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Two-acceleration-error-input proportional-integral-derivative control for vehicle active suspension

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Abstract: The objective of this work is to present a new two-acceleration-error-input (TAEI) proportional-integral-derivative (PID) control strategy for active suspension. The novel strategy lies in the use of sprung mass acceleration and unsprung mass acceleration signals simultaneously, which are easily measured and obtained in engineering practice. Using a quarter-car model as an example, a TAEI PID controller for active suspension is established and its control parameters are optimized based on the genetic algorithm (GA), in which the fitness function is a suspension quadratic performance index. Comparative simulation shows that the proposed TAEI PID controller can achieve better comprehensive performance, stability, and robustness than a conventional single-acceleration-error-input (SAEI) PID controller for the active suspension.

Key words: vehicle; active suspension; PID; two-acceleration-error-input; optimization

1 Introduction

Because the active suspension has a huge potential to enhance vehicle ride comfort and handling stability, it has been a hot area in vehicle engineering for several years (Khan et al. 2014; Feizi and Rezvani 2014; Brezas and Smith 2014; Koch and Kloiber 2014; Formentin and Karimi 2012). The key technology of active suspension is control method. Recently, different control methods have been applied to the control of active suspensions, such as linear quadratic Gaussian (LQG) control (He and McPhee 2005), adaptive control (Yu and Crolla 1998), and proportional-integral-derivative (PID) control (Yildirim 2004; Priyandoko et al. 2009; Feng et al. 2003). Each control method has its own advantages and has made positive contributions to the solutions to the problem. However, each method also has its disadvantages. For example, although the active suspension based on LQG control can achieve better ride comfort, it needs main signal inputs of the state vectors describing vehicle system vibration, specially for the road irregular excitation. Adaptive control often requires a great amount of computing time for online parameter identification and also

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depends on identification accuracy. PID control is used widely because it responds fast, system stability is high and steady state error is small. Therefore, in recent years, more and more attention has been devoted to the development of PID control for active and semi-active suspensions separately or assembled with fuzzy logic control.

It was reported frequently that the PID controller was adopted for the active or semi-active suspension based on a quarter-car model (Yildirim 2004; Priyandoko et al. 2009). There was only one control error input which was arranged on the sprung mass acceleration or the sprung mass displacement, and so on. The sprung mass acceleration error is usually the main one because the acceleration signal is easily measured and obtained in engineering practice and the sprung mass acceleration is the main evaluating index of vehicle ride comfort. The traditional neuron control (TNC) and integrated error neuron control (IENC) for active or semi-active suspension can be taken as the extensions of PID control because they will degenerate to common PID control when the learning rates of weights are set as zero (Jin and Yu 2008).

In fact, the unsprung mass acceleration is easier to obtain than the sprung mass one in engineering practice and is related with the unsprung mass dynamic load which is one of evaluating indexes of vehicle ride comfort.

This work aims to develop a new two-acceleration-error-input (TAEI) PID control strategy to enhance the comprehensive of the active suspension. The TAEI PID controller for the active suspension will use two control errors which are the acceleration error of the sprung mass and the one of the unsprung mass.

The following main issues are presented in this research: (a) a TAEI PID controller is established to enhance the comprehensive performance of the active suspension; (b) the control parameters of TAEI PID controller are optimized; (c) comparative simulation and analysis are given to prove the effectiveness and robustness of the proposed TAEI PID control strategy.

2 Dynamics model of active suspension

Here a quarter-car-model active suspension is adopted in Fig. 1. According to Newton's Second Law, the following motion equations are obtained for the active suspension

$$\begin{cases} m_1\ddot{x}_1 = -k_1(x_1 - q) + k_2(x_2 - x_1) + c_0(\dot{x}_2 - \dot{x}_1) - F \\ m_2\ddot{x}_2 = -k_2(x_2 - x_1) - c_0(\dot{x}_2 - \dot{x}_1) + F \end{cases}$$

$$\dot{q} = 2\pi n_0 \omega \sqrt{G_q(n_0) v} - 2\pi f_0 q$$

where m_1, m_2 are the unsprung mass and the sprung mass respectively; k_1, k_2 are the tire equivalent stiffness and the suspension stiffness respectively; F stands for the active control force; c_0 stands for the suspension basal damp; q stands for road input to the suspension; n_0 is the reference spatial frequency and equals to 0.1 m^{-1}; $G_q(n_0)$, ω are road white-noise function and road roughness coefficient decided by various road classes, respectively; v is vehicle speed; f_0 is the lower cut off frequency and equal to $0.011v$; x_1 is vertical unsprung mass displacement; x_2 is vertical sprung mass displacement.

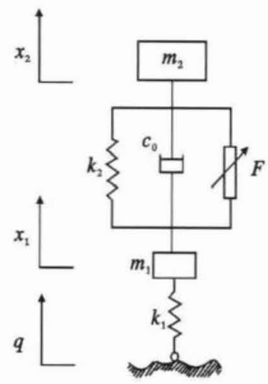

Fig. 1 Active suspension model

The state vector of active suspension is written as follows

$$X = (q, x_1, x_2, x_3, x_4)^T$$
$$x_3 = \dot{x}_1$$
$$x_4 = \dot{x}_2$$

The state model is expressed as follows

$$\dot{X} = AX + BU + GW$$

$$A = \begin{bmatrix} -2\pi f_0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ \frac{k_1}{m_1} & -\frac{k_1 + k_2}{m_1} & \frac{k_2}{m_1} & -\frac{c_0}{m_1} & \frac{c_0}{m_1} \\ 0 & \frac{k_2}{m_2} & -\frac{k_2}{m_2} & \frac{c_0}{m_2} & -\frac{c_0}{m_2} \end{bmatrix}$$