Control of an Active Vehicle Suspension Using Electromagnetic Motor

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Abstract Two criteria of good vehicle suspension performance are typically their ability to provide good road handling and increased passenger comfort. So far, The existing active vehicle suspension uses pneumatic and hydraulic actuators that enhance road handling and passenger comfort. But these kinds of actuators have nonlinear characteristic less than an electromagnetic motor.

In this research, we are trying to examine the feasibility and the experiment of an active vehicle suspension using electromagnetic motor in order to enhance the ride quality because existing active vehicle suspension using active power sources such as compressors, hydraulic pumps has nonlinear characteristic. Active vehicle suspension using electromagnetic motor will have the ability to behave differently on smooth and rough roads. The desired response should be soft in order to enhance ride comfort, but when the road surface is too rough the suspension should stiffen up to avoid hitting its limits.

Keywords: active vehicle suspension, quarter-car model, skyhook, optimal control

1. INTRODUCTION

The primary function of vehicle suspension is to isolate the vehicle body and passengers from the vibration created by the road roughness and produce a continuous road-wheel contact.
At present, three types of vehicle suspensions are passive, semi-active passive and active ones. All the systems known as implemented in automobiles are based in hydraulic or pneumatic operation. The active vehicle suspensions are characterized by a requirement that at least a portion of suspension force generation is provided through active power sources such as compressors, hydraulic pumps, etc. However existing hydraulic or pneumatic suspension has nonlinear characteristic and noise. Therefore it can't perfectly control suspension. The practical application of the active vehicle suspension has been facilitated by the performance improvement of microprocessors, associated electronics, actuator and sensor.

Vehicle ride and handling is influenced by two main sets of disturbance. One is caused by road roughness, and the other is loading, braking, turning and wind. In this paper, we will focus on the former

In the last decade, the evolution occurred in power electronics, permanent magnet materials and microelectronics allowed very important improvements in the electrical drives domain. Now more and more electrical devices are improving dynamic and steady state performance, volume and weight reduction, unconstrained integration with the electronic control system, reliability, and cost reduction. Therefore, someday it will be alternated conventional suspensions with a suspension using electromagnetic motor that has more linear characteristic, powerful and cheaper than the past

This paper will focus on the application of control methods for active vehicle suspension. Optimal control method is the best in suspension methods. In order to generate the actuator force for the optimal control system, the performance of the actuator must be precise and the size of the actuator is biggest in suspension systems. Now, it is wise and economical that we apply the skyhook system to the active vehicle suspension. In the future, the optimal control is realized.

2. VEHICLE DYNAMICS

2.1 Quarter -Car Model

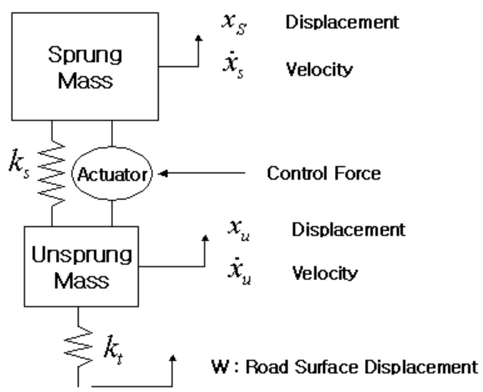

Fig. 1 Quarter-Car Model

A quarter vehicle model is used in this paper, Because of the fact that a Quarter-car model shows the bounce motion of the sprung mass with the heaving of the unsprung mass and provides a clear insight on the relationships between control law design and performances using the proposed strategy, a half vehicle model with partly supported active vehicle suspension is used in this study.

Fig. 1 shows a quarter-car model. The values of vehicle parameters are

Sprung mass $m_s = 500kg$

Unsprung mass $m_u = 50kg$

Spring stiffness $K_s = 25000N/m$

Tire stiffness $K_t = 215500N/m$

2.2 Skyhook Control of the Active Vehicle Suspension

The ideal skyhook force can be written as,

$$u(t) = c_{sh}\dot{x}_s \tag{1}$$

A variable damping force can be written as,

$$u = c_d(\dot{x}_s - \dot{x}_u) \tag{2}$$

With the assumption that two above equation is same, the variable damping coefficient can be determined as,

$$c_d = c_{sh}\frac{\dot{x}_s}{\dot{x}_s - \dot{x}_u} \tag{3}$$

Where, c_{sh} is the skyhook coefficient

The equation of motion of the quarter car motel with 2 degrees of freedom yields,

$$\ddot{x}_s = -\frac{k_s}{m_s}(x_s - x_u) - \frac{1}{m_s}u \tag{4}$$

$$\ddot{x}_u = k_s(x_s - x_u) - \frac{k_t}{m_u}(x_u - x_r) + \frac{1}{m_u}u \tag{5}$$

