INTEGRATED SLIDING MODE CONTROLLER DESIGN FOR SEMI ACTIVE VEHICLE SUSPENSION SYSTEM USING HYPERBOLIC TANGENT

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***Abstract*— In today's world suspension system is a hot issue in the recent research of automotive industry, which is to generate active force to compensate the variation of the vehicle and improve safety and comfort for the passengers. This paper describes the control of a semi-active suspension system using a quarter-car model, by sliding mode controller with integrator, which generates active force between the sprung and the unsprung masses to compensate the variation produces by road surface. The influence of parameter uncertainties reduced against external disturbances which shows robustness is improved. The asymptotically stability of the sliding mode control system is proved based on the Lyapunov stability theory. Numerical simulations demonstrate the effectiveness of the proposed sliding mode control with integral action by reducing steady state error.**

Keywords: Sliding Mode Control(SMC),Semi Active Suspension System(SA),Hyperbolic tangent.

I. INTRODUCTION

The performance of vehicle suspension system is typically evaluated by its handling safety and riding comfort. The current vehicles can only offer a compromise between these two by providing spring and damping coefficients with fixed rates. Among of them, semi-active suspension control systems have wide application prospects in the future. Compared with active suspension system, the advantages of the semi-active suspension system are simple, economical, safe and a small power demand. Therefore semi-active suspension system has been researched.

A variety of control algorithms have been proposed for semi-active suspension. From skyhook, LQG and fuzzy control strategies have been studied. Karnopp et al [1] first proposed a skyhook control algorithm for a vehicle suspension system and demonstrated that this system can improve performance over a passive system when applied to a single-degree-of-freedom system. Dyke et al. [2] applied a clipped-optimal control strategy (LQG) based on acceleration feedback. The performance of LQG or LQR controllers is dependent upon the choice of weighting matrices for the vector of regulated responses and control forces. Fang and Chen [3] applied a fuzzy control strategy to a 4-DOF vehicle model and developed a useful control strategy.

As we known, vehicle is a complicated vibration system. Easy for the research, it needs to be simplified in order to build its dynamic model. However, simplified model is not exact. Otherwise, the variation in load, the nonlinear of spring and damper, the wear of tires as well as the pressure variation in tires could give rise to the variation of parameters in systems, causing model parameter uncertainty. In order to reach a high robustness against model parameter uncertainty and road disturbance, robust control schemes should been adopted. Various robust control strategies have been proposed including sliding mode control [4], adaptive control [5] and so on.

Variable structure control (VSC) with sliding mode control was introduced in the early 1950s by Emelyanov and was published in 1960s [6]. Sliding mode control (SMC) has been recognized as a robust and efficient control method for complex high order nonlinear dynamical system. The major advantage of sliding mode control is the low sensitivity to a system's parameter changing under various uncertainty conditions, and it can decouple system motion into independent partial components of lower dimension, which reduces the complexity of the system control and feedback design. A major drawback of traditional SMC is chattering, which is generally disadvantageous within control system.

The objective of this study is to design a sliding mode controller (SMC) which will easily be carried out. According to the theory of SMC controller will utilize a modified ideal damper suspension systems for eliminating the necessity of a road signal as well as measuring damper force, which is trying to make the whole process simple and easy to implement, and result in better ride quality and handling performance and vehicle handling performance. At present, there are so many results in better ride quality and handling performance. The effectiveness of the controller is investigated by numerical simulation.

II. MODELING OF SUSPENSION SYSTEM

The role of the vehicle suspension system is to support and isolate the vehicle body and payload from road disturbances, maintain the traction force between tires and road surface. The SA suspension system can offer both the reliability and versatility including passenger ride comfort with less power demand.

In this paper, the 1/4 semi active vehicle model of two degree of freedom is defined, as shown in Fig.1.

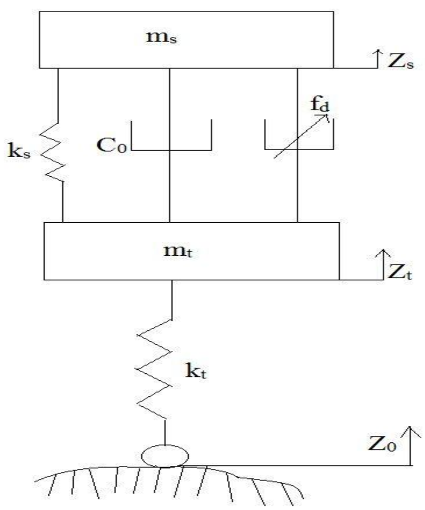


Fig.1. Dynamic model of a vehicle suspension system

The dynamic differential equations of suspension system are set up as follows.

$$m_s\ddot{z}_s = K_s(Z_s - Z_t) + f_d + C_0(\dot{Z}_s - \dot{Z}_t) - m_s g$$

$$m_t\ddot{z}_t = -K_s(Z_s - Z_t) + K_t + K_t(Z_t - Z_0) - f_d - C_0(\dot{Z}_s - \dot{Z}_t) - m_s g$$

Where m_s and m_t are the sprung mass and the unsprung mass of the system, K_s is the suspension rigidity, K_t is the tyre rigidity， *C0* is the suspension damper，Z_s and Z_t are the displacements of the sprung mass and the unsprung mass. Z_0 Represents the road displacements and g is Gravity acceleration.

$$\dot{X} = A_x + B_u + Cw$$

Here four state variables are follows:

$x1 = (Z_s - Z_t)$

$x2 = (Z_t - Z_0)$

$x3 = \dot{z}_s$

$x4 = \dot{z}_t$

The State space matrix is given by

WHERE, $A=\begin{bmatrix} 0 & 0 & 1 & -1 \\ 0 & 0 & 0 & 1 \\ \frac{-ks}{ms} & 0 & 0 & 0 \\ \frac{ks}{mt} & \frac{-kt}{mt} & 0 & 0 \end{bmatrix}$, $B=\begin{bmatrix} 0 \\ 0 \\ \frac{-1}{ms} \\ \frac{1}{mt} \end{bmatrix}$, $C=\begin{bmatrix} 0 \\ -1 \\ 0 \\ 0 \end{bmatrix}, w = z_0$

III. SLIDING MODE CONTROLLER DESIGN

Sliding mode controller involves two steps.

1. Design a sliding surface and
2. Design a control law.

Sliding surface in terms of error and rate of change of error.

$$s = \boldsymbol{\lambda e} + \dot{\boldsymbol{e}}$$

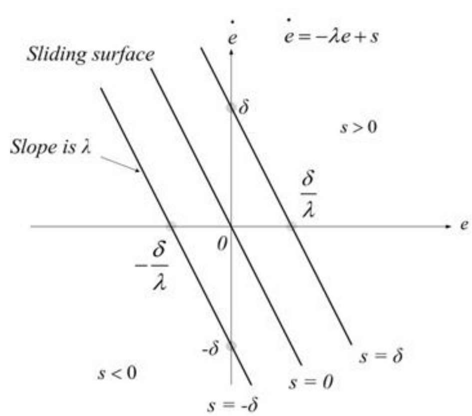
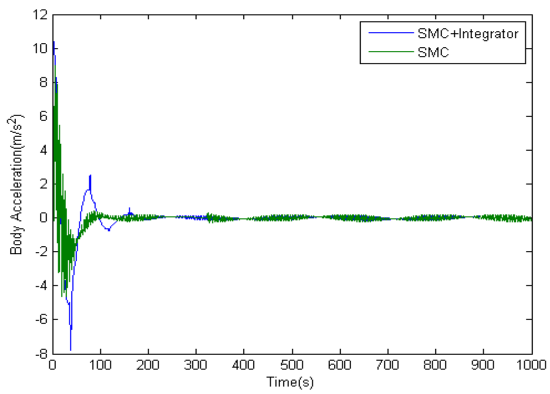


Fig.2. Sliding Surface design.

S is the sliding surface of the hyper-plane, which is given in Equation and shown in Figure 2, where λ is a positive constant that defines the slope of the sliding surface. Without Model Reference error in terms of body velocity and rate of change of error in term of body acceleration in vertical motion. If the error dynamics is in sliding mode, that is s = $\dot{s}$ = 0.From the Lyapunov stability theorem, states that is a globally asymptotically stable equilibrium point for the control system.

$$v = \frac{1}{2} s . s^{T}$$



Controller can reduce the resonant peak of the sprung mass quite significantly and thus can achieve a good ride quality. By borrowing this idea to reduce the sliding chattering phenomenon, a soft switching control law is introduced for the major sliding surface switching activity in Equation, which is to achieve good switch quality for the SMC. The variable of s is defined in Equation, which contains the system information. It can be taken as a part of the SMC control law in Equation, where c_0 is an assumed positive damping ratio for the switching control law. The SMC needs to be chosen in such a way that the existence and the reachability of the sliding mode are both guaranteed. Noting that δ is an assumed positive constant which defines the thickness of the sliding mode boundary layer.

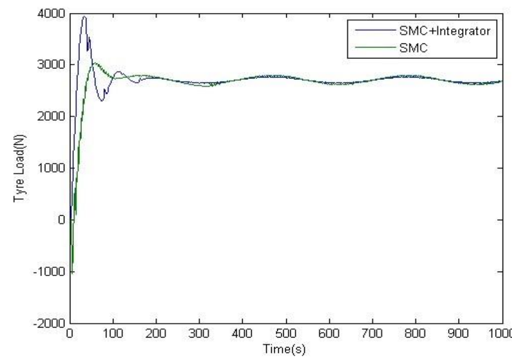
$$\text{Usmc} = \begin{cases} -c_0 \tanh\left(\frac{s}{\delta}\right) & s\dot{s} > 0 \\ 0 & s\dot{s} \leq 0 \end{cases}$$

In this paper Control law is defined by Hyperbolic Tangent and with integrator. This can reduce the chattering and steady state error.

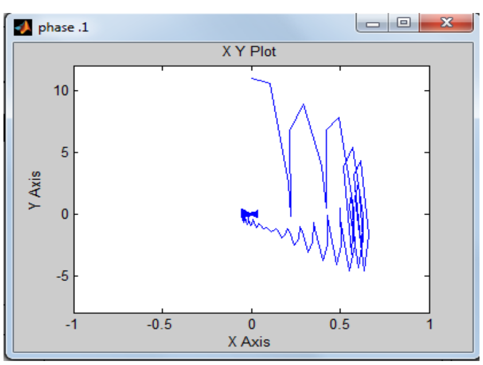
IV. SIMULATION RESULTS

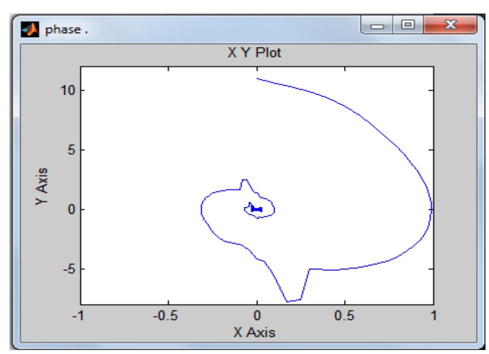
In the simulation for the control on 2-DOF SA suspension system, it is excited by Sine wave road disturbance loading. The numerical results are obtained using a MATLAB/SIMULINK. All the results are generated using the following parameters.

Table 1. suspension parameters.



Parameter	Unit	Value
mt, Unsprung Mass	Kg	36
ms, Sprung Mass	Kg	240
C0,Suspension damping coefficient	Ns/m	1400
Kt, Tire stiffness coefficient	N/m	160000
Ks, Suspension stiffness coefficient	N/m	16000
g, Gravity acceleration	m/s2	9.81
Ce, Equivalent damping Coefficient	-	-5000
δ, Thickness of the sliding mode boundary layer	-	28.1569
λ, slope of the sliding surface	-	10.6341





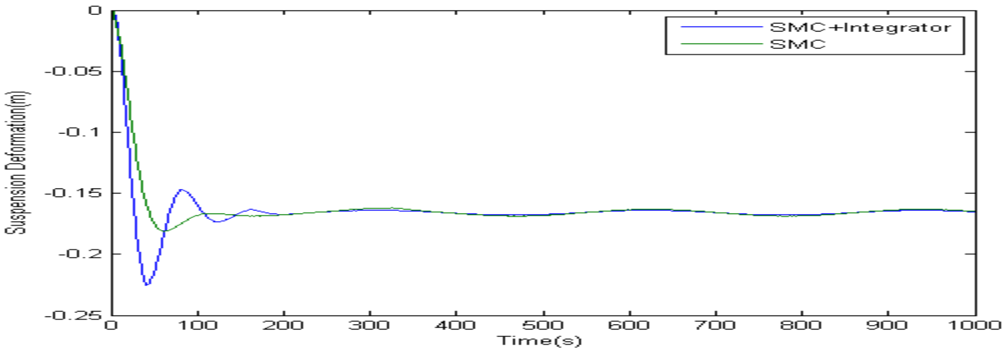


Figure 3.SA suspension system body acceleration response, tire load, suspension deformation with SMC vs. SMC+ integrator control.

Fig.4 Phase plane trajectory(with hyperbolic tangent)

Fig.5 Phase plane trajectory (with itegrator)

V. CONCLUSION

A sliding mode controller with integrator is designed for semi active suspension system, which generates active force to compensate the variation in vertical acceleration of the vehicle generated by road input. The performance of the proposed SMC based controller with integrator and without integrator were compared. The comparison shows that proposed controller design with integrator gives better performance by reducing the steady state error. Designed controller gives better performance with smooth chattering against normal SMC. Numerical simulation results show that both ride quality and handling performance are improved using the SMC. So finally SMC gives a better robustness and stability against uncertainty and external disturbance. This approach towards the design of semi-active suspensions can be further pursued for a practical setup that could validate the simulation results.

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