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Sliding Mode Control of Vehicle Suspension System Under Different Road Conditions

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Abstract- Technological development in the automotive sector caused to comfort and security problems that was an important topic for engineering studies. Many vibrations sourced from external factors that occur, these vibrations adversely affect the vehicle's internal dynamics, comfort and safety. To better damp these vibrations, controllers are required for suspensions. In this study, the mathematical model of the quarter vehicle suspension system is modeled by SIMULINK toolbox of MATLAB. Then, the system has been combined with proportional–integral–derivative controller (PID) and sliding mode control (SMC). After applying roads disturbance as inputs to the controllers, the performance of system is compared with uncontrolled system.

Keywords PID, sliding mode control, suspension, MATLAB, Simulink

1. Introduction

Increased efforts improving the comfort and safety systems besides minimum fuel consumption at maximum efficiency with technology constantly evolving and changing. In case of any kind of load and driving (braking, acceleration, high-speed cornering) react to wishes very quickly and better road holding, security and comfort are only possible thanks to an improved suspension system. When the vehicle is exposed to road roughness, it should not cause high amplitude oscillations and if this occurs they must be absorbed away in the shortest time. Suspension system provides better driving comfort and safety besides moves the vehicle body and transmits all effects originated from road. Better driving safely is provided by vehicle suspension system has been designed properly and aligned with the vehicle movement.

Variation of tire load is a display for road contact and can be used to specify a quantitative value for safety. Driving comfort is a related surface irregularity, aerodynamic forces, motor vibrations produced by motor and transmission vibrations. The acceleration of the body is a clear criterion for the motion and vibration of the car body

Studies performed in the literature in this area showed that various control Strategies have been used to be able to do a better dumping such as PID controller, Skyhook control, Fuzzy Logic Control, H_∞ control, adaptive control systems [1]. Andronic Florin et al.[2]created mathematical models for suspension system and has developed a block diagram in Matlab Simulink that provides analysing the suspension responses.

Darus and Enzai [3] in 2010 examines quarter vehicle suspension performance using Linear Quadratic Regulator (LQR) and Proportional Derivative Integral control (PID).

Daniel Fischer et al [4] derived the mathematical models for suspensions with variable dampers and springs as well as active components for fault detection and diagnosis of the damper by combining parameter estimation and parity equation methods. the neural network based robust control was designed to control the vehicle unwanted vibration and then compared to PID controller performance by Ikbal Eski et al. [5].

A hybrid control technique was performed to the quarter vehicle suspension model using skyhook and adaptive neuro active force control by G.Priyandoko et al. [6].

A robust control scheme and a linear mathematical model for the quarter vehicle under a bad road profile was presented besides a sliding mode controller was designed to prevent changes in the body of the vehicle by Ervin Alvarez-Sanchez [7]. An active suspension system was developed for the quarter-vehicle model and applying a PID controller to improve its performance by Mouleeswaran Senthil Kumar [8]. P.E. Uys et al. [9] report on on damper settings to provide the best comfort at different road conditions and speeds. Daniel A. Mantaras at el. [10] examined the kinematic behavior of a McPherson-type steering suspension, he presented a three-dimensional model and determined the angle of the wheel, camber and steering that affected the vehicle's transport in the operation of the system's operational factors.

There are many researches about the active suspension control have been performed. In a paper, adaptive sliding mode control was researched with sliding mode and fuzzy approached. Simulation results show that the effectiveness of the proposed control scheme for a half vehicle active suspension model [11]. An adaptive backstepping control method is used in another study to improve the ride comfort under the parameter uncertainties, different damping rates and extension movements [12]. In another research, a recursive derivative non-singular higher order sliding mode control algorithm is used for quarter suspension of vehicle to improve the performance of suspension [13]. A research about to control of a suspension system is performed to obtain a good trade-off between ride quality and road holding and results show the effectiveness of the determined method [14]. In another study, an enhanced adaptive self-organizing fuzzy sliding mode controller was developed for the active suspension systems and an experimental work was performed [15]. Similar researches are performed to obtain better drive performance, stability and road grip [16-19].

In this study, it is determined how the uncontrolled suspension systems absorbed road input and then, the same road input is used for PID controller and the SMC controller based suspension system hence the performance of three cases is compared at different road condition. As a result, the performances of PID and SMC are illustrated and discussed.

2. Suspension Systems and Oscillations Occurring in The Vehicle

Forces originating from the road surface are transmitted to the chassis that damages the driver and passengers, and the mechanical structures are affected the forces of the fatigue load in such a way as to damage [20].

