Chapter 1

Introduction

This chapter provides an introduction to the contents of this document and the research conducted for this study on structural vibration suppression with smart materials (PZTs). The introduction focuses on shunted and actively controlled PZTs, and some of the additional applications of this technology. First, the motivation behind this research is given, along with some background information on various shunting and active damping techniques with smart materials. Next, the research objectives for this study and the approach followed to achieve these objectives are provided. The final section of the chapter is an outline of this entire document, with a brief summary of each chapter provided.

1.1 Motivation

With the recent advances in smart material systems (SMS), there has been an increased interest in the applications of smart materials, or piezoelectric materials (PZTs), for passive and active structural damping. With the advancement of smart material technology, smaller actuators and sensors have been created and successfully incorporated into structures. The research conducted in this study focuses on two different smart material techniques: a parallel resistor-inductor shunt circuit technique, and an active control technique with positive position feedback. In contrast to the methods studied in this research, there has been significant work to reduce structural vibrations with passive damping treatments, such as constrained layer damping using asphalts or carpeting treatments. There is often no science to the application of these passive-damping materials, which often leads to unwanted changes in structural dynamics. Moreover, some of these passive-damping treatments are ineffective at frequencies below 200 Hz, and add a significant amount of weight to the structure. Piezoelectric materials (PZTs) can be used to control structural vibrations and noise without adding much weight to the structure.

In the various shunt circuit techniques, the main feature of piezoelectric materials is energy transduction. This occurs when mechanical work is done on an element and some portion is converted to and stored as dielectric energy. In a vibrating structure, a shunting network can be configured to accomplish vibration control by modifying the dynamics of the electrical system. The particular shunt circuit used for this research was a parallel resistor-inductor circuit (RLC shunt circuit), where the PZTs were represented by a capacitor and a voltage source. The result of this technique is a mass-spring system that acts as a vibration absorber. If tuned properly, this RLC vibration absorber can add significant damping to a structure.

Most of the past studies in the area of vibration suppression, however, are based on active control techniques. The particular technique used for the research conducted for this paper is a position based sensing technique that requires a generalized displacement measurement. This technique is known as Positive Position Feedback (PPF). The advantages of PPF are that the stability condition of the controller is nondynamic and the controller can be designed to attack multiple modes of the structure. This reduces a phenomenon known as “spillover,” which is caused by the presence of uncontrolled or unmodeled modes within the bandwidth of the closed loop system.

In this document, the results of both the RLC shunt technique and the active control technique are presented. These techniques are presented in terms of the reduction of vibration levels and overall controller efficiency. In addition, a comparison is made between the results obtained with the RLC shunt circuit technique and the active control technique. Next, the research objectives of this study are provided.

1.2 Research Objectives

The primary objectives of this study are:

a) Explore the feasibility of using smart materials and fiber optics for simultaneous health monitoring and active damping of a representative aircraft panel,
b) determine how optical fiber sensors may be used to detect vibration modes of an aircraft panel by investigating their use on a representative test article,
c) determine how piezoelectric patches may be used to detect and counteract fundamental resonances of a representative test article,
d) determine a control algorithm and hardware system to increase substantially the damping in the fundamental mode of the representative test article over wide temperature ranges,
e) develop a health-monitoring algorithm based on fiber optic sensors to detect impedance changes in a representative test article,
f) investigate coupling with the active damping and health monitoring by using the same hardware for each, and
g) make a comparison between the results of an RLC shunting technique conducted in an earlier study by Kristina Jeric [1] and the active control technique used for this study.

1.3 Approach

To achieve the objectives of this study, a flat 20-guage steel plate was used for testing, in conjunction with a special test rig that was validated in an earlier study [1]. These tests were setup to compare the RLC shunt circuit technique with the active control technique. A Hewlett Packard dynamic signal analyzer was used for the data acquisition system, which is described in detail in Chapter 3. In addition, an electromagnetic shaker was used to excite the plate, which was clamped in the test-rig. The active control system was implemented through Matlab's Simulink Toolbox. The health monitoring system for simultaneous active control and damage detection was implemented with a Hewlett Packard impedance analyzer. The data taken in the simultaneous active control and health monitoring tests was then compared with the results obtained by Jeric in her study of RLC shunt circuits [1].

1.4 Outline

Chapter 2 provides background information on this study on active control with PPF and the work completed by Kristina Jeric in her study of RLC shunt circuits [1]. In addition, Chapter 2 includes a discussion of piezoelectric materials and their applications, and a comprehensive literature review of related research topics. Also, a description of the shunt circuit design and active control system design are provided.

Chapter 3 focuses on the test setups for the RLC shunt circuit tests and the active control tests. The purpose of this chapter is to describe the setup for the experimental equipment used for testing in the Advanced Vehicle Dynamics Laboratory (AVDL). This chapter also includes a discussion of the test rig design and the validation tests performed on the test plate and the clamping frame. In addition, this chapter describes the data acquisition system used for the RLC shunt circuit tests and the active control tests.

Chapter 4 focuses on presenting the results obtained in the shunt circuit tests and the active control tests. This chapter describes the development of the smart test plates and the test setups used for experimentation. In addition, the results of the simultaneous active control and health monitoring tests are provided.

Chapter 5 presents a comparison between the results of the active control tests with positive position feedback and the results of the RLC shunt circuit tests. The comparison between these two methods of control is based on their effectiveness at reducing the vibration levels of the plate. This analysis takes into account both the narrowband and broadband frequency reductions. In this chapter, additional methods are developed to compare the results of the active control tests and the RLC shunt circuit tests based on how much weight was added to the undamped test plates. It should be noted that an undamped test plate is a plate without any piezoelectric materials bonded to its surface.

Chapter 6 presents the conclusions made from the research conducted in this study on active control with PPF and the study performed by Kristina Jeric [1]. This chapter also summarizes the results of the research conducted for this paper and provides recommendations for future work in the area of smart damping.