

DESIGN OF ELASTOMERIC-PIEZOELECTRIC CERAMIC SMART-STRUCTURES
FOR USE AS TUNED RESONATORS

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ABSTRACT

The process of developing a tunable absorber device is discussed. A smart material composite - piezoelectric device embedded within a silicone rubber matrix - will be analyzed (as the tunable absorber). In order to understand the behavior of the composite, so as to be able to implement it as the desired device, testing will be performed on both the elastomer and composite.

INTRODUCTION

Investigating the use of smart materials in mechanical applications has become a very important and valuable field. Of particular interest for Rowan University has been the development of the smart composite combination of an elastomer and piezoelectric ceramic actuator. These composite structures will possess both the versatility of rubber along with the controlling actuation of the piezoceramic. By understanding and characterizing the properties of the composite, it is the ultimate goal of the project to design, build, and control a tunable absorber device.

The National Science Foundation has provided the funding for this project and seeks to promote the progress of science. Therefore this project should ultimately be able to influence and enlighten the field of science and engineering technology. For this project, the classical tuned resonator problem will be considered as represented in Figure 1.

Here, a cantilever beam is attached to a dynamic shaker with Mass 1 attached rigidly to the underside of the beam. On the topside of the beam, above Mass 1 is an elastic body. A second mass, Mass 2, is then attached to this elastic body.

The shaker will provide an input to the system, causing the beam to vibrate. The desired effect will be to alter the stiffness in the elastic body, such that the beam and Mass 1 will not oscillate regardless of the dynamic input to the system. To better illustrate how this can be done, consider the two degree of freedom spring-mass system shown in Figure 2, which is analogous to Figure 1.

The solution to the two degree-of-freedom system presented in Figure 2 is well known:

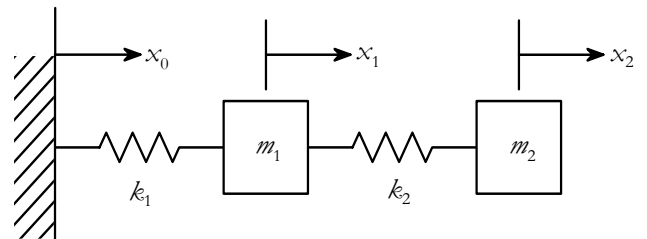


Figure 2: Two DOF model with two masses and springs

$$(1) \quad x_1 = A_1 \cos \omega t \quad x_2 = A_2 \cos \omega t$$

where

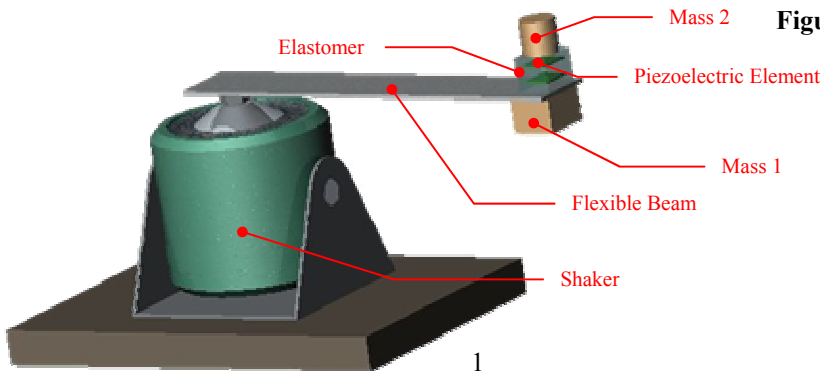


Figure 1: Tuned Resonator

$$(1a) \quad A_1 = \frac{A_0 k_1 (k_2 - m_2 \omega^2)}{(k_2 - m_2 \omega^2)(k_1 + k_2 - m_1 \omega^2) - k_2^2}$$

$$A_2 = \frac{A_0 k_1 k_2}{(k_2 - m_2 \omega^2)(k_1 + k_2 - m_1 \omega^2) - k_2^2}$$

From this solution it can be seen that when $k_2 = m_2 \omega^2$ the displacement of Mass 1 will equal zero, i.e. the motion of mass 1 is suppressed. This occurs because the inertial force has been shifted to Mass 2 as it resonates [1].

In the analogous system presented in Figure 2, the bending stiffness of the beam provides the first element stiffness of the 2 DOF system k_1 ; m_1 and m_2 correspond to the first and second masses in both the resonator and 2 DOF systems. Most importantly, the elastic body provides the second spring stiffness k_2 . The system of Figure 1 is governed by equation 2 as is the system in Figure 2 and consequently by careful choice of the stiffness of the elastic body, it is possible to suppress the motion of Mass 1, the tip of the beam [1].

The goal of this project is to develop a composite structure whose compressive stiffness is controllable. This device is then utilized as the elastic body in figure 1 and thereby allows dynamic control of the stiffness k_2 .

PREVIOUS WORK

Previous research has been done to test and analyze piezoelectric actuator behavior. In an early clinic project, a Serially-Mounted Force Absorber (Spring 2001) was fabricated and tested. Here, the composite was composed of a cylindrical actuator embedded inside a cylindrical body of elastomer and was subsequently tested. The basic purpose behind experimentation was to send a sinusoidal force, produced by a shaker, through the composite and attempt to reduce the magnitude of the force translated through the composite (Figure 3).

