PID Controller Design for Semi-Active Car Suspension Based on Model from Intelligent System Identification

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Abstract-**This paper presents a new method to design a semi-active suspension system. A semi-active suspension is developed by installing a variable shock absorber parallel with the passive suspension system and controlled using PID controller. A high fidelity mathematical model for capturing the realistic dynamic of car passive suspension system for the basic element of the semi-active suspension system is determined using the intelligent system identification. The car passive suspension system is assumed to have NARX model. The result shows that the response of the semi-active suspension system can follow the input signal, it means the PID controller is successfully control the variable shock absorber in order eliminate the road surface disturbances effect to the car body.**

Keyword-**PID controller; semi-active suspension system, intelligent system identification**

I. INTRODUCTION

A vehicle suspension system performs two major tasks. It should isolate the vehicle body from external road disturbances for the sake of passenger comfort and control the vehicle body attitude and maintain a firm contact between the road and the tyre to provide guidance along the track. A Basic automobile suspension that is known as a passive suspension system consists of an energy storing element normally a spring and an energy dissipating element normally a shock absorber [1].

The main weakness of the passive suspension is that it is unable to improve both ride comfort and safety factor simultaneously. In the passive suspension system, there is always trade-off between vehicle ride comfort and safety factor [1,2]. To improve the ride comfort, the safety factor must be sacrificed, and vice versa. One way to overcome such a problem, the car suspension system must be controlled.

To design and analyze the car suspension system controller, thus the high fidelity mathematical model for capturing the realistic dynamic of a car suspension system is necessary [3,4].

As in [4,5,6,7], the best way to determine the high fidelity mathematical model of the system is by using system identification. The successful applications of neural networks contribute to the widely use of it in field of system identification as the intelligent system identification [8,9].

In this paper, a semi-active suspension system is proposed [10,11,12,13]. The semi-active suspension system is developed based on the passive suspension system. A variable shock absorber is installed parallel with the passive suspension. This shock absorber is controlled by PID controller.

The PID controller has a function to adjust the damping coefficient of the variable shock absorber in order to keep the car body always stable. Adjustable process is based on the characteristic of the road surface.

II. NARX MODEL OF THE QUARTER CAR PASSIVE SUSPENSION SYSTEM

The Nonlinear AutoRegressive with eXogenous input (NARX) model of the quarter car passive suspension system derived from the intelligent system identification has polynomial order of $n_a = 5$ and $n_b = 7$ [14]. Where, equation (1) and (2) show the vehicle body vertical displacement and vehicle axle vertical displacement respectively.

$$\begin{aligned} &Z_s(kT) = f(Z_s((k-1)T),\cdots,\\ &Z_s((k-5)T),\ Y((k-1)T),\cdots,\\ &Y((k-7)T)) \end{aligned} \tag{1}$$

$$\begin{aligned} &Z_{us}(kT) = f(Z_{us}((k-1)T),\cdots,\\ &Z_{us}((k-5)T), Z_o((k-1)T),\cdots,\\ &Z_o((k-7)T),\ Y((k-1)T),\cdots,\\ &Y((k-7)T) \end{aligned} \tag{2}$$

where, Z_s is the sprung mass position, Z_{us} is the unsprung mass position, Z_o is the road surface elevation as the input variable, f is a nonlinear function, T is sampling time and $k = 1,2,\cdots$.

Equation (3) represents the suspension displacement (Y) and is chosen to be the output variable.

$$Y(kT) = f(Z_s(kT), Z_{us}(kT)) \tag{3}$$

The nonlinear function of the model is written as

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$$f(x) = C\left(e^{c.x} / 1 + e^{c.x} - 0.5\right) \quad (4)$$

III. THE SEMI ACTIVE CAR SUSPENSION SYSTEM PID CONTROLLER DESIGN

Fig. 1 shows the physical model of the semi active car suspension system. The variable shock absorber (C_c) is installed parallel with the original suspension system. The suspension and tire system are represented by a spring and a damping component respectively.

