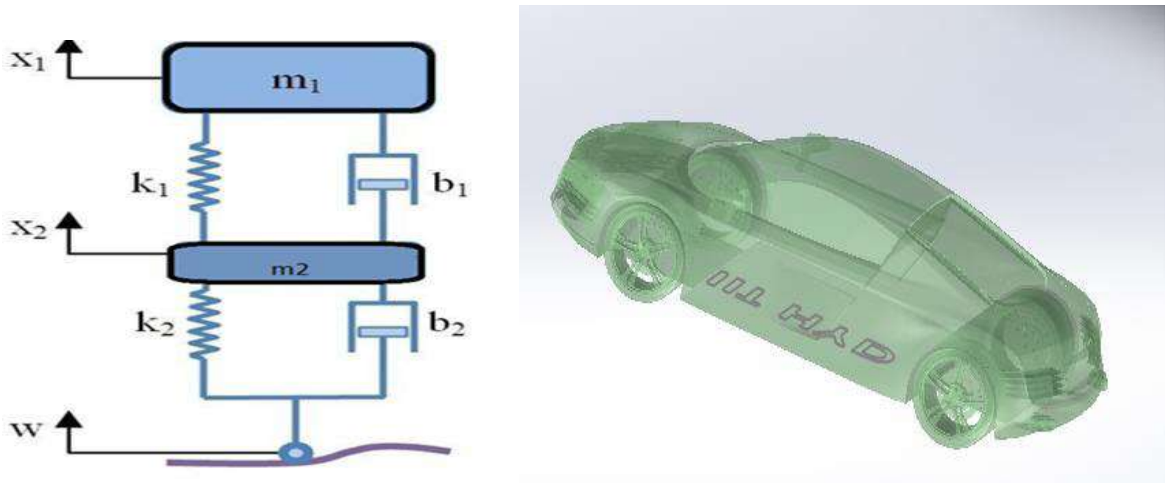

Fig.1: Passive Quarter Car suspension system

2.2 Parameters Of Car Suspension System

- (M1) 1/4 car body mass - 500kg
- (M2) suspension mass - 100 kg
- (K1) spring constant of suspension system-50,000 N/m
- (K2) spring constant of wheel and tire - 500,000 N/m

- (B1) damping constant of suspension system -300 N.s/m
- (B2) damping constant of wheel and tire 13,020 N.s/m
- (U) Control force
- (W) Disturbance

