Signal frequency based self-tuning fuzzy controller for semi-active suspension system

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Abstract: A new kind of fuzzy control scheme, based on the identification of the signal's main frequency and the behavior of the ER damper, is proposed to control the semi-active suspension system. This method adjusts the fuzzy controller to achieve the best isolation effect by analyzing the main frequency's characters and inspecting the change of system parameters. The input of the fuzzy controller is the main frequency and the optimal damping ratio is the output. Simulation results indicated that the proposed control method is very effective in isolating the vibration.

Key words: Semi-active suspension, ER damper, Frequency identification, Fuzzy controller
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INTRODUCTION

Road vehicle suspension design has received great attention in recent years. The performance of the suspension system plays an important role in achieving good handling and riding comfort. Practically, the simplest and most common types of suspensions are passive in the sense that no extra energy is required. But further development is held down because the spring and damper elements cannot be dynamically adjusted.

Active suspensions with their spring and damper elements replaced by active force actuators can remove the inherent restrictions of passive suspensions and offer better riding performance. But due to manufacturability, reliability and economy concerns, it appears that only a few types of active suspension systems have been realized so far. Semi-active suspension plays an important role gradually because it is more agile than passive suspension and cheaper than active suspension. With the development of electrorheological (ER) fluid in recent years, the ER damper replaces the hydraulic shock absorber or the adjustable valve and becomes the executive element of the suspension system (Gavin et al., 1996a; 1996b). The ER damper can change its damping coefficient rapidly when the voltage changes, so it shortens the control time and increases the reliability of the control system greatly.

Most control strategies for semi-active suspension systems are based on optimal control algorithms. Besides this, the application of adaptive control such as model reference adaptive control and nonlinear self-turning control for vehicle suspension systems were investigated by Sunwoo et al. (1990a; 1990b). Generally speaking, these controllers can minimize a defined performance index but do not have good capability for adapting to significant changes of the road and system parameters. Fuzzy inference, one of the knowledge-based approaches, has been recently applied to the design of semi-active suspensions of such complicated systems to achieve improved performance because it is easy to construct the suspensions without considering the nonlinearity and uncertainty. Lin et al. (1993) built a model following fuzzy controller of vehicle suspension systems. He used the error and change in error between the reference model acceleration and that of the active suspension as

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the two input variables in the fuzzy inference mechanism. Yoshimura et al. (2000) used the displacements and velocity of the sprung mass and unsprung mass as the input of the fuzzy controller, and damper force as the output, to control the system by 49 fuzzy rules. Foda (2000) and Rao et al. (1997) took the relative displacement and velocity as the input of the fuzzy controller, and active force as the output. All these methods have provided improved performance to the semi-active suspension system. If we think more about the road input of the semi-active suspension system, we can achieve better performance.

This work aimed to develop a new fuzzy logic controller that can be used for semi-active suspension system that is based on the identification of the road input signal’s main frequency. Based on the behavior of the ER damper, this method adjusts the fuzzy controller to achieve the best isolation effect by analyzing the main frequency’s characters and inspecting the change of system parameters. The input of the fuzzy controller is the main frequency and the optimal damping ratio is the output. Simulation and experimental results indicated that the proposed control method is very effective in isolating vibration.

DYNAMIC MODEL OF SEMI-ACTIVE SUSPENSION SYSTEM

A 2 DOF quarter vehicle suspension is employed (Fig.1) and modeled by the linear spring coefficient $k_1$, tire spring coefficient $k_2$, and damping coefficient $c$. The active model consists of the sprung mass $m_1$, the unsprung mass $m_2$, and displacements for the sprung mass and unsprung mass, $z_1$ and $z_2$, respectively. And $r$ is the road disturbance. The system dynamics is described by:

$$m_1\ddot{z}_1 = - k_1(z_1 - z_2) - c(z_1 - z_2)$$
$$m_2\ddot{z}_2 = k_1(z_1 - z_2) + c(z_1 - z_2) - k_2(z_2 - r)$$

(1)

Here $c$ can be changed with the voltage of the ER damper.

From Eq. (1), we can get the sprung mass' frequency response in Fig.2. Here $f_0$ is the resonant frequency and $f_c$ is the intercross frequency. For the road input signal with single main frequency, we can easily choose the best damping ratio $\xi_{OPT}$ to achieve the best isolation effect. When the main frequency is less than $f_c$, we can use the maximal damping ratio $\xi_{MAX}$; and $\xi_{MIN}$ is used when the main frequency is greater than $f_c$. But according to the complex input signal, we could not use the above methods to achieve best control effects because the signal has different main frequencies of different amplitude and angle. A best damping ratio cannot be found easily because some frequencies are less than $f_c$, and the others are greater than it at the same time. So we develop an adjustable fuzzy controller to choose the best damping ratio $\xi_{OPT}$ according to the complex signal’s main frequencies.

![Fig.1 The semi-active suspension system](image)

![Fig.2 Dynamic response of the system](image)