Chapter 1

Introduction

The primary purpose of this chapter is to provide an overview of vibration control techniques, in particular the semiactive and adaptive control techniques. It further provides the objectives and outline of the document.

1.1 Introduction

As early as in the sixteenth century, Galileo Galilei began to study the vibratory phenomena. Since then, the vibration theory has been expanding from discrete systems to continuous systems, from harmonic vibration analysis to random vibration problems, from linear vibration theory to nonlinear vibration analysis, and from vibration analysis to vibration control systems design. From theoretic research to engineering applications, scientists and engineers have taken advantages of the expanded knowledge to benefit the world.

In order to minimize the harmful vibration, passive and active vibration isolators have been widely applied, for instance, machine mounts and vehicle suspensions. With the advent of real-time adjustable passive devices, i.e., semiactive devices, semiactive vibration isolators have also been extensively explored. In the following sections, we will summarize the characteristics of semiactive systems and adaptive approaches, and point out the need for the development of semiactive adaptive systems for better vibration isolation performance.

1.2 Semiactive Systems

The idea of semiactive dampers (or shock absorbers) has been in existence for more than two decades. Introduced by Karnopp and Crosby [1] in the early 1970’s, semiactive dampers have most often been studied and used for vehicle primary suspension systems. A semiactive damper draws small amounts of energy to operate a valve to adjust the damping level and reduce the amount of energy that is transmitted from the source of vibration energy (e.g., the axle in a vehicle) to the suspended body (e.g., the vehicle structure) [1-4]. Therefore, the force generated by a semiactive damper is caused by the relative velocity across the damper (similar to a passive damper). Another type of damper that is usually considered for vibration control is a fully active damper. Active dampers draw relatively substantial amounts of energy to produce forces that are not necessarily in direct relationship to the relative velocity across the damper.

The virtues of active and semiactive dampers versus traditional, passive dampers have been addressed in many studies [3-6]. Using various analytical and experimental methods, these studies have concluded that in nearly all cases semiactive dampers reduce vibration transmission across the damper and better control the suspended (or sprung) body, in comparison to passive dampers. Further, they have shown that, for vehicle suspension systems, semiactive dampers can lower the vibration transmission nearly as much as fully active dampers, but without the inherent cost and power requirements associated with active vibration control systems. Since semiactive systems employ adjustable dampers that are inherently passive devices, there is no stability problem with semiactive vibration isolation systems in case of a component failure.

1.3 Adaptive Systems

The earlier section described semiactive systems, as compared to passive and active systems. This section will briefly present the virtues of the adaptive control technique.

Adaptive control systems refer to the class of systems that are able to adapt to the changes that may occur in the system. Adaptive control techniques have been successfully applied to a wide variety of engineering problems, ranging from motion control, to communication problems, to noise cancellation systems, to speech analysis and synthesis, and to many other signal processing problems. The primary impetus for using adaptive control techniques is that often the systems to be controlled are noisy (i.e., are subjected to disturbances), or have unknown or unmodeled characteristics. Adaptive control methods for such systems are advantageous over fixed systems, because the controller parameters can be adjusted or tailored to the unknown and varying characteristics of the system.

Most often, the adaptation process occurs in real time at either a high rate (fast-acting systems) or at a slow rate (slow-acting systems). The adaptation rate is selected by the control designer, based on the system environment and performance requirements. The discussions about adaptive control systems that will be presented next are applicable to both fast- and slow-acting systems, as well as linear and nonlinear systems.

Most adaptive control systems can be divided into two categories: feedforward adaptive controllers and feedback adaptive controllers [7-9].

Feedforward adaptive control uses a reference and an error signal to adjust the controller to adapt to the system changes or uncertainties. Thus, the effect of the measurable signals on the control systems behavior should be known a priori. The typical methods are gain scheduling and LMS adaptive filters. The disadvantages are that there is no feedback loop to compensate for unpredictable variations in the systems.

The feedback adaptive control involves automatic experimentation with these adjustments and knowledge of their outcome in order to optimize a measured system performance, Widrow and Stearns [9]. There are two approaches for implementing the feedback adaptive control. One is the direct adaptive control that incorporates the plant parameters into the control law. The other is the indirect adaptive control in which the adaptation is performed based on the system identification of the unknown plant parameters.

The choice of feedback versus feedforward adaptive control depends on such conditions as the availability of input and output signals, and computational capabilities of the microprocessors or DSP used in the system. Feedback adaptive control can be more effective in resisting the variations and disturbances, as compared to feedforward adaptive control techniques.

1.4 Semiactive Adaptive Systems

In order to take advantage of the features of semiactive and adaptive systems, several studies in the past have discussed semiactive adaptive systems. The main effort of most of these studies has been on linear systems that use semiactive and skyhook control policy or its variations, as will be discussed in more detail in Section 2.4 [1, 10-15]. A number of these studies performed have emphasized the application of such techniques as self-tuning control, model reference adaptive control (MRAC) or LMS adaptive filters to the semiactive systems based on the system linearization.

The vast majority of semiactive devices, however, are nonlinear. For instance, shock absorbers have a bilinear characteristic, and electro-rheological (ER) dampers and magneto-rheological (MR) dampers exhibit hysteretic nonlinearities. As mentioned earlier, although other past studies have addressed semiactive adaptive systems, none has addressed how to design semiactive adaptive control directly to deal with the nonlinearities of semiactive devices as subjected to immeasurable non-stationary vibration sources. This study intends to address this issue.

1.5 Objectives

The primary objectives of this study are to

1. explore effective methods for combining semiactive systems with adaptive control concepts,
2. provide modeling, experimentation, and analysis techniques that will enable development and analysis of adaptive semiactive control concepts, and
3. develop new adaptive semiactive control techniques that can be readily used in commercial systems.

1.6 Outline

Chapter two provides a background on semiactive systems and adaptive control concepts, along with an overview of some of the past studies. In Chapter three, a non-parametric model is proposed for magneto-rheological dampers. A comparison between parametric and non-parametric models is also presented. Chapter four provides the details of how a skyhook damper is implemented on a seat suspension, and describes two modifications to skyhook control to improve the suspension system's isolation characteristics. Chapter five includes the mathematical formulation of the proposed semiactive adaptive control system. The stability analysis of adaptive damping tuning is demonstrated. Chapter six highlights the results of a numerical simulation of the proposed adaptive control. It also illustrates a comparison between the proposed adaptive control and passive dampers. Chapter seven further validates the results of Chapter six, by examining the performance of the adaptive semiactive control in the laboratory. The proposed adaptive control is implemented on a seat suspension and the results are analyzed for various frequency ranges of the system input. Chapter 8 summarizes the results of this study and provides recommemdations for future research.