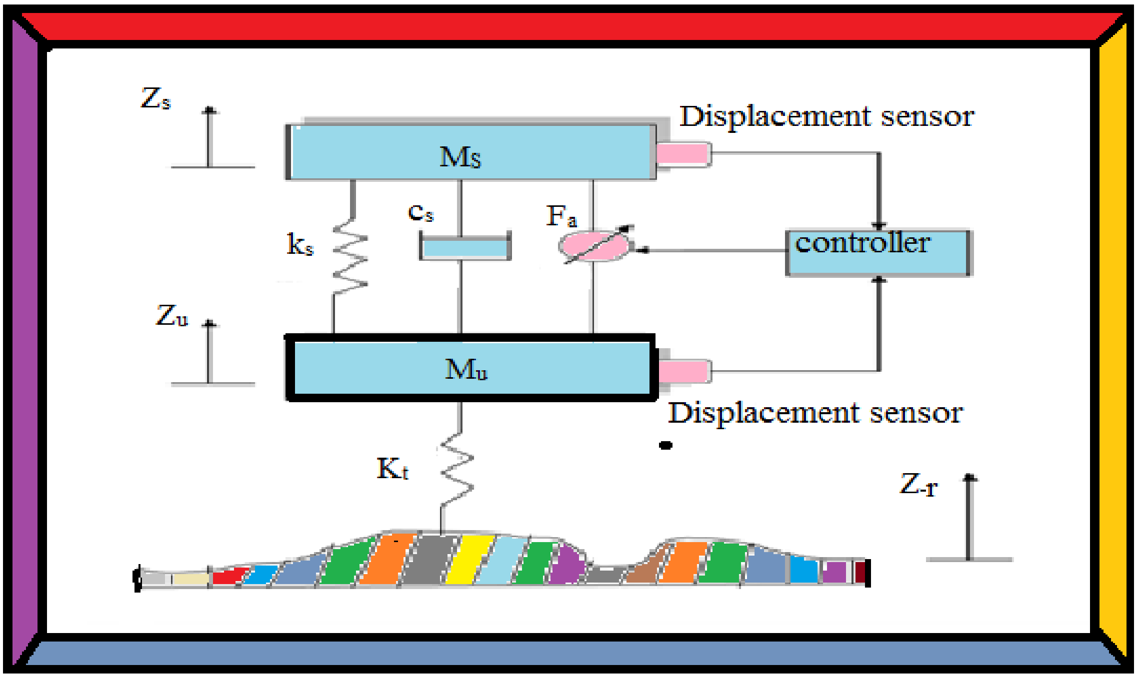

Fig.2: Quarter car semi active suspension model

2.3 Mathematical modelling of suspension system

$$M_1X_1 + K_1(X_1 - X_2) + B_1(X_1 - X_2) = U$$

$$M_2X_2 - K_1(X_1 - X_2) + K_2(X_2 - W) + B_2(X_2 - W) = -U$$

Assuming zero initial condition, Laplace transform gives

$$(M_1s^2 + B_1s + K_1)X_1(s) - (B_1s + K_1)X_2(s) = U(s)$$

$$(B_1s + K_1)X_1(s) + (M_2s^2 + (B_1 + B_2)s + (K_1 + K_2))X_2(s) = (B_2s + K_2)W(s) - U(s)$$

$$\begin{bmatrix} (M_1s^2 + B_1s + K_1) & -(B_1s + K_1) \\ -(B_1s + K_1) & M_2s^2 + (B_1 + B_2)s + (K_1 + K_2) \end{bmatrix} \begin{bmatrix} X_1(s) \\ X_2(s) \end{bmatrix} = \begin{bmatrix} U(s) \\ (B_2s + K_2)W(s) - U(s) \end{bmatrix}$$

Transfer function

$$G_1(s) = \frac{X_1(s) - X_2(s)}{U(s)} = \frac{(M_1 + M_2)s^2 + B_2s + K_2}{\Delta}$$

$$G_2(s) = \frac{X_1(s) - X_2(s)}{W(s)} = \frac{-M_1B_2s^3 - M_1K_2s^2}{\Delta}$$

International Journal of Advance Research in Science and Engineering
Volume No.07, Issue No.05, May 2018
www.ijarse.com
IJARSE
ISSN: 2319-8354