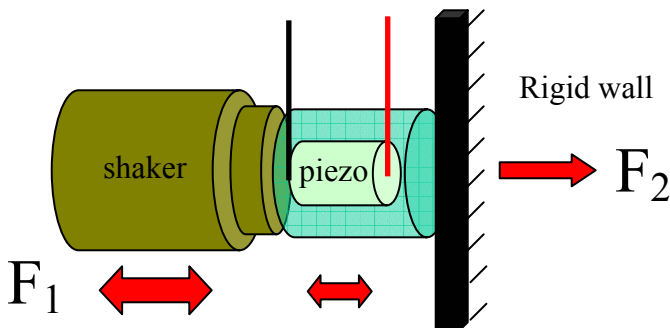


Figure 3: Serially-Mounted Force Absorber

In this project, the students were able to excite the crystals in the piezo and measure vibrations at the surface of the composite, but were unable to alter the stiffness of the composite structure, which would be required in order to decrease the translated force.

A second style composite was designed and fabricated by another clinic team (Fall 2001). This composite is the proposed design to be used as the tunable absorber for current testing. The proposed device uses two piezoelectric bending elements embedded again in an elastomer matrix in parallel orientation as shown in Figure 4.

Application of an electric field across each piezoelectric element causes them to bend thereby pre-stressing the matrix

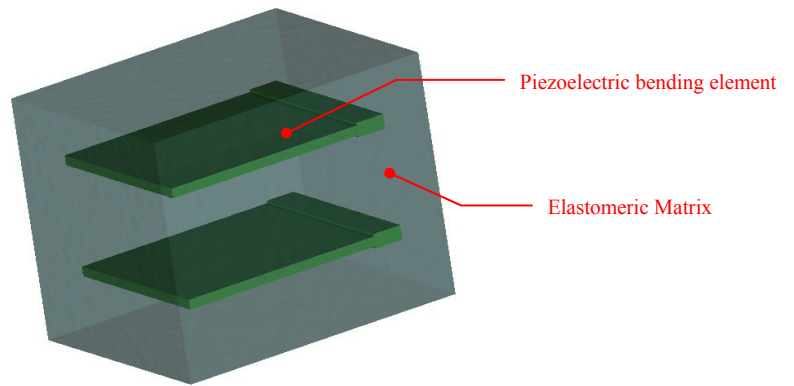


Figure 4: Elastomer-piezoelectric smart composite

which produces a change in the stiffness of the composite. The amount by which the stiffness can be varied is a function of the force-deflection characteristics of the piezoelectric material, the stress-stretch behavior of the elastomer matrix, and the geometry of the composite.

The elastomer used in both composites is a two-part RTV (room temperature vulcanizing silicone resin) encapsulant. It is flexible and optically clear.

CURRENT OBJECTIVES

This proposal focuses on the development, testing, and modeling of tunable resonators made of piezoelectric-elastomer composite material.

The primary objectives for Spring Semester 2002 and beyond are to test both the elastomer and composite, develop a constitutive model for the elastomer-piezoceramic composite, and develop a control algorithm for the tunable absorber. Currently, this semester's clinic team is performing the necessary testing of both elastomer and composite. A graduate student is researching possible modeling techniques for the

composite and an additional student has been employed to develop the control algorithm.

Testing

In order for a constitutive model to be accurately developed, testing of the elastomer and composite are required to aid in its validation. The compressive testing of both elastomer and composite is performed under quasi-static conditions. The main deliverable for quality assessment of the collected testing data is that it must demonstrate repeatable results.

The testing was performed on an MTS Elastomer testing machine. Last semester’s clinic team ordered platens for the MTS machine and several load cells (5, 10, and 5000 lb load cells). The MTS machine was set up to perform vertical compressive tests on a sample placed between two platens. In addition, this team obtained appropriate power supplies to power the actuators for performing the composite testing.

The first series of tests were performed on the elastomer alone. Small diameter samples were tested. The initial testing, done on the platens alone at low frequency, 0.01Hz, proved to be inconsistent because sticking occurred between the platen and elastomer sample (Figure 5).

repeatable tests are shown. In this case the operating frequency was 0.01Hz and the obtained modulus, or slope of the line on the stress vs. stretch graph is approximately 55.5psi.

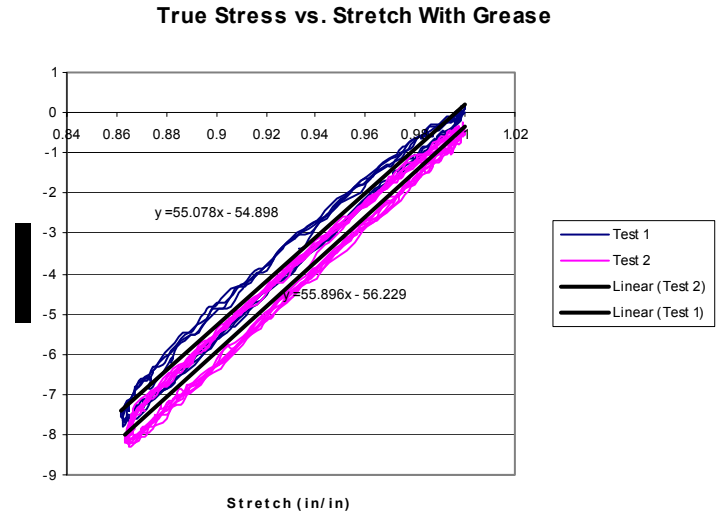


Figure 6: Elastomer Testing with Grease on Teflon

The testing of the composite is currently in progress. In this line of testing again repeatable results are desired, but in addition, a measurable difference in stiffness between modes and at different voltages will also need to be apparent. A switch was developed this semester that would control the different modes of the composite. The possible piezoelectric states can be seen in Figