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Analysis of Active Suspension System for Nonlinear Half Car Model

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Abstract - Modeling and control of automotive suspension system are highly significant from passenger comfort to road handling. This paper presents an active suspension system for nonlinear half car model using fuzzy logic control system. A shock absorber also called damper is the vital element of the suspension system and typically characterized by the force-velocity curve which is hysteresis and nonlinear in behaviour. Modeling and analysis of quarter car, half car and full car are widely used to understand the dynamics of vehicle. Half car model is devolved by using characteristics of damper, spring, tire stiffness and actuator correspondingly sprung and unsprung mass. The nonlinearity of half car model is contributed by using piecewise linear damper model which are located at front and rear axle of the half car model. For comparison, the response of linear half car model with viscous damping coefficient is also carried out. The modeling and simulation is carried out by using simulink for bump road perturbation. The simulation results show that the active suspension system with fuzzy control, exhibits noteworthy outcomes to the passenger comfort.

Keywords: *Active suspension, Nonlinear half car, piecewise linear damper, fuzzy logic.*

1. INTRODUCTION

Vehicle suspension framework is significantly design and developed for segregating vehicle body from road roughness keeping in mind the end goal to boost the passenger comfort. Passive suspension systems are mostly used in ground vehicles but cannot effectively prevent vehicle vibrations under various road disturbances. Hence it is important to develop the control system to suppress the vibrations of automotive suspension system. Vibration control of vehicle suspension system falls in three categories namely passive, semiactive and active controls [1]. The active controlled suspension systems are more flexible and efficient than other control systems that make active control systems more able to offer road comfort [2-5].

The real suspension system is nonlinear in behaviour. The shock absorber is the key element in the suspension system which is utilized to control the transient conduct of the sprung and unsprung masses of the vehicle [6]. It is also the most complex and nonlinear part of suspension system. In order to characterize the nonlinearities of shock absorber for vehicle suspension systems, several studies have been conducted [7-11]. Wallaschek [7] said that by using experimental data, an equivalent linear model can be model for a real nonlinear system. The author has also stated that if the properties of a shock absorber are identified using the experimental technique then the equivalent linear model can be used for the dynamics of shock absorber. The experimental analysis, dynamical testing and modeling of shock absorber has been carried out by some of the researchers [8-10]. Liu and Zhang [8] carried out the experiment on twin tube hydraulic shock absorber of passenger car and obtained the damping force–velocity curves which are characterized to be hysteretic loop by the MTS absorber test machine by sinusoidal excitation. The author also developed the virtual prototype of the hydraulic shock absorber in the Adams environment. A Calvo et al. [9] analyzed the influence on a vehicle's dynamic behavior due to the shock absorber models and concluded that it is not necessary to depends on hysteresis behavior of shock absorber model for better ride comfort, piecewise linear modeling shock absorber was sufficient to obtain satisfactory result of the simulation of vehicle dynamic.

The objective of this paper is to compare the variation of responses between a linear and piecewise linear damper model for a half car suspension system and also to present a fuzzy logic algorithm to improve the passenger ride comfort for half car model. The nonlinear dampers are employed to a half car vehicle, running on irregular road surfaces where it is subjected to bounce i.e. vertical motion and pitch. The modeling and simulation are carried in simulink environment.

2. NONLINEAR HALF CAR MODELING

Modeling and analysis of quarter car, half car and full car are widely used to understand the dynamics of vehicle [12]. A four degrees-of-freedom half car model of suspension system is shown in Figure 1. Half car model is devolved by using characteristics of damper, spring, tire stiffness and actuator correspondingly sprung and unsprung mass. The equations of motion for the vehicle body for the front and rear wheels are given by;

$$m_s\ddot{x}_s + c_{s1}(\dot{x}_{s1} - \dot{x}_{u1}) + c_{s2}(\dot{x}_{s2} - \dot{x}_{u2}) + k_{s1}(x_{s1} - x_{u1}) + k_{s2}(x_{s2} - x_{u2}) - f_a - f_b = 0 \quad (1)$$