2.4 Simulink Implementation of a car suspension system

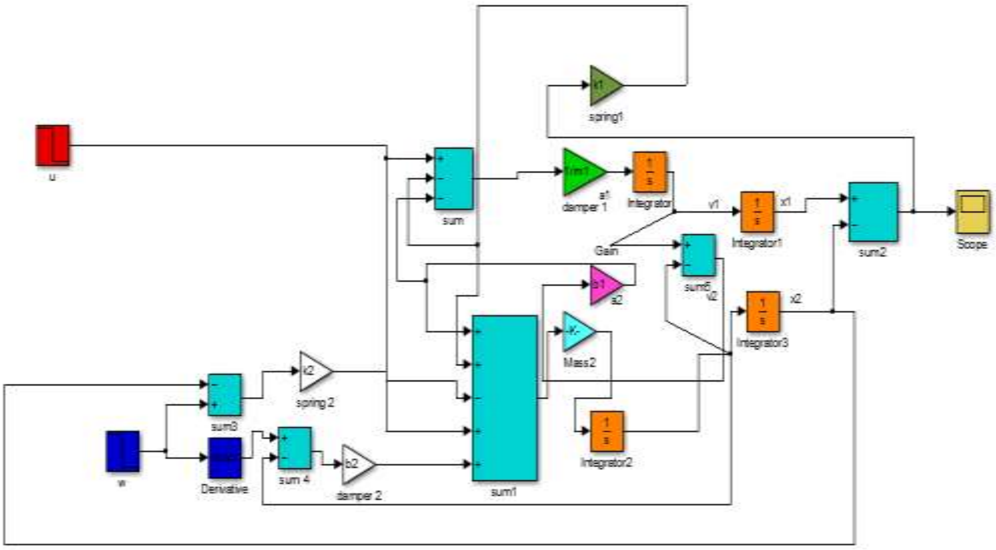

Fig. 3: Simulink Model of Car Suspension System

The car suspension shown in Figure 1 has been implemented in SIMULINK as shown in Figure 3.
The MATLAB/SIMULINK is used to display how the original open-loop system performs without any feedback control. The response of the system to a unit step actuated force input and unit step disturbance input is observed. The road disturbance in this problem will be simulated by a step input. This step could represent the car coming out of a pothole.

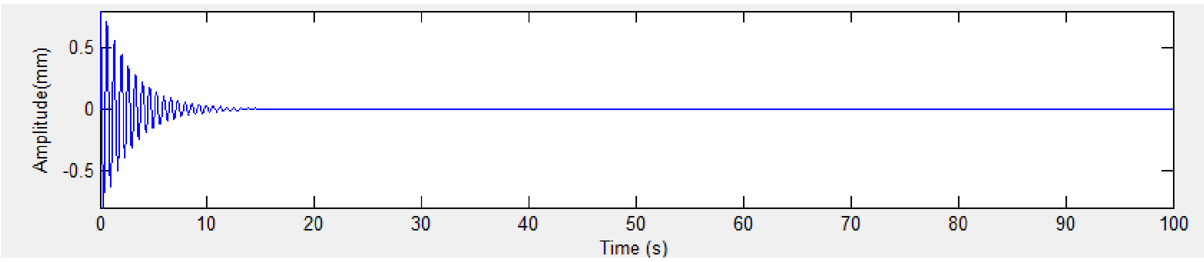

Fig. 4: Amplitude Vs Time Response

IJARSE
ISSN: 2319-8354

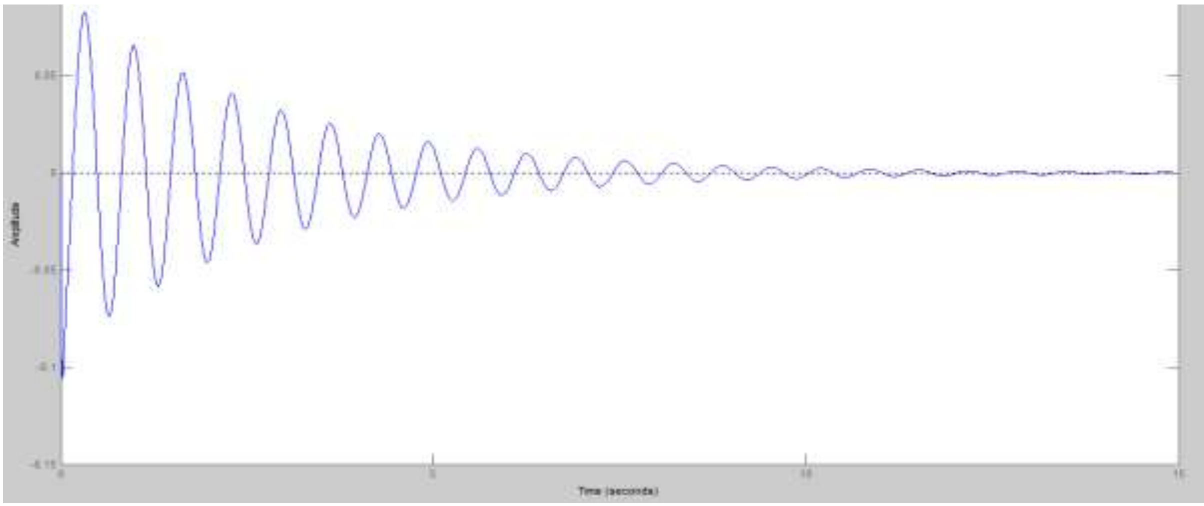

Fig.5: Open –loop step response of disturbance

Now we can see the response for a step disturbance input, W(s), with magnitude 0.1 m. When consider the disturbance input W**(s)** only, set **U(s)** = 0. Thus, observe an Open-Loop response of unit step disturbance force as shown in Fig .5.

