Chapter 7

Conclusions

7.1 Summary

A special test rig was constructed and validated for the purpose of achieving the objectives of this study, which included evaluating the feasibility and noise, vibration, and harshness effectiveness (NVH) of smart damping materials for augmenting the performance of passive damping materials. Passive damping materials fulfill a role that the passive dampers cannot perform: damping at selected discrete frequencies. The tests further included SAE J1400 tests, conducted at a transmission loss test facility, in order to evaluate the effects of smart materials on sound transmission loss. The test results indicated that, with the application of smart damping, it is possible to decrease

- vibration peaks by up to 22 dB,
- broadband vibrations by up to 11 dB, and
- broadband sound pressure levels by up to 4.7 dB SPL.

The test results further indicated strong commercial potentials for smart damping materials in terms of

1. extending the benefits of the passive damping treatments used currently for automotive markets, and

2. providing equivalent or improved performance at selected frequencies with weight savings as measured by noise and vibration reduction per added weight, in comparison with passive damping treatments.

7.2 Recommendations for Future Research

The test results identified strong potential benefits of smart damping materials for multiple applications. In addition to automotive and aerospace applications, smart damping treatments that were considered in this study can be used in other applications such as home appliances, disk drives, and microelectronic components.

Another area that deserves further investigation is evaluating alternative shunting techniques, such as those mentioned in the literature review of Section 2.3, for better control of vibration in various structural and acoustical modes. For example, more tests should be conducted with the alternative shunt design with a parallel RL circuit that was investigated by Wu [20] and the multi-mode shunt circuit demonstrated by Wu and Bicos [21]. An alternate shunt method might reduce the time required for the tuning process and a multi-mode shunt will reduce the number of PZTs required for the same amount of damping. Another method that might help expedite the tuning process would be to utilize a data acquisition system that can provide a real-time response so that the shunt components can be continuously tuned. More research should also be performed on the optimization of piezoceramic placement and modeling. In practical applications, it is more difficult to experimentally determine areas of high strain for vibrating structures that are more complicated than a plate. Finite element modeling could prove to be useful in determining these areas that are ideal for PZT placement. The finite element model could also be used to theoretically predict the damping performance of different PZT configurations.

For future research in regards to the research presented in this paper, the ultimate benefits and application of smart materials should be determined by applying the materials to actual automotive structures in the field, laboratory, or both. A more complex structure such as a stripped car body, a 'body-in-white,' would be ideal for future research on the application of smart damping for automotive benefits.

References

1. Eisenstein, Paul A., "NVH: The New Battleground," *Automotive Industries*, Vol. 174, pp.108-111, February 1994 .

2. Lord Corporation Website: http://www.lordtalent.com

3. Encarta Concise Encyclopedia Online Website: http://encarta.msn.com

4. *IEEE Standard on Piezoelectricity: Std 176-1987*, The Institute of Electrical and Electronics Engineers, Inc, 1988.

5. Sensor Technology Limited Website: http://www.sensortech.ca/fig1-3.html

6. Hagood, N. W. and von Flotow, A., "Damping of Structural Vibrations with Piezoelectric Materials and Passive Electrical Networks," *Journal of Sound and Vibration, Vol. 146*, No. 2, pp.243-268, April 1991.

7. Mulcahey, B. and Spangler, R. L., "Peizos Tame Tough Vibrations," *Machine Design, Vol. 70*, No. 4, pp. 60-63, February 1998.

8. "Batter Up! Piezo Dampers Take Sting Out of Swing," *Machine Design*, *Vol. 70*, No. 15, pp. 46-47, August 1998.

9. Sun, J.Q., Norris, M.A., Rossetti, D.J., and Highfill, J.H., "Distributed Piezoelectric Actuators for Shell Interior Noise," *Transactions of the ASME Journal of Vibration and Acoustics*, Vol. 118, No.4, pp. 676-681, October 1996.

10. Shields, W., Ro, J., and Baz, A., "Control of Sound Radiation from a Plate into an Acoustic Cavity Using Active Piezoelectric-Damping Composites," *Proceedings of the SPIE-The International Society for Optical Engineering, Vol. 3039*, pp. 70-90, 1997.

11. Varadan, V.V., Wu, Z., Hong, S.Y., and Varadan, V.K, "Active Control of Sound Radiation from a Vibrating Structure," *IEEE 1991 Ultrasonics Symposium Proceedings*, Vol. 1386, pp. 991-994, 1991.

12. Varadan, V.V., Gopinathan, S.V., Hun Lim Young, and Varadan, V.K., "Radiated Noise Control via Structural Vibration Control," *Proceedings of the SPIE-The International Society for Optical Engineering, Vol. 3323*, pp. 546-553, 1998.

13. Lecce, L., Franco, F., Maja, B., Montouri, G., and Zandonella, N.C., "Vibration Active Control Inside a Car by Using Piezo Actuators and Sensors," *28th International Symposium on Automotive Technology and Automation*, pp. 423-432, 1995.

14. Henrioulle, K.K., Dehandschutter, W., and Sas, P., "Increasing the Sound Transmission Loss Through a Double Panel Partition Using a Distributed Acoustic Actuator," *Journal-A, Vol. 39*, No. 1, pp. 30-34, March 1998.

15. Xiaoqi, B., Varadan, V.V., and Varadan, V.K., "Active Control of Sound Transmission Through a Plate Using a Piezoelectric Actuator and Sensor," *Smart Materials and Structures, Vol. 4*, No. 4, pp. 231-239, December 1995.

16. Forward, R.L., "Electronic Damping of Vibrations in Optical Structures," *Applied Optics, Vol. 18*, No. 5, pp. 690-697, March 1979.

17. Davis, C.L., and Lesieutre, G.A., "A Modal Strain Energy Approach to the Prediction of Resistively Shunted Piezoceramic Damping," *Journal of Sound and Vibration, Vol. 184*, No. 1, pp. 129-39, 1995.

18. Edberg, D.L., Bicos, A.S., and Fechter, J.S., "On Piezoelectric Energy Conversion for Electronic Passive Damping Enhancement," *Proceedings of Damping*, San Diego, CA, 1991.

19. Hollkamp, J.J., "Multimodal Passive Vibration Suppression with Piezoelectric Materials and Resonant Shunts," *Journal of Intelligent Material Systems and Structures, Vol. 5*, No. 1, pp. 49-57, January 1994.

20. Wu, S.Y., "Piezoelectric Shunts with Parallel R-L Circuits for Structural Damping and Vibration Control," *Proceedings of the SPIE, Vol. 2720*, pp. 259-269, June 1996.

21. Wu, S.Y., and Bicos, A.S., "Structural Vibration Damping Experiments Using Improved Piezoelectric Shunts," *Proceedings of the SPIE-The International Society for Optical Engineering, Vol. 3045*, pp. 40-50, 1997.

22. Hollkamp, J.J., and Gordon, R.W., "An Experimental Comparison of Piezoelectric Constrained Layer Damping," *Smart Materials and Structures, Vol. 5*, No. 5, pp. 715-722, October 1996.

23. Ghoneim, H., "Application of the Electromechanical Surface Damping to the Vibration Control of a Cantilever Plate," *Journal of Vibration and Acoustics, Vol. 118*, pp. 551-557, October 1996.

24. Aldrich, J.B., Hagood, N.W., von Flotow, A, and Vos, D.W., "Design of Passive Piezoelectric Damping for Space Structures," *Proceedings of the SPIE-The International Society for Optical Engineering, Vol. 1917*, No. 2, pp. 692-705, 1993.

25. Edberg, D.L., Bicos, A.S., "Design and Development of Passive and Active Damping Concepts for Adaptive Space Structures," *Active Materials and Adaptive Structures-*

Proceedings of the ADPA/AIAA/ASME/SPIE Conference, Vol. 925, pp. 377-382, 1992.

26. Hollkamp, J.J., and Starchville, T.F., "A Self-Tuning Piezoelectric Vibration Absorber," *Journal of Intelligent Material Systems and Structures, Vol. 5,* pp. 559-566, July 1994.

27. Davis, C.L., Lesieutre, G.A., "An Actively-Tuned Solid State Peizoelectric Vibration Absorber," *Proceedings of the SPIE-The International Society for Optical Engineering, Vol. 3327,* pp. 169-82, 1998,.

28. Horowitz, P. and Hill, W., *The Art of Electronics,* Cambridge University Press, Cambridge, pp. 281, 1989.

29. Beis, D.A., and Hansen, C.H., *Engineering Noise Control: Theory and Practice*, E&FN Spon, London, UK, 1996.

30. "Laboratory Measurements of the Airborne Sound Barrier Performance of Automotive Materials and Assemblies," *SAE Standards,* Document Number J1400, May, 1990.