

Passive and Semi-active Vibration Control of Piezoelectric Laminates

A thesis presented
by

Sam Behrens

B.E. (Mech.)

Supervisor: Dr. S. O. Reza Moheimani

The Department of Electrical and Computer Engineering
University of Newcastle, Australia

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Declaration

I hereby certify that the work embodied in this thesis is the result of original research and has not been submitted for a higher degree to any other University or Institution.

Sam Behrens
December 2000

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Contributions

Some of the work presented in this thesis was in collaboration with Dr. S. O. Reza Moheimani and Mr. Andrew Fleming. Dr. S. O. Reza Moheimani introduced the concept of optimal shunting damping. Design, construction and testing of the synthetic impedance circuit were in collaboration with Mr. Andrew Fleming. The negative capacitance (semi-active) controller was also in collaboration with Mr. Andrew Fleming. All other theoretical work and implementation presented was solely mine.

The simply supported beam experimental apparatus was designed by myself. Mr. Russel Hicks constructed the experimental apparatus; this work included gluing the piezoelectric laminate patches onto the beam structure and the construction of the bench clamps.

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Publications

During the course of this research, a number of papers have been submitted to international journals and conferences. The following is a list of those articles, which have already appeared in an international journal or have been submitted for publication. Conference papers, which have been presented or submitted for presentation, are also listed. Technical reports and patents follow these international publications.

• Journal Publications

1. A. J. Fleming, S. Behrens and S. O. R. Moheimani. Synthetic impedance for implementation of piezoelectric shunt damping circuits, **36**(18):1525-6, *IEE Electronics Letters*, 31st August 2000.
2. A. J. Fleming, S. Behrens and S. O. R. Moheimani. Optimization and implementation of multi-mode piezoelectric shunt damping systems. Submitted to *IEEE/ASME Transactions on Mechatronics*, 2000.
3. S. Behrens, A. J. Fleming and S. O. R. Moheimani. Negative capacitor for multiple mode semi-active shunt damping of a piezoelectric laminate beam. Submitted to *IEE Electronics Letters*.

• Conference Proceedings

1. A. J. Fleming, S. Behrens and S. O. R. Moheimani. A new approach to piezoelectric shunt damping. *In: Proceedings of International Symposium on Smart Structures and Microsystems*, Hong Kong, October 2000.
2. A. J. Fleming, S. Behrens and S. O. R. Moheimani. Innovations in Piezoelectric Shunt Damping. *In: Proceedings of SPIE: Smart Structures and Devices 2000*, Melbourne Australia, 13-15th December 2000.

3. S. Behrens and S. O. R. Moheimani. Optimal resistive elements for multiple shunt damping of a piezoelectric laminate beam. *In: Proceedings of IEEE Conference on Decision and Control*, Sydney, Australia, December 2000.

- **Technical Reports**

1. A. J. Fleming, S. Behrens and S. O. R. Moheimani. Synthetic impedance for damping of smart structures. Technical Report EE0016. The Department of Electrical and Computer Engineering, University of Newcastle. March 2000.
2. S. Behrens and S. O. R. Moheimani. Optimal resistive elements for multiple mode shunt damping of a piezoelectric laminate beam. Technical Report EE0015. The Department of Electrical and Computer Engineering, University of Newcastle. March 2000.
3. S. Behrens and A. J. Fleming. Negative capacitor for multiple mode semi-active shunt damping of a piezoelectric laminate beam. Technical Report EE0045. The Department of Electrical and Computer Engineering, University of Newcastle. October 2000.

- **Patents**

An impedance synthesising arrangement, an improved vibrational damping apparatus and a method for deriving a digital signal processing algorithm. (Lodged: May 2000 - Pending)

Abstract

This thesis considers a number of related problems in the areas of passive and semi-active vibration control of piezoelectric laminates.

The thesis consists of three main parts. The first part of the thesis develops a mathematical model of a physical resonant system–piezoelectric laminated simply supported beam. It is essential to have a good understanding of the physical system so that the associated problems with passive and semi-active shunt damping can be addressed.

The second part of the thesis is concerned with problems related with current passive shunt damping techniques using a single piezoelectric laminate. One of the current problems with multiple mode techniques is determining the correct resistive damping for each resonant mode. Therefore, a systematic method is presented for determining the optimal resistance elements by minimizing the \mathcal{H}_2 norm of the damped system. After the design process, shunt circuits are normally implemented using discrete resistors, capacitors and virtual inductors (Riordan Gytrators). The difficulty in constructing the shunt circuits and achieving reasonable performance has been an ongoing problem. A new approach to implementing piezoelectric shunt circuits is presented. A “synthetic impedance”, consisting of a voltage controlled current source and digital signal processor (DSP) system, is used to synthesize the terminal impedance of a required shunt network.