It is observed from the open-loop response that for a unit step actuated force; the system is under-damped. The overshoot is about 0.08 and settling time is 14 sec. People sitting in the Car will feel very small amount of oscillation but it takes an unacceptably long time to reach the steady state (the settling time is very large). The solution to this problem is to add a controller into the system to improve the performance.

3. CONTROLLER

A controller is a device, may be in the form of analogue circuit, chip or computer that monitors and physically alters the operating conditions of a given dynamical system. From the past decades, the importance of the control system has been increased due to the increment in complexity of the system under control and to achieve optimum performance of the system. The block diagram of closed-loop Car Suspension System is shown in Fig.6.

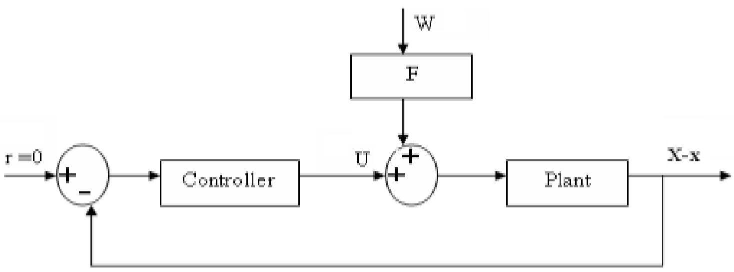

Fig. 6: Closed loop step response of Car Suspension System

International Journal of Advance Research in Science and Engineering
Volume No.07, Issue No.05, May 2018
www.ijarse.com
IJARSE
ISSN: 2319-8354

In this paper, three controllers, Proportional Integral Controller, Fuzzy Controller and Fuzzy PID controller are used to improve the response of the system.

3.1 Proportional-Integral-Derivative Controller

A proportional-integral-derivative controller (PIDcontroller) is a generic control loop feedback mechanism widely used in industrial control systems - a PID is the most commonly used feedback controller.

A PID controller calculates an "error" value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs. In this section, the method to obtain the controller for the car suspension system is described when a PID scheme is used to perform control actions and *C*(*s*) the transfer function of PID controller has a form

$$C(s) = K_P + K_I/S + K_D S \quad (2)$$

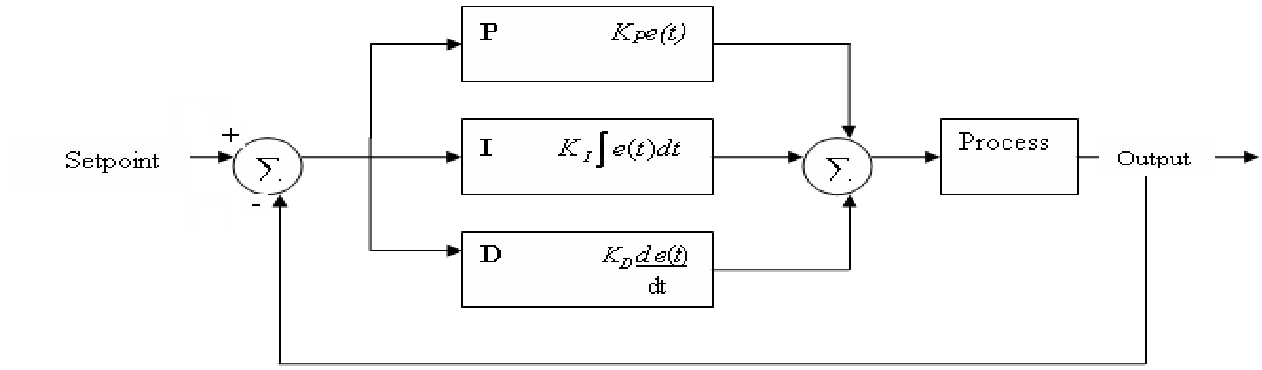

Fig. 7: Block Diagram of PID controller

The PID controller calculation involves three separate parameters, and is accordingly sometimes called three-term control: the proportional, the integral and derivative values, denoted P, I, and D.

The proportional value determines the reaction to the current error, the integral value determines the reaction based on the sum of recent errors, and the derivative error has been changing. The weighted sum of these three actions is used to adjust the process via a control element such as the disturbances of a Car suspension system. Zeigler Nicholas tuning is used for calculation of PID parameters.

3.2 Fuzzy controller

Fuzzy logic is a form of multi – valued logic to deal with reasoning that is approximate rather than precise. This is in contradiction with “crisp logic” that deals with precise values. Also, binary sets have binary or Boolean logic (either 0 or 1), which finds solution to a particular set of problems. Fuzzy logic variables may have a truth value that ranges between 0 and 1 and is not constrained to the two truth values of classic propositional logic.

Fuzzy logic, introduced in the year 1965 by Lotfi A. Zadeh, is a mathematical tool for dealing with uncertainty. Dr. Zadeh states that the principle of complexity and imprecision and correlated: “the close one looks at a real world problem, the fuzzier becomes its solution.” Fuzzy logic offers soft computing paradigm the important concept of computing with the world.

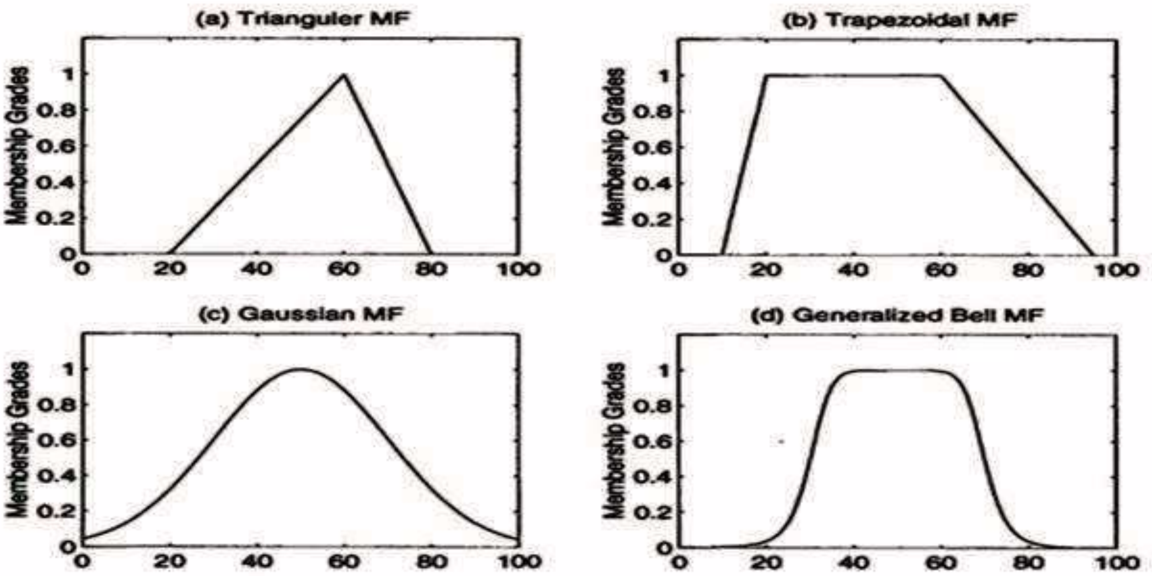

Fig.8. Example of four classes of parameterized MFs (a) triangular (x;20,60,80); (b) trapezoidal(x;10,20,60,80); (c) Gaussian(x;50,20) (d) bell (x;20,4,50)

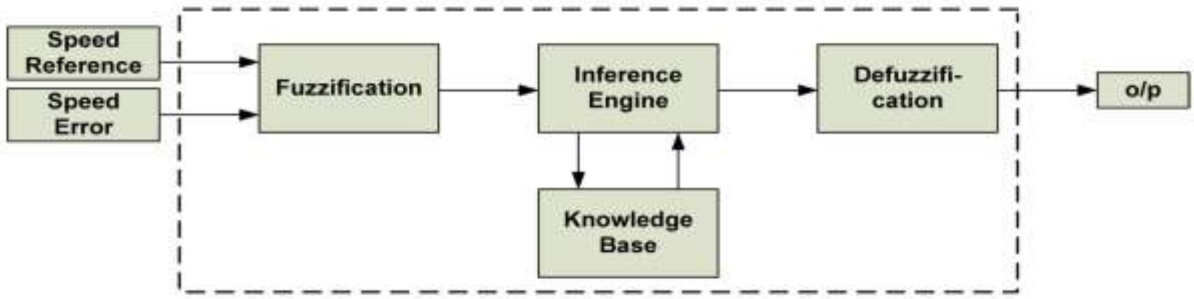

Fig.9. Block diagram for fuzzification and defuzzification in Fuzzy Inference System