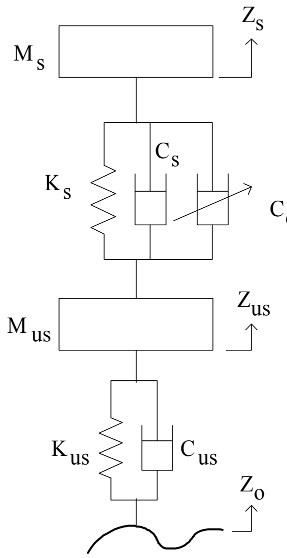

Figure 1. Semi active car suspension system physical model

Where: M_s is the sprung mass, M_{us} is the unsprung mass, K_s is the suspension spring element, C_s is the suspension damping element, C_c is the damping element of the variable shock absorber, K_{us} is the tire spring element, C_{us} is the tire damping element. Z_s, Z_{us} and Z_o are the sprung mass position, the unsprung mass position and road surface elevation respectively.

The variable damper has a function to supply force to the suspension system or absorb force from suspension system in order to keep the car body always stable related to the type of the road surface hit by the car. This process is realized by controlling the damping coefficient of the variable damper. The PID controller was applied since it is one type of widely used controller [15].

The PID controller is the most common form of feedback. PID controllers are today found in all areas where a control is used. Their useful functions are sufficient for a large number of process applications and the transparency of the features leads to wide acceptance by the users. On the other hand, it can be shown that the internal model control (IMC) framework leads to PID controllers for virtually all models common in practice [15,16]. PID control is an important ingredient of a distributed control system.

The PID algorithm is described by:

$$u(t) = K(e(t) + 1/T_i \int_0^t e(\tau)d\tau + T_d de(t)/dt \quad (5)$$

Where, y is the measured process variable, r is the reference variable, u is the control signal and e is the control error $(e = y_{sp} - y)$. The reference variable is often called the set point (y_{sp}).

The control signal is thus a sum of three terms: the P-term (which is proportional to the error), the I-term (which is proportional to the integral of the error), and the D-term (which is proportional to the derivative of the error). The controller parameters are proportional gain K, integral time T_i, and derivative time T_d. In general form the PID algorithm can be represented by the transfer function below:

$$G(s) = K(1 + 1/sT_i + sT_d / \alpha sT_d + 1 \quad (6)$$

where α typically takes a value of 1/10. This type of controller is called interacting controller and it is easier to be tune manually [15]. Fig. 2 shows the block of the PID controller related to equation (6).

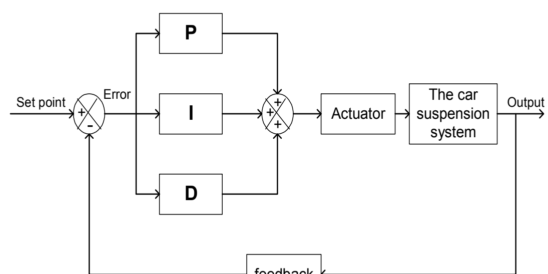

Figure 2. Block of the quarter car PID controller

IV. SIMULATION RESULTS

Simulation for PID controller of the semi-active car suspension model is done by using Matlab Simulink. The input signal type is a step signal as an imitation of bump type of real road surface. Three types controller are applied, they are PID, PI and PD. The response of each controller is compared in order to decide which one the suitable controller for a semi-active car suspension system. The Matlab Simulink block for the control system is shown in Fig.3 below.

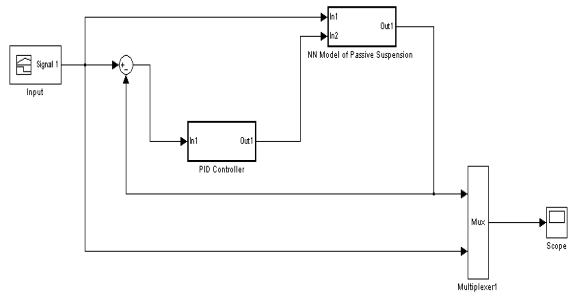

Figure 3. The quarter car PID control Simulink block

Fig. 4 is the response of the quarter car passive suspension system to step type of road surface input. The upper line curve is the step signal and the lower curve is the quarter car response. This figure also shows that the car suspension can not reduce the vibration, as the response does not follow the input signal.