This system model can be written in state space form as,

$$\dot{x}(t) = Ax(t) + Bu(t) + Dw(t) \tag{6}$$

$$x(t) = [\dot{x}_s, x_s, \dot{x}_u, x_u] \tag{7}$$

$$A = \begin{bmatrix} 0 & 1 & 0 & 0 \\ -\frac{k_s}{m_s} & 0 & \frac{k_s}{m_s} & 0 \\ 0 & 0 & 0 & 1 \\ k_s & 0 & -k_s - \frac{k_t}{m_u} & 0 \end{bmatrix} \tag{8}$$

$$B = \begin{bmatrix} 0 \\ \frac{1}{m_s} \\ 0 \\ -\frac{1}{m_u} \end{bmatrix}, \quad D = \begin{bmatrix} 0 \\ 0 \\ 0 \\ \frac{k_t}{m_u} \end{bmatrix}$$

2.3 Optimal Control of the Active Vehicle Suspension

It is desirable to isolate the driver from vibrations due to road disturbances and enhance vehicle handling.

The performance index J is the integral of the sum of the square of the chassis acceleration, the suspension travel, the tire deflection and the control force.

$$J = \lim_{T\to\infty}\int_0^T [\rho_1\ddot{x}_s^2 + \rho_2(z_s - z_u)^2 + \rho_3(z_u - z_r)^2 + \rho_4 u_1^2]dt \tag{9}$$

The Control law follows from the requirement that J is minimal. The Performance index can be written as

$$J = \lim_{T\to\infty}\int_0^T [x^T Qx + 2x^T Nu + 2x^T Sw + w^T Tw + u^T Ru]dt \tag{10}$$

With easily determinable relations for Q,N,S,T and R.

The weighting coefficients ρ_i are used for adjusting the comfort and road holding capability criteria. In this model, we have chosen $\rho_1 = 1$, $\rho_2 = 1000$, $\rho_3 = 1000$ and $\rho_4 = 0.001$. This choice has proven to be a good trade-off between comfort and road holding capacity.

Hamilton equation can be written as

$$H = \frac{1}{2}(x^T Qx + 2x^T Nu + 2x^T Sw + w^T Tw + u^T Ru) + \lambda^T(Ax + Bu + Dw) \tag{11}$$

When the active vehicle suspension controller is designed, the input of the control system is assumed as,

$$u = -R^{-1}[(N^T + B^T P)x] \tag{12}$$

Riccati equation can be written as,

$$Q_n + PA_n - PBR^{-1}B^T P + A_n P = 0 \tag{13}$$

Where $Q_n = Q - NR^{-1}N^T$, $A_n = A - BR^{-1}N^T$.

3. MOTOR CONTROL

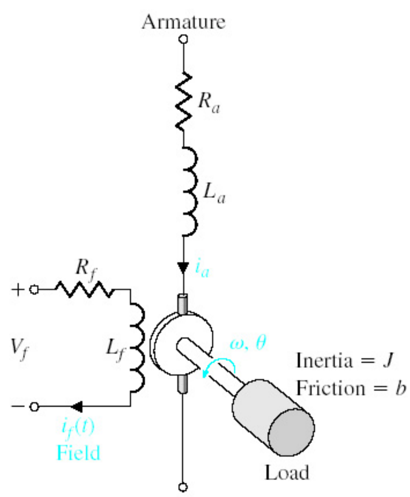

Fig. 2 DC motor

The dc motor is a power actuator device that delivers energy to a load, as shown in Fig. 2. The dc motor converts direct current (dc) electrical energy into rotational mechanical energy. Because of features such as high torque, speed controllability over a wide range, portability, well-behaved speed-torque characteristics, and adaptability to various types of control methods, dc motors are widely used in numerous control applications, including manipulators, tape transport mechanisms, disk drives, machine tools and servo valve actuators.

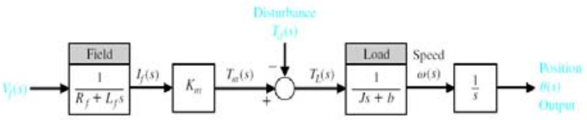

Fig. 3 Block diagram model of a DC motor

The output velocity of a direct current motor can be controlled either by varying the armature voltage or the field current.

According to the fig.3 we can obtain the transfer function below.

$$\frac{\theta_1}{V} = \frac{K_m}{s[(R_a + L_a s)(JS + b) + (K_b K_m)^2]} = \frac{K_m}{s(s^2 + 2\xi w_n s + w_n{}^2)} \quad (14)$$

Generally, $\tau_a = L_a / R_a$ is negligible, and therefore

$$G(s) = \frac{\theta(s)}{V_a(s)} = \frac{K_m}{s[R_a(Js+b) + K_b K_m} = \frac{[K_m / (R_a b + K_b K_m)]}{s(\tau_1 s + 1)} \quad (15)$$

Where $\tau_1 = R_a J / (R_a b + K_b K_m)$

4. RESULT

4.1 Vehicle Response for the Bump Input

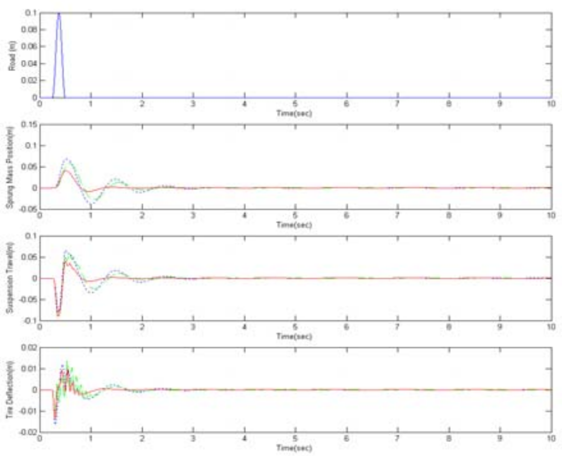

Fig. 4 Vehicle Response for the Step Input

In order to determine the appropriate control logic for the system, we simulated and analyzed the motion of vehicle

The first graph is about a bump input and the second graph is about the position of sprung mass, the third graph is about the suspension deflection and the last graph is about the tire deflection for passive, ideal skyhook and optimal control suspensions.

Fig. 4 shows that the position performance of a sprung mass for the ideal skyhook suspension is the best of the three suspension systems but the tire deflection performance for the ideal skyhook suspension is the worst of the three suspension systems.

The optimal control suspension compensates the weak point of the skyhook suspension for tire deflection. On the other hand, we must consider the actuator design. Next section, we will deal with the control force of the actuator.

4.2 Frequency Response

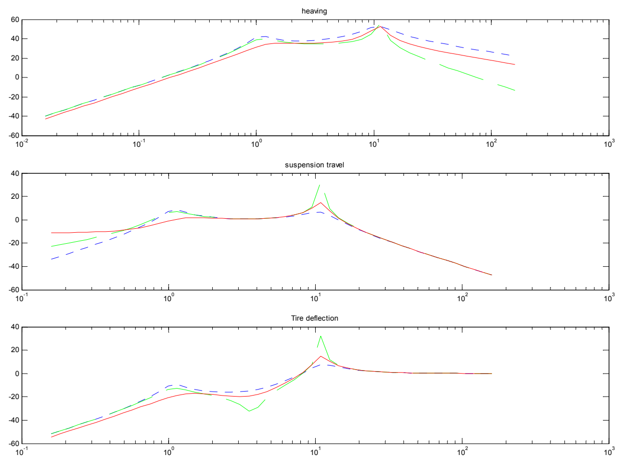

Fig. 5 Bode Diagram of three Suspensions

Control systems are often designed by use of frequency response method. Many techniques are available in the frequency response method for the analysis and design of control. The optimal control system can compensate the weak point of the system for state vector. Otherwise, the control logic is more complicated and the system should retain many sensors.

The first graph is about the magnitude of heaving and the second graph is about the magnitude of tire deflection and the last graph is about the magnitude of suspension travel for three suspensions.

In Fig. 5, we observe that the optimal control system compensate the handling performance for the ideal skyhook and the ride performance for the passive system.

4.3 Control Force of the Active Vehicle Suspension

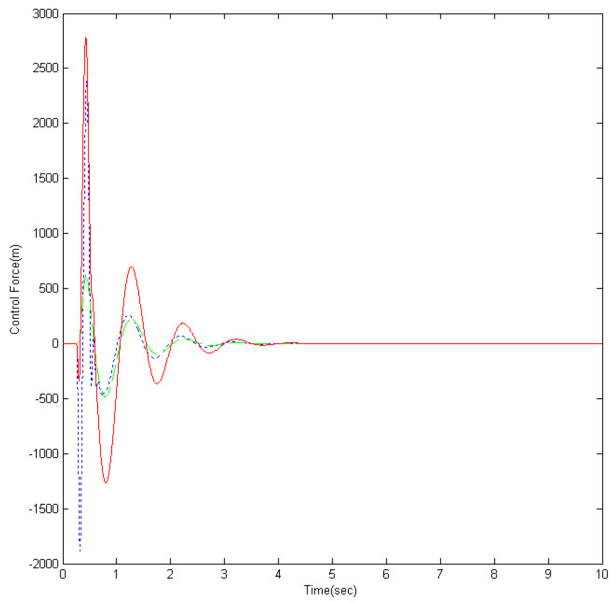

Fig. 6 Control Force of the Actuator

Fig. 6 shows the control force for the skyhook and the optimal control suspension. From 0.5 second to 3 second, the control force for the skyhook system is 50% lower than for the optimal control system. The frequency of optimal control force is approximately 0.1 Hz. After 3 second, the graph characteristic is same. It is difficult to find the actuator of the optimal control for performance.

4.4 Power Spectrum Density

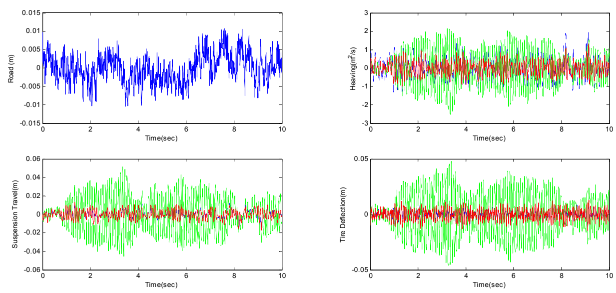

Fig. 7 Response for Road Data Bosch

Fig 7 shows the reaction of three kinds of systems that is calculated through road data that is produced by Bosch, The simulation results are used in order to obtain power spectrum density of three kinds of suspension.

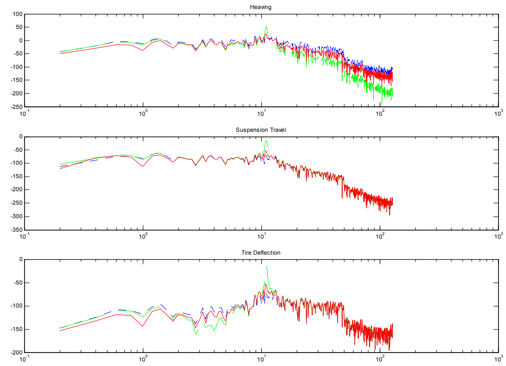

Fig. 8 PSD of Three kinds of Suspension

Through Bosh road data, performance data of three suspensions is evaluated by numerical simulation. Power Spectrum Density of three suspensions is acquired using the performance data. As shown in Fig.8, the characteristic of Power Spectrum Density for the three suspensions is similar to frequency response.

5. CONCLUSION

Good vibration isolation is required to secure the occupants' ride comfort, whereas good road holding is important for vehicle handing, which in general leads to enhanced safety. In other to obtain the best performance, we compared the three suspensions. In this paper, this active vehicle suspension system with electromagnetic motor is proposed. If we consider the reality and the economical efficiency, it is wise to choose the skyhook control method now.

A hydraulic actuator makes the high power but has the nonlinear characteristic. Because the motor is linear and precise, we will apply the motor to the active vehicle suspension.

In the future, we will design the active vehicle suspension using electromagnetic motor precisely and obtain the appropriate parameters of the suspension. Our plan is that we choose the motor actuator that can be operated at the hard situation and a half car models will be used and experimented because we want to get more accurate data.

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