4. Design of PID , FUZZY and FUZZY-PID Controller

In this section, PID FUZZY and FUZZY –PID Controllers are applied to the Car Suspension System. To design these Controllers MATLAB/SIMULINK is used.

Substituting all parameters of (2.2) in (2.3), then the steady state model system is obtained as –

$$G_1(s) = \frac{s^2+8s+285}{162s^4+11460s^3+480854s^2+457714s^1+14285714}$$

And the transfer function of the state disturbance input of magnitude 0.1 m is obtained as:

$$G_2(s) = \frac{-s^3-38.40s^2}{0.0145s^4+1.026s^3+43.08s^2+41.01s^1+1280}$$

4.1 Design of PID Controller

The test presented in this section is related to the PID Controller performance for the car suspension system. The main purpose of this implementation is to get the desired response of the system. The Simulink model of the Car Suspension system using PID Controller is shown in Fig. 10

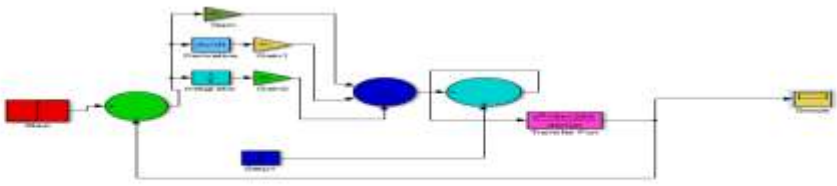

Fig.10. Car Suspension Model with PID Ziegler-Nichols Tuning

The values of K_P and K_I and K_d are 47132, 146146.52 and 50000 respectively are taken. The response of the Car Suspension System using PID Controller is shown in Fig. 11. which depicts that the people sitting in bus feels small amount of oscillations for 5 seconds.