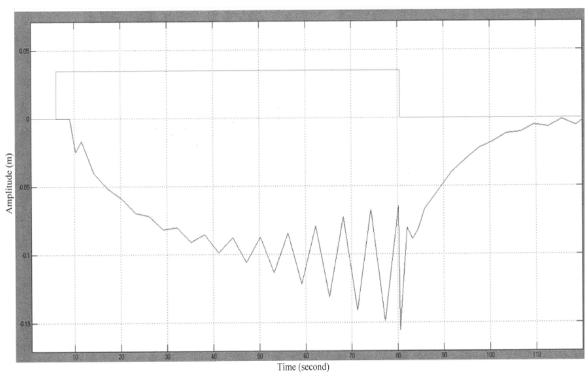

Figure 4. Suspension deflection response to step type of road surface without controller

Fig. 5 represents the semi-active car suspension system with PID controller to step type of road surface input.

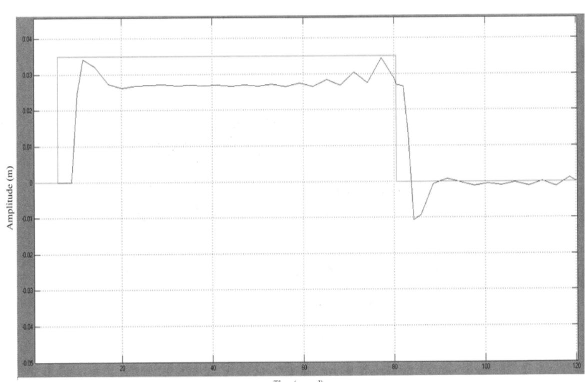

Figure 5. The semi-active suspension deflection response to step type of road surface under PID control

Fig. 6 represents the semi-active car suspension system with PI controller to step type of road surface input.

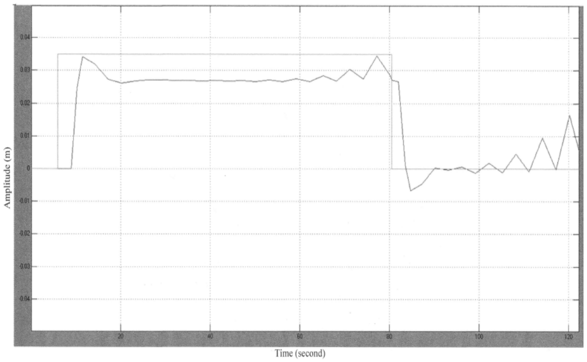

Figure 6. The semi-active suspension deflection response to step type of road surface under PI controller

Fig. 7 represents the semi-active car suspension system with PD controller to step type of road surface input.

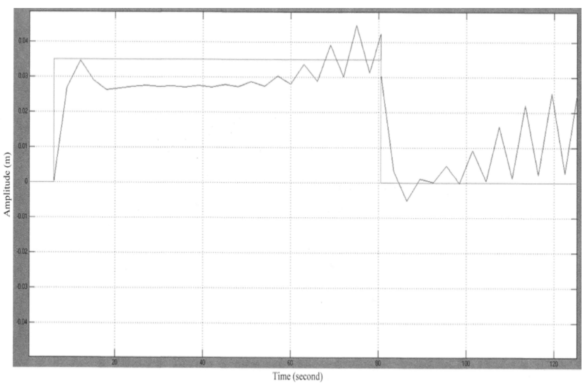

Figure 7. The semi-active suspension deflection response to step type of road surface under PD controller

Fig. 5, 6 and 7 below show the response of the quarter car semi-active suspension system to the step type of road surface under PID, PI and PD controller respectively. The system responses with PID controller have good performance than the others. The PID controller successfully reduce the bump effect to the car body position while car hits bump and also after bump. On the other hand, PI and PD controller are not able to eliminate it.

Parameters of each type controller are shown in table 1 below.

TABLE 1. CONTROLLER PARAMETER

		Type of Controller		
		PID	PI	PD
Parameter	K_p	0.1211	2.970	0.00001
	T_i	0.0980	0.105	∞
	T_d	0.1200	0	0.0000001

Based on Fig. 7 and table 1 above, PD controller has no more challenge to implement in this system. PD controller has very small amount of parameters and bad performance responses.

V. CONCLUSION

In this paper, the semi-active car suspension system has been successfully controlled by using PID Controller. The PID controller is able to controller the variable damper which is indicated by the car suspension system response can exactly follow the input trend. Therefore, the PID controller can said as one kind of suitable control for semi-active car suspension system in practical implementation.

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