Final Report for NSF# 0116240 "Design of Piezoelectric-Elastomer Composites for Use as Tunable Absorbers"

1 Participants

1.1 People

1.1.1 Faculty

- Paris von Lockette, PI, Mechanical Engineering, Rowan University, NJ
- Eric Constans, co-PI, Mechanical Engineering, Rowan University, NJ
- Jennifer Kadlowec, co-PI, Mechanical Engineering, Rowan University, NJ
- Raul Ordonez (year 1), co-PI, Electrical Engineering, University of Dayton, OH
- Ravi Ramachandran (year 2) , co-PI, Electrical and Computer Engineering, Rowan University, NJ

1.1.2 Rowan Undergraduate Students

- Mechanical Engineering: Jennifer Akers, Richard Johnson, John Masiello, Joeseph Westenberger, Kenny Beverly, Matt Smith, Scott Perkis
- Electrical Engineering: David Drozd, Stephan Krause, Greg Digneo, Jeff Gladnick, Matt King

1.1.3 Rowan Graduate Students

- Nishanth Chamala, Vishal Kayatham
- Steven Miller (Master's Thesis, 12/03)

1.2 Organizations

- Rowan University Materials Group

2 Activities and Findings

2.1 Research Activities and Findings

The grant sought to determine the feasibility of using the nonlinear hyperelastic properties of elastomers and the active capabilities of piezoelectric materials to create tunable vibration absorbers. The grant produced one Master's thesis and several undergraduate projects.

The grant was successful in developing a prototype which used a controllably-compressed elastomer bushing to reduce the amplitude of vibration transmitted to a test system by a dynamic shaker. The work showed that attenutation could be achieved over a range of 50-220 Hz, see Figures.. The attenuation due to the tuning of the absorber (decoupled from the mass of the absorber) had a maximum value between 6-25 dB over that range, see Figures. The grant further determined the requirements of the piezoelectric actuator needed to drive the tunable system. Based on the properties of a single PXE HPA #4322-020-1907 actuator from American Piezoceramics, the system studied would yield a frequency range of +/- 8% of the passive absorber resonance. The results indicate that for good control the piezoelectric-elastomer composite absorber will be restricted to systems where the primary mass's inertia is low with respect to the piezoelectric actuation force. Another option is the use of more complicated parallel actuation arrangements to increase the driving force of the actuators.

2.2 Educational and Outreach Activities

Interdisciplinary Course Modules: Electrical and Computer Engineering professors teaching junior level *Digital Signal Processing* courses developed laboratory course materials which covered methods of modeling the tunable absorber problem as a circuit. The modules included comparing analytical dynamics theory with simulated circuit analysis. Students were tested on the concepts taught in lab. Course evaluations showed that students agreed (average score of 4.0/5, n=23) that "the laboratory assignment on modeling mechanical systems as circuits enhanced your appreciation of the multidisciplinary nature of circuit", as asked in the evaluation.

Vertical Integration: This grant utilized graduate students and undergraduates in a vertically integrated learning environment. Graduate students worked on laying the theoretical foundations and final prototyping of the experimental test setups, while undergraduates built initial prototypes and ran basic experiments. Both groups worked side-by-side in the same laboratory environment which facilitated the flow of knowledge, information, and ideas.

Junior/Senior Engineering Clinics: The Engineering Clinics are Rowan's capstone design courses. During these courses, groups of students involved in the research were taught elastomer constitutive theory and the relevant physics to understand the projects. Undergraduate students then worked alongside graduate students running experiments and fabricating prototype devices.

Summer Institute in Materials Science: Graduate and undergraduate students working on the project gave demonstrations to 40 high school seniors and 10 high school teachers attending Rowan's Institute in Materials Science over the two years.

Materials Science and Manufacturing Courses: The undergraduate students working on the project gave demonstrations to the PI's Materials Science and Manufacturing courses reaching approximately 60 students over the two years.

2.3 Training Opportunities

The project has trained roughly 20 undergraduate students and 3 graduate students on vibrational data collection and experimentation techniques.

3. Products

Publications: The PI and graduate students are working on a manuscript for the *International Journal of Smart Materials and Structures*.
Web Sites: www.personal.rowan.edu/~vonlocke/reserach#smart
Products: A student built device for vibration isolation is used regularly for classroom demonstrations and outreach events.

4. Contributions

4.1 Principal Discipline

Publications will provide a design envelope for piezoelectric-elastomer composites used as tunable absorbers, giving useful limits for frequency/attenuation ranges based on the characteristics of the primary system being attenuated and the available piezoelectric actuators.

4.2 Other Disciplines

Publications will yield a theory of piezoelectric-elastomer composite behavior that includes the full nonlinear-hyperelastic behavior of the elastomer. Current models either neglect hyperelasticity, or assume linearity, of the rubber during deformation.

4.4 Infrastructure for Research and Education

The grant has improved the PI's and co-PI's ability conduct research at Rowan by

- Providing funds for research specific equipment
- Helping the PI's establish a research group of faculty, graduate students, and groups of undergraduates

The grant has aided institutional goals by

- Fostering interdisciplinary projects in the Engineering Clinics
- Improving our ability to develop interest in science and engineering in K-12 students through outreach activities
- Improving our ability to aid the region by training K-12 educators in providing science/engineering content.