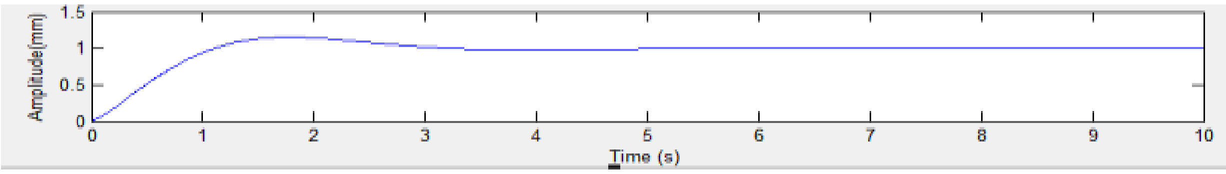

Fig.11: Response of Car Suspension System using PID Controller

4.2 Design Of Fuzzy Controller

Table 1. - Fuzzy Rule set for three membership functions

CE \ E	NE	Z	PE
NE	NV	NV	Z
Z	NV	Z	PV
PE	Z	PV	PV

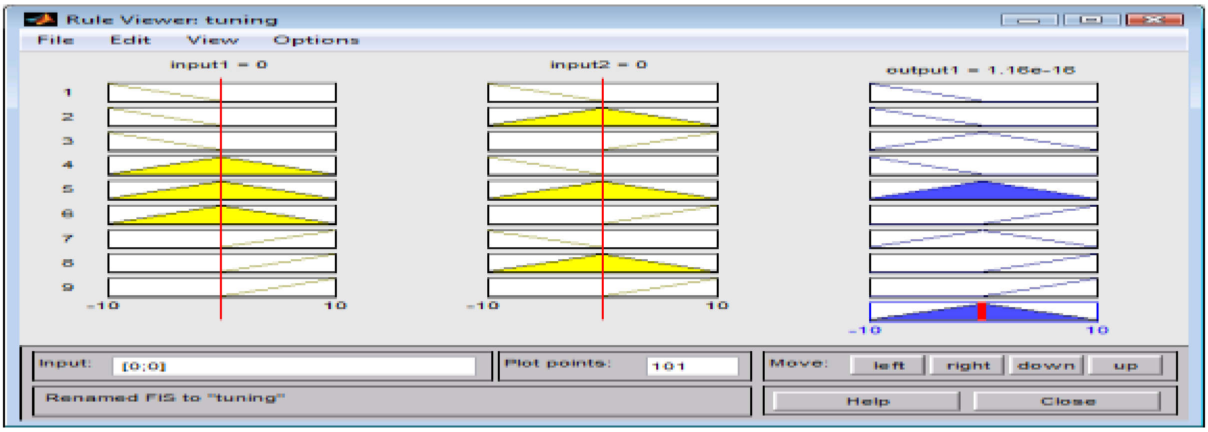

Fig.12. FIS Rule view for three MFs

Where, the values are defined as,

NE- Negative Error \ Change in Error, NV – Negative Value

ZE – Zero Error \ Change in Error, ZV- Zero Value

PE- Positive Error \ Change in Error, PV- Positive Value

These nine rules are as follows:

- 1. If (input1 is NE) and (input2 is NE) then (output1 is NE)
- 2. If (input1 is NE) and (input2 is ZE) then (output1 is NE)
- 3. If (input1 is NE) and (input2 is PE) then (output1 is NE)
- 4. If (input1 is ZE) and (input2 is NE) then (output1 is PE)
- 5. If (input1 is ZE) and (input2 is ZE) then (output1 is ZE)
- 6. If (input1 is ZE) and (input2 is PE) then (output1 is NE)
- 7. If (input1 is PE) and (input2 is NE) then (output1 is PE)
- 8. If (input1 is PE) and (input2 is ZE) then (output1 is PE)
- 9. If (input1 is PE) and (input2 is PE) then (output1 is PE)