Vehicle is passes over bumps and potholes on the road, suspension system should provide comfort and should be satisfactory in terms of road-holding capability. Against discomfort on the road (Eg holes, cracks, uneven asphalt) vehicle mass should not make wide swings and these swings should be eliminated as soon as possible.

Fig. 1. Overview on the vehicle suspension system.

Wobble

According to center of gravity, the vehicle’s front and rear are moving up and down. This wobble in particular, occur where used on gravel rough and very potholed roads.

Rolling

A spring on the side of the vehicle shortened other starts elongation when the vehicle rotates or moves on the rough road. As a result of this vehicle body from one side to the other side make lateral movements.

Bounding

It is completely up and down movement of vehicle. It occurs when vehicle is used at high speeds on uneven roads. Soft spring cause to increase the bounce.

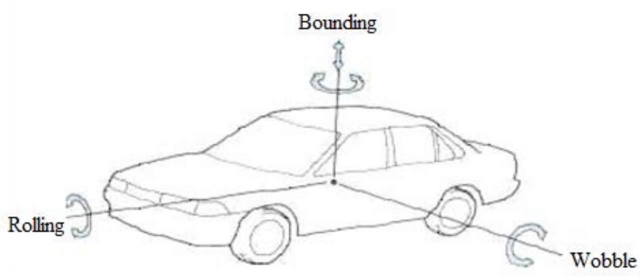

Fig. 2. Oscillations occurring in the vehicle

3. Control Algorithms

When quarter car suspension system that is a wheel of the vehicle is designed in this study, it has been recognized as a one dimensional spring-damper system. As shown in Fig.1, there is an active suspension system by the use quarter model with two degrees of independence. Undoubtedly, model is among the best efficient models for evaluating the suspension system and is presented grounded on model of wheel. Linear equations for suspension system are shown by Eq.1 and Eq.2.

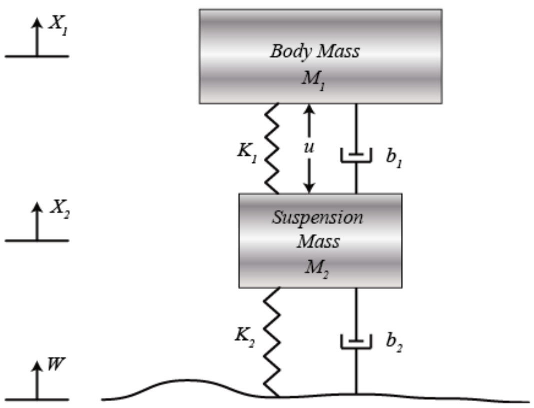

Fig. 3. Quarter car model

System parameters

(M_1) The main mass 300 kg

(M_2) The suspension mass 80 kg

(K_1) Spring constant of the suspension system 16,000 N/m

(K_2) The spring constant of the wheel 170,000 N/m

(b_1) Damping constant of the suspension system 600 N.s/m

(b_2) The damping constant of wheel 150,000 N.s/m

Motion equations from the Newton's laws:

$$M_1\ddot{X}_1 = -b_1(\dot{X}_1 - \dot{X}_2) - K_1(X_1 - X_2) + U \quad (1)$$

$$M_2\ddot{X}_2 = b_1(\dot{X}_1 - \dot{X}_2) + K_1(X_1 - X_2) + b_2(\dot{W} - \dot{X}_2) + K_2(W - X_2) - U \quad (2)$$

For solving this equation, we used Matlab Similunk software and firstly create simulink blok diagram. The behavior of the quarter vehicle suspension system was analyzed using input parameters.

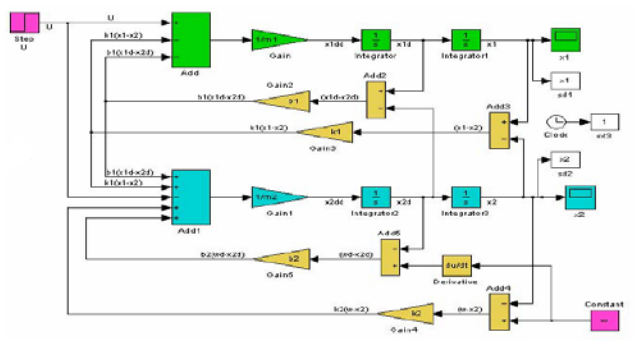

Fig. 4. Matlab Simulink blok diagram

Given the input parameters that we run the program and the graphical representations of the system of equation, we can calculate the mass movements of the vehicle and its suspension.