$$J\ddot{\theta} + l_a\{c_{s1}(\dot{x}_{s1} - \dot{x}_{u1}) + k_{s1}(x_{s1} - x_{u1}) - f_a\} + l_b\{c_{s2}(\dot{x}_{s2} - \dot{x}_{u2}) + k_{s2}(x_{s2} - x_{u2}) - f_b\} = 0 \quad (2)$$

$$m_{u1}\ddot{x}_{u1} - c_{s1}(\dot{x}_{s1} - \dot{x}_{u1}) - k_{s1}(x_{s1} - x_{u1}) + k_{t1}(x_{u1} - x_{r1}) + f_a = 0 \quad (3)$$

$$m_{u2}\ddot{x}_{u2} - c_{s2}(\dot{x}_{s2} - \dot{x}_{u2}) - k_{s2}(x_{s2} - x_{u2}) + k_{t2}(x_{u2} - x_{r2}) + f_b = 0 \quad (4)$$

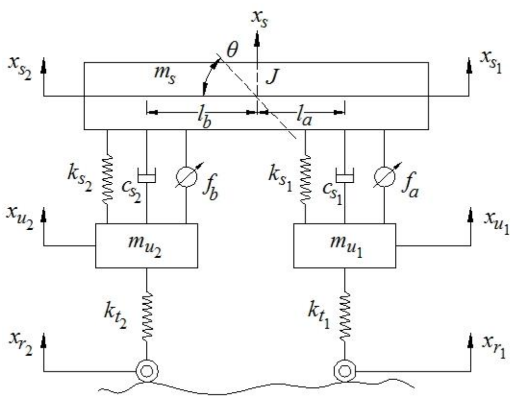

Figure 1. Half car model

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where m_s is the mass for the vehicle body, J is the mass moment of inertia for the vehicle body, m_{s2} and m_{s1} are the masses of the front and rear wheels respectively, c_{s1} and c_{s2} are the damping coefficients of the front and rear suspensions, k_{s1} and k_{s2} are the spring stiffness constant of the front and rear suspensions, f_a and f_b are the active controls at the front and rear suspension, k_{t1} and k_{t2} are the spring constants of the front and rear tires, x_s is the vertical displacement of the vehicle body at the centre of gravity, θ is the rotary angle of the vehicle body at the centre of gravity, x_{s1} and x_{s2} are the vertical displacements of the vehicle body at the front/rear suspension locations, x_{u1} *and* x_{u2} are the vertical displacements of the front and rear sprung and unsprung masses, x_{r1} and x_{r2} the irregular excitations from the road surface, and l_a and l_b the distances of the front and rear suspension locations, with reference to the centre of gravity of the vehicle body. The damping characteristics of shock absorber c_{s1} and c_{s2} assumed to be expressed by piecewise linear functions.

2.1 Damper Model

In order to provide the damping in the suspension system, the shock absorber dissipates energy in the compression stroke (jounce) and extension stroke (bounce) whenever a vehicle moved over a bump on a road. Hence for the choice of the shock absorber model, On the basis of the piecewise bilinear model proposed by Calvo et al. [9] the equation (3) and (4) are selected for the mathematical representation of the force-velocity relation for the compression and rebound region.

For rebound

$$f = \begin{cases} 3030\, v, & 0\ m/s \le v < 0.2\ m/s \\ 1303\, v, & v \ge 0.2\ m/s \end{cases} \quad (3)$$

And, for compression

$$f = \begin{cases} 1760\, v, & -0.2\ m/s \le v < 0\ m/s \\ 855\, v, & v < -0.2\ m/s \end{cases} \quad (4)$$

In order to compare the response of nonlinear half car model with linear model, a constant damping coefficient is also used and analysed the half car suspension system with road perturbation. The important vehicle parameters used for the quarter car simulation are listed along with their numerical values in Table 1.