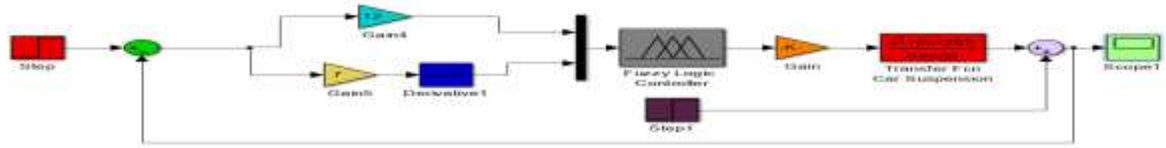

Fig.5.13. Car suspension with Fuzzy controller

- Gain4=12 , Gain5=7 and Gain(k) = 102459.25

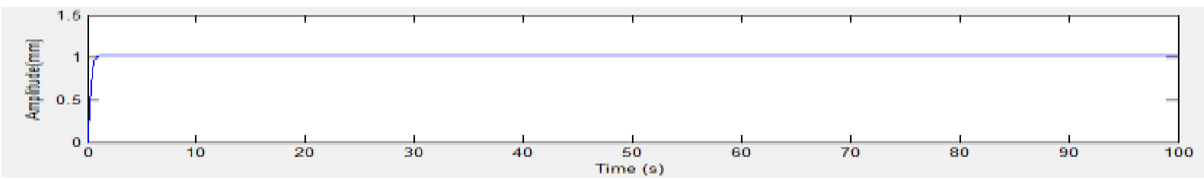

Fig.5.14 Output response of Car suspension with Fuzzy controller

4.2 Design Of Fuzzy- PID Controller

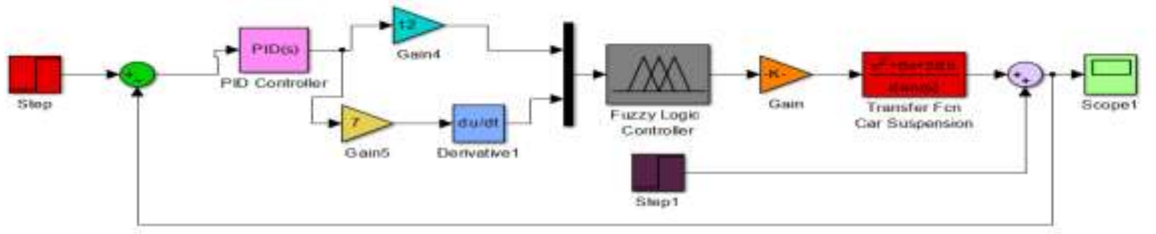

Fig.5.15. Car suspension with Fuzzy PID controller

- Gain4 = 12, Gain 5 = 7 & Gain = 100500 , For PID ($K_P = 40$, $K_I = 1$, $K_D = 10$)

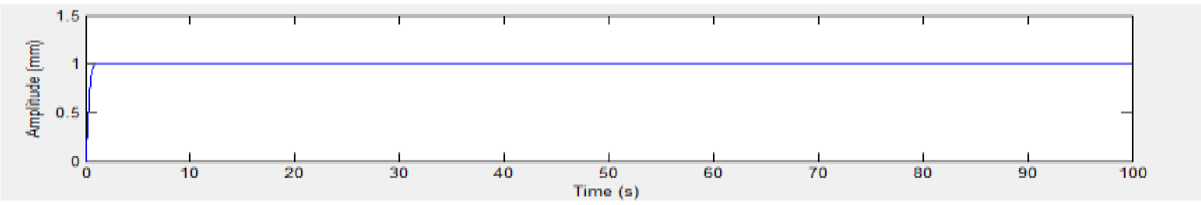

Fig.5.16. Output response of Car suspension with Fuzzy PID controller

Table 2 - Comparison of Different controllers with Open-Loop

Properties	Open-loop	PID	FUZZY	FUZZY-PID
Settling time	14 sec	5 sec	1 sec	1 sec
Rise time	0.256	1.8 sec	1 sec	1 sec
Overshoot	0.8mm	15%	1 %	0 %

5. CONCLUSION

In this Paper, it has been observed that the one dimension car suspension is a highly non – linear system. The mathematical modeling of Car suspension is derived with the help of simple one dimension mass spring damper equation of quarter car model.

Matlab Simulink of quarter CAR Suspension model with conventional and intelligent controllers has been performed. When there is no controller with the suspension system, the system generated an inverse response together with an overshoot and steady state error. But when conventional PID- ZN tuning controller has been implemented with Car Suspension, the problem of inverse response and steady state error are controlled in the above processes, but then showing instability in terms of overshoot and settling time.

Intelligent controllers such as Fuzzy Logic and Fuzzy – PID Controllers are also used with Car Suspension. During the results comparison and analysis it has been observed that the response of Fuzzy –PID controller is better than PID and FUZZY Controllers. Thus, it has been concluded that Fuzzy – PID controller is the best controller for the vibration control in the car suspension system.

REFERENCES

[1] Kuo Y. P. and T. H. S. Li, *“GA-Based Fuzzy PI/PID Controller for Automotive Active Suspension System”*, IEEE Transactions on Industrial Electronics*, vol. 46, pp. 1051–1056,* December 1999.

[2] Zhuang, M. and D. P. Atherton, *“Automatic tuning of optimum PID controllers*,” IEEE Proceeding Part D, *vol. 140, pp. 216-224, 1993*.

[3] Sheilza Aggarwal and Manisha Garg, “*Design and Simulation of PID controller of nanopositioner for minimum integral of error”*, International Journal of Engineering Sciences (ISSN) online*-2277-9698, pp. 127-132, 2012.*

[4] K. Matsumoto, K. Yamashita and M. Suzuki, “ *Fuzzy control of decoupled automobile active suspension system”,* IEEE Transaction on Automatic Controller*, vol. 44, pp.392-396, 1999.*

[5] Elmadany, M., “*Integral and state variable feedback controllers for improved Performance in automotive vehicles”,* Computer Structure., *vol. 42, no. 2, pp. 237-244, 1992*.

[6] Isobe, T. and O. Watanabe, “*New semi-active suspension controller design using quasi-linearlization and frequency shaping*”, Control Eng. Pract., *vol. 6, pp. 1183-1191, 1998.*