3.1. PID Controller Design

A proportional-integral-derivative (PID) controller is a generic control loop feedback mechanism. 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. The PID controller algorithm involves three separate constant parameters, and is accordingly sometimes called three-term control the proportional, the integral and derivative values, denoted P,I, and D. Simply put, these values can be interpreted in terms of time, P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve or a damper. Where; Kp: Tuning parameter of proportional gain, Ki: Tuning parameter of integral gain, and Kd: Tuning parameter of derivative gain.

The tuning of control parameters is performed by using Ziegler-Nichols method. Here, Kp=79800;Kp=Kmak*0.6, Ki= =0.1470588 ,Kd= 0.0367647

$$fa = Kp + Ki\int_0^t e(t)dt + Kd\frac{de(t)}{dt} \quad (3)$$

Where fa=Actuator force

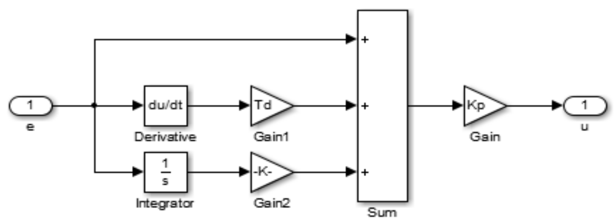

Fig. 5. Simulink block diagram of PID

3.2. Sliding Mode Controller Design

In this study, the sliding-mode control theory is adopted to design the controllers because of its robustness [21]. The sliding-mode index S slide is defined as:

$$S_{slide} = E_{slip} + \lambda\dot{E}_{slip} \quad (4)$$

Where $E_{slip} = S^* - S$, S^* the target slip and λ is a strictly positive constant. $\dot{E}$ slip is the derivative of E_{slip}:

$$\dot{E} = \frac{dE_{slip}}{dt} \backsim \frac{E_{slip}(k+1) - E_{slip}(k)}{t_s} \quad (5)$$

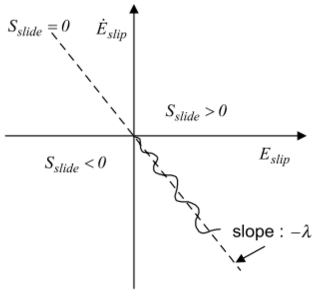

Fig. 5. Phase-plane of SMC phenomenon [12]

Where; t_s is the sampling time. In Fig.5 , the sliding surface S_{slide} =0 separates the phase plane into two semi-planes: one is $S_{slide} > 0$ and the other is $S_{slide} < 0$. Initially, sliding-mode switching control laws are adopted in the design of the controller, which give rise to discontinuous control signals and, as a consequence, chattering. In general, smoothing out the control discontinuity in a thin boundary neighboring the sliding surface can eliminate chattering.

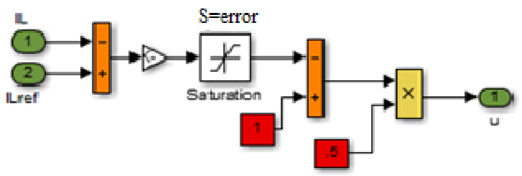

Fig. 6. Simulink block diagram of SMC

4. Results and Discussion

The system has been simulated by using MATLAB and Simulink, PID controller and SMC.

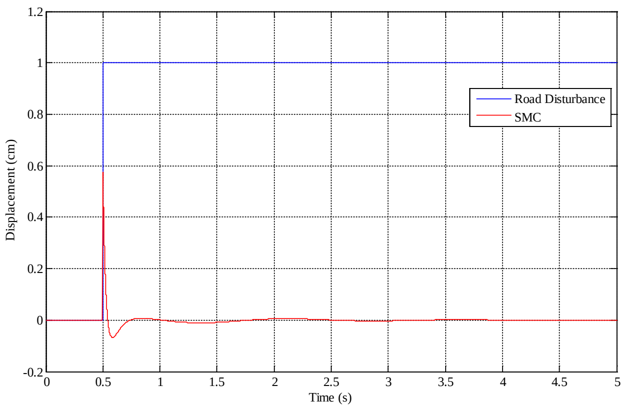

Fig. 7. Constant road input

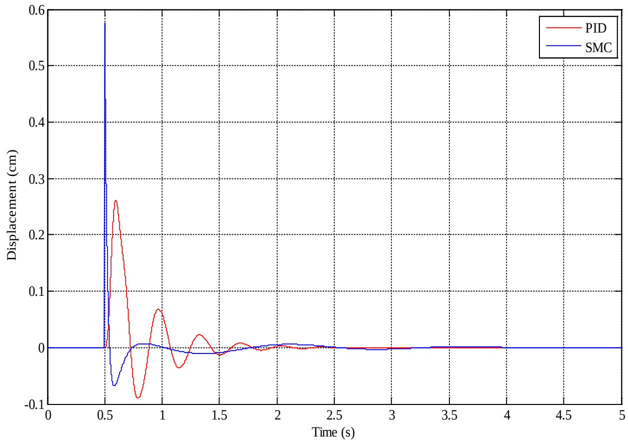

Fig. 8. The response of the suspension system with PID and SMC control

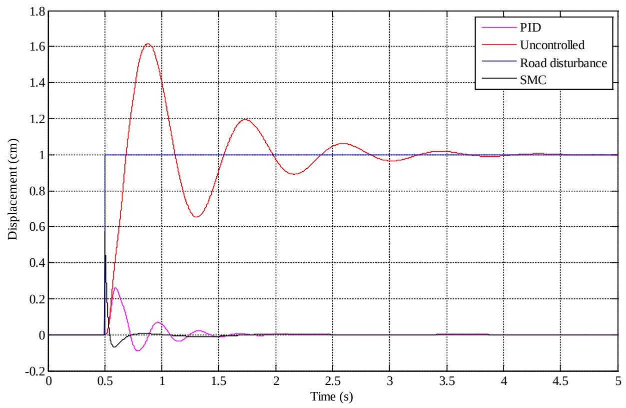

Fig. 9. The response of the uncontroled suspension system and equiped with PID and SMC control under constant road input

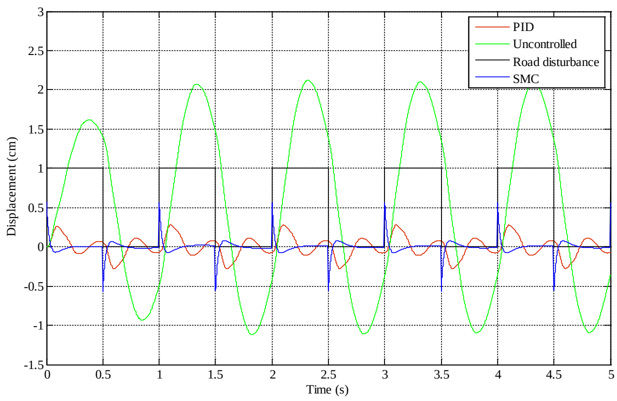

Fig.10. The response of uncontroled suspension system and equiped with PID and SMC under fixed recurring input

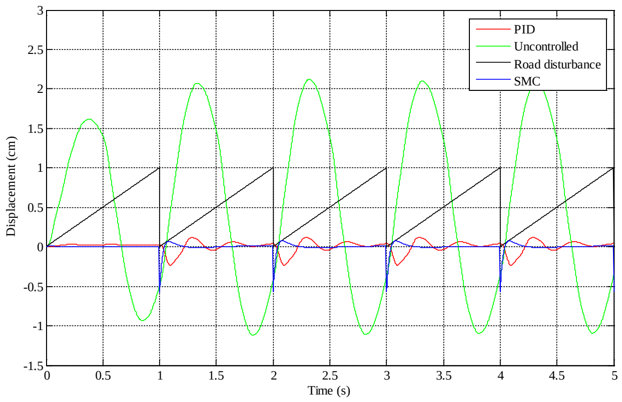

Fig.11. The response of uncontroled suspension system and equiped with PID and SMC under sawtooth road input

5. Conclusion

This study showed that an uncontrolled suspension system damps the road effects at longer time than controlled suspension systems and the vehicle body is released with larger amplitudes. The parametrical study showed that increasing using controller significantly improves the comfort and safety of vehicle. Two controller successfully designed and have been applied to the suspension system and based on the results and analyzes, we show that PID and SMC have the ability to control the vehicle suspension system. All the successfully designed controllers were compared. Under different road input simulation results in Fig. 8, Fig.9, Fig.10 and Fig. 11 show that SMC controller has better performance compared to PID controller in controlling the suspension system. This paper particularly has shown to improve the ride comfort in vehicles, a sliding mode controller should be preferred.

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