Table 1. Half car suspension parameter

Parameter	Values	Unit
Sprung mass of vehicle (m_s)	550	*Kg*
Moment of inertia (J)	630	*Kgm*^{2}
Unsprung mass of front/rear axle (x_{u1}/ x_{u2})	40	*Kg*
Spring constant of front/rear axle (x_{s1} / x_{s2})	16800	*N/m*
Stiffness of the front/rear tire material (k_{t1} / k_{t2})	190	*KN/m*
Front body length from C.G. (l_a)	1.32	*m*

Rear body length from C.G. (l_b)	1.42	*m*

2.2. Road Profile

In the simulation study, the road profile needs to be expressed in terms of mathematical equations and the road input to excite the quarter car models set in the form shown below (equation 5).

The following road disturbance profile used by Conde et al. [13] has been used.

$$x_r = \begin{cases} \frac{a(1-\cos(8\pi t))}{2} & if\ 0.50 \le t \le 0.75 \\ & 3.00 \le t \le 3.25 \\ & 0\ otherwise \end{cases}$$

(5)

where, *a* denotes maximum bump amplitude which is set to be 11 cm for $0.5 \le t \le 0.75$ and 5.5 cm for $3.00 \le t \le 3.25$.

3. ACTIVE FUZZY CONTROL

The fuzzy logic control (FLC) is proposed in this paper to design a nonlinear half car model with active suspension system. The control system consists of three stages; fuzzification, fuzzy inference engine and defuzzification as shown in figure 2.

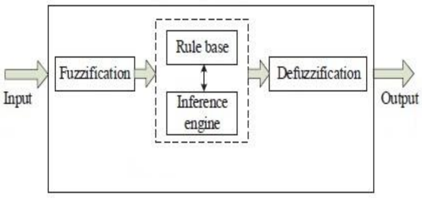

Figure 2. Fuzzy control system

The fuzzification stage converts real-number (crisp) input values into fuzzy values, while the fuzzy inference machine processes the input data and computes the controller outputs in cope with the rule base and data base. These outputs, which are fuzzy values, are converted into real-numbers by the defuzzification stage. The FLC used in the active suspension has two inputs that are body velocity and suspension deflection, and one output which is desired actuator force. A triangular type is the probable preference of the membership functions for the three mentioned variables of the active suspension system. The rule base parameters for control system are as shown in Table 2.

Table 2: Rule base

		Suspension deflection				
		NS	NB	ZE	PS	PL
Velocity	NB	PL	PL	PS	PS	ZE
	NS	PL	PS	PS	ZE	NS
	ZE	PS	PS	ZE	NS	NS
	PS	PS	ZE	NS	NS	NB
	PL	ZE	NS	NS	NB	NB
Control Force						

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4. MODELING AND SIMULATION

It is widely known that Simulink has been used for linear and nonlinear modeling of dynamic system and subsequently capture their dynamic responses. The half car modeling for passive (linear), passive (nonlinear) and active suspension system is carried by using simulink to compare the performances of vehicle for bump road disturbances. The simulation is carried out to plot the front and rear axle displacement, vehicle body (sprung mass) displacement and sprung mass rotational displacement vehicle suspension system by using half car model. Figure 3 shows Simulink modelimg for nonlinear half car model.

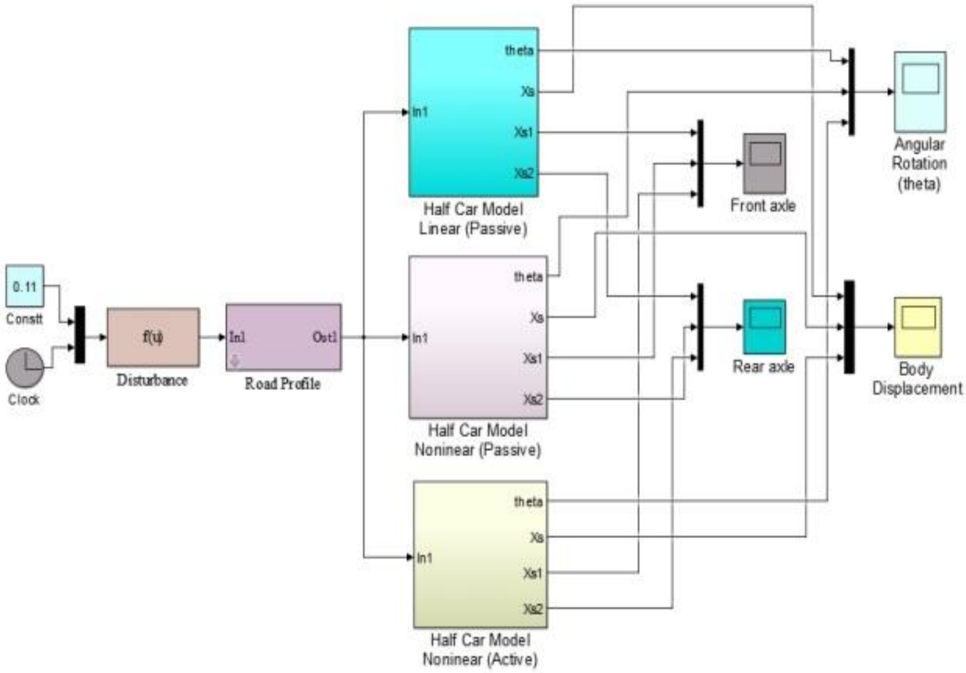

Figure 3. Simulink modelling for linear/nonlinear half car model

5. RESULTS AND DISCUSSION

In this paper, performances of passive suspension system by incorporating linear and nonlinear characteristics of damper in to suspension with constant spring stiffness and active suspension system for nonlinear characteristics of damper are compared. The active suspension system is developed by using for Fuzzy logic controller. The simulation results for body displacement and sprung mass rotational displacement are shown in Figure 4 and Figure 5 respectively. Maximum peak amplitude (overshoot) and settling time are the parameter used to establish the efficacy of the model. From Figure 4, which shows the response of vertical displacement of vehicle body, it can be seen that the maximum amplitude occurred at the maximum height of the road perturbation for all the models. The overshoot for the active suspension is reduced to 0.024 m as compare to passive (linear) 0.044 and passive (nonlinear) 0.038 m, it is also worth to note that the settling time is reduced for the active suspension model. Figure 5 shows the response of the angular rotation of the sprung mass (angle of tilt of the car due to road bump), in this case also the active suspension using fuzzy logic control shows that that there is an improvement in the ride-comfort, however the response shows undershoot instead of overshoot.