The third part of the thesis is concerned with is semi-active vibration control of piezoelectric laminates. This part addresses a number of associated problems with the current passive shunt damping schemes. The foremost being the complexity of the shunt circuits required to dampen multiple modes. They generally act to minimize structural vibration at a specific frequency - which are rarely stationary. Therefore, a new broadband semi-active shunt technique for controlling multiple modes has been developed. The “negative capacitor” controller is proposed theoretically, and then validated experimentally. The negative capacitor is similar in nature to a passive shunt damper as it uses a single piezoelectric transducer to dampen multiple modes of a flexible structure.

Contents

1	Introduction	1
1.1	Piezoelectric Devices	1
1.1.1	Piezoelectricity	1
1.1.2	Piezoelectric Model	2
1.2	Overview	3
1.3	Motivations and Application	5
1.4	Outline of the Thesis	7
2	Physical Modeling	9
2.1	Dynamics of the Beam with a Piezoelectric Actuator	11
2.2	Dynamics of the Beam with a Piezoelectric Shunt Sensor	14
2.3	Dynamical Model of the Beam System	15
2.4	Experimental Boundary Conditions	20
2.5	Verification of Experimental Boundary Condition	24
2.6	Model Verification	25
2.7	Chapter Conclusion	30
3	Passive Shunt Damping	31
3.1	Introduction	31
3.1.1	Resistive Shunt Damping	31
3.1.2	Single Mode Shunt Damping	31
3.1.3	Multiple Mode Shunt Damping	32
3.2	Dynamic Model of the Composite System	34
3.3	Determining the Shunting Resistances via Optimization	36
3.3.1	Optimization Technique	37
3.4	Experimental Verification	38

3.5	Chapter Conclusion	44
4	Synthetic Impedance	45
4.1	Introduction	45
4.2	Implementation of Shunt Damping Circuits	46
4.2.1	The Synthetic Impedance	46
4.2.2	Circuit Diagram / Transfer Function Equivalence	47
4.3	Experimental Results	48
4.3.1	Synthesis of Impedance	49
4.3.2	Test Example: Synthesizing a series $R - L$ impedance	50
4.3.3	Shunt Damping Performance	51
4.4	Synthetic Impedance vs Direct Circuits	52
4.5	Chapter Conclusion	58
5	Shunt Damping using a Negative Capacitance Circuit	59
5.1	Introduction	59
5.2	Modeling the Composite System in Transfer Function Form	60
5.3	Developing the Negative Capacitance Controller	65
5.4	Optimal R Damping using \mathcal{H}_2 norm Optimization	66
5.5	Simulated Results	67
5.6	Experimental Results	68
5.6.1	Creating the Negative Capacitance	68
5.6.2	Test Example: Negative Capacitance	70
5.6.3	Semi-active Shunt Damping	71
5.7	Chapter Conclusion	72
6	Conclusions and Further Research	75
6.1	Conclusion	75
6.1.1	Physical Modeling	75
6.1.2	Passive Shunt Damping	75
6.1.3	Synthetic Impedance	76
6.1.4	Shunt Damping using a Negative Capacitance Circuit	76
6.2	Suggestions for Further Research	77
6.2.1	Active Shunt Controllers	77
6.2.2	Negative Capacitance (Semi-active Controller)	77

A	Summary of Active Inductors	78
A.1	Grounded Simulated Inductor	78
A.2	Floating Simulated Inductor	79
B	Beam Parameters	81
C	Shim Parameters	82
D	PIC151 PZT Piezoelectric Parameters	83

List of Figures

1.1	Two equivalent electrical models for a piezoelectric shunting layer: (a) parallel and (b) series piezoelectric equivalent models.	2
1.2	F-22 Jet Fighter (Boeing-Lockheed Martin-Pratt & Whitney 2000).	6
1.3	“Smart Ski Technology” (K2 Sport 2000).	6
2.1	(a) Cross-section of the beam with piezoelectric laminates present; and (b) the piezoelectric laminated simply supported beam.	10
2.2	Anti-symmetric piezoelectric actuator.	11
2.3	Decomposition of <i>wafer</i> strain distribution: (a) asymmetric strain distribution, (b) flexural component and (c) longitudinal component [10].	12
2.4	Torsional spring boundary conditions.	21
2.5	Experimental boundary conditions, $L_{sh} = 5mm$	21
2.6	Shim material with a moment load at the free end, i.e. a fixed-moment beam.	21
2.7	Experimental simply supported piezoelectric laminated beam, $L_{sh} = 5mm$	24
2.8	First mode, $\omega_1 = 20.63Hz$	25
2.9	Second mode, $\omega_2 = 75.31Hz$	26
2.10	Third mode, $\omega_3 = 171.3Hz$	26
2.11	Fourth mode, $\omega_4 = 306.6Hz$	27
2.12	Fifth mode, $\omega_5 = 474.4Hz$	27
2.13	Frequency responses of a) $ G_{vv}(s) $, b) $ G_{yv}(0.170, s) $: experimental (\cdots) and modeled results ($—$).	29
3.1	Examples of single mode shunt circuits: (a) parallel case and (b) series case.	32
3.2	Examples of multiple mode shunt circuits: (a) parallel case [28] and (b) series case.	33
3.3	Shunt piezoelectric element schematic.	35
3.4	Parallel case: $G_{yv}(0.170, s)$ \mathcal{H}_2 norm cost surface as a function of R_1 and R_2	39

3.5	Series case: $G_{yv}(0.170, s)$ \mathcal{H}_2 norm cost surface as a function of R_1 and R_2 .	39
3.6	Experimental parallel shunt circuit for R_1, R_2, L_1, L_2, L_3 and C_3	40
3.7	Experimental series shunt circuit for R_1, R_2, L_1, L_2, L_3 and C_3	40
3.8	Parallel and series shunt circuit cases of $ G_{yv}(0.170, s) $: theoretical (—) and experimental results (\cdots).	41
3.9	Experimental time responses, $V_{el}(0.170, s)/V_a(s)$	42
4.1	Current source implementation.	46
4.2	Parallel block equivalence.	48
4.3	Series block equivalence.	49
4.4	Ideal test circuit.	50
4.5	Test circuit with synthetic impedance.	51
4.6	Theoretical (—) and experimental (\cdots) frequency responses, $ V_c(s)/V_z(s) $	52
4.7	Admittance transfer function: (a) parallel and (b) series multi-mode shunts.	53
4.8	Parallel and series shunt circuit cases, $ G_{yv}(0.170, s) $: experimental (\cdots) and theoretical results (—).	54
4.9	Experimental time domain results, $V_{el}(0.170, s)/V_a(s)$	55
4.10	Compare 2nd mode theoretical model with experimental synthetic impedance and direct circuit results.	56
4.11	Compare 3rd mode theoretical model with experimental synthetic impedance and direct circuit results.	57
5.1	Flexible structure with piezoelectric patches attached.	61
5.2	Schematic of piezoelectric shunting layer with a shunting impedance Z present.	62
5.3	Composite system transfer function block diagram.	64
5.4	Negative capacitance controller with appropriate damping resistance.	66
5.5	$G_{yv}(0.170, s)$ \mathcal{H}_2 norm plotted against resistance R (Ω), for 5 modes.	67
5.6	Simulated responses: $ G_{yv}(0.170, s) $ undamped (\cdots) and $ \hat{G}_{yv}(0.170, s) $ damped system (—).	68
5.7	$G_{yv}(0.170, s)$ undamped poles (o) and $\hat{G}_{yv}(0.170, s)$ damped poles (\times).	69
5.8	Example of a negative impedance converter.	69
5.9	Test circuit with negative capacitance present.	71
5.10	Frequency responses $\tilde{V}_{out}(s)/\tilde{V}_{in}(s)$ of the test circuit: ideal (\cdots) and experimental results (—).	73

5.11	Experimental responses: $ G_{yv}(0.170, s) $ undamped (\cdots) and $ \hat{G}_{yv}(0.170, s) $ damped system ($—$).	74
6.1	Current controlled voltage sources.	77
A.1	Simulated grounded inductor.	79
A.2	Simulated floating inductor.	80

List of Tables

2.1	Model frequencies: mathematical models vs experimental results.	30
2.2	Damping parameters determined experimentally.	30
3.1	Summary of resistance damping elements.	43
3.2	Summary of magnitude reduction results.	43
3.3	Summary of experimental time results.	43
4.1	Circuit values: theoretical model, virtual circuit and synthetic impedance.	54
4.2	Compare amplitude reduction using benchmark circuit values: theoretical model, synthetic impedance and virtual circuit.	55
5.1	Parameters of negative capacitance test circuit.	71
5.2	Amplitude reduction: simulations and experimental results.	72
B.1	Parameters of the simply supported beam.	81
C.1	Parameters of the shim material.	82
D.1	Parameters of the PIC151 piezoelectric patches.	83