5. Figures

The figure below shows the frequency response curves of the prototype vibration absorber. The ticks represent increasing levels of precompression in the elastomer bushing which induce the nonlinear-elastic response. The graph shows the shift in natural frequency of the absorber (identified by the peak in the frequency response curve) with increasing ticks (or pre-compression). The figure is taken from the master's thesis of Steven Miller.

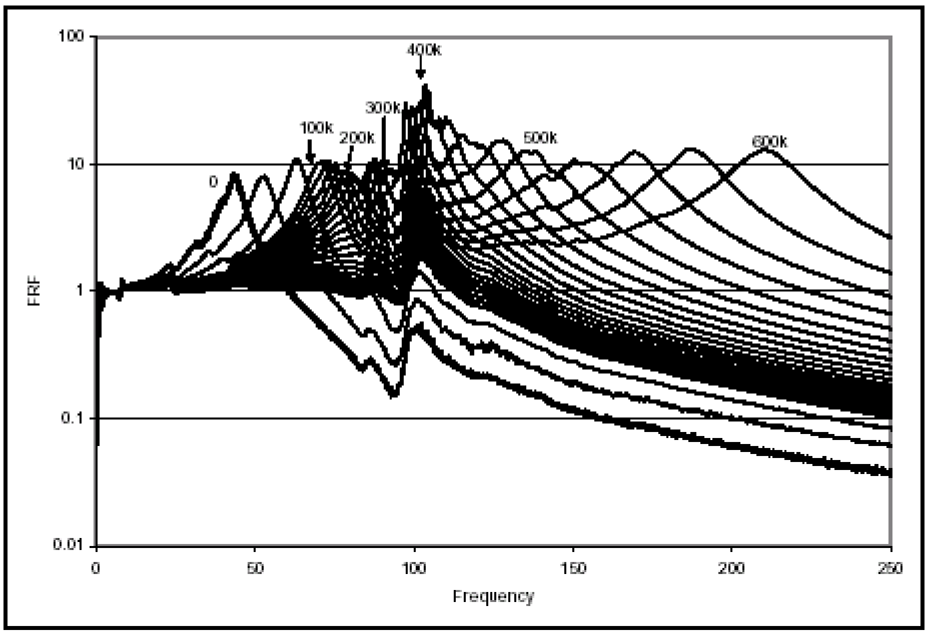

Figure 4.6: A plot of the frequency response curves of the absorber mass with respect to the primary system with the servo at positions ranging from 0 to 600,000 ticks in intervals of 25,000 ticks. The curves are labeled at intervals of 100,000 ticks. Notice that the resonance peaks shift fastest between 400k and 600k and between 0 and 100k, but more slowly between 100k and 400k.

The figure below shows the total, mass, and tuning attenuations of the absorber over a range of frequencies. The total attenuation is decomposed into mass attenuation and tuning attenuation. The mass attenuation shows the effect an un-tuned absorber mass would have on the system whereas the tuning attenuation shows the actual effect of tuning the stiffness of the absorber mass. The majority of the attenuation is due to the tuning effect. The figure is taken from the master's thesis of Steven Miller.

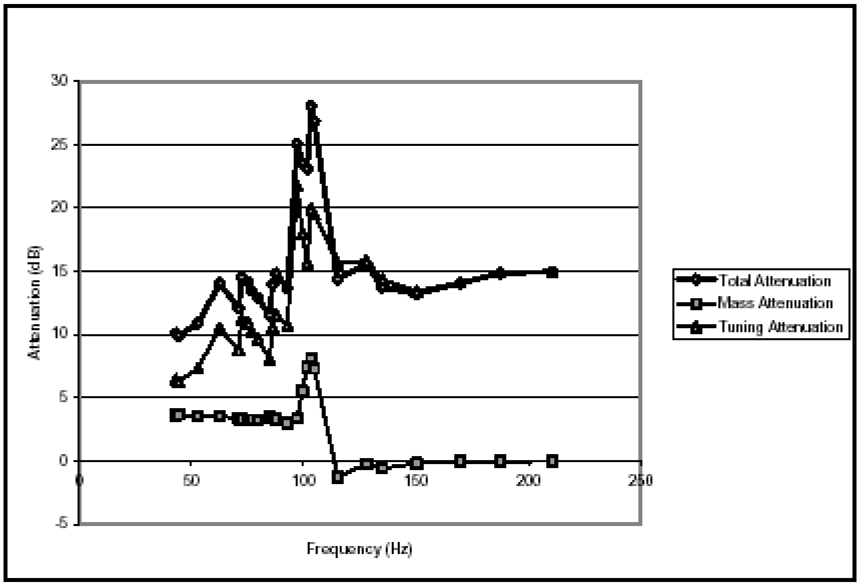

Figure 4.10: A plot of the total, mass, and tuning attenuation metrics for the experimental apparatus for different tuned frequencies. The frequency axis indicates the tuned frequency state of the absorber prototype during the test. Each test is indicated by the markers along the test curves.