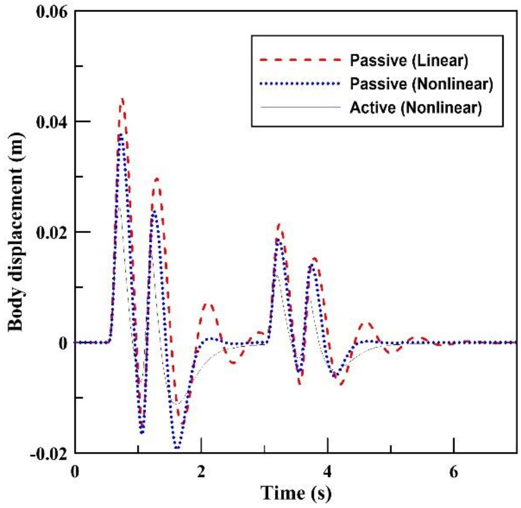

Figure 4. Vehicle body displacement

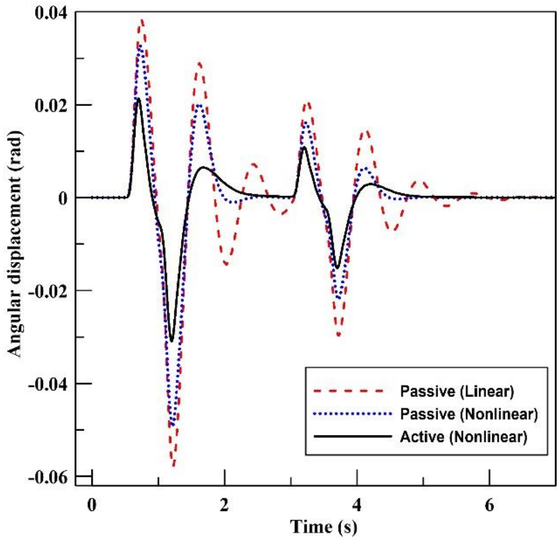

Figure 5. Angular rotation of sprung mass

The response variation of front axle displacement and rear axle displacement are as shown in Figure 6 and Figure 7 respectively. These results are also shown better passenger comfort or less vibration of vehicle as compare to passive suspension for active suspension system.

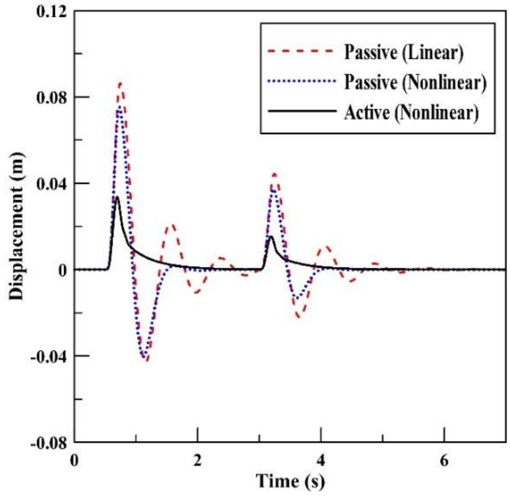

Figure 6. Front axle displacement

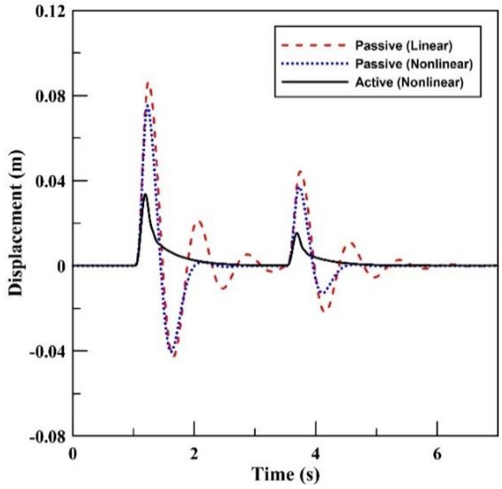

Figure 7. Rear axle displacement

From the simulated results of half car passive suspension system for linear and nonlinear damper model, it seems that, the linear model (using constant damping coefficient) not able to capture the actual performance of vehicle suspension system. Hence it is important to consider the nonlinear characteristics of damper to understand the dynamics of vehicle.

6. Conclusion

In this paper, the modeling and simulation of half car model for active suspension using fuzzy logic control system is carried out. In order to consider the nonlinearity in the system, the piecewise linear characteristics of damper is incorporated in the suspension along with constant spring stiffness. The simulation results show that, the performance characteristics of vehicle suspension using proposed fuzzy logic controller improved the road comfort to the passengers as compare to passive suspension. The ride quality of suspension system enhances by minimizing the vertical body displacement and angular rotation of the sprung mass (vehicle body). According to simulation results, the proposed active suspension system can be better option to control the vehicle vibration and to provide the stability to the vehicle over the passive suspension system. It is also observed that to study the dynamics of vehicle, it is important to consider the nonlinear characteristics of the key elements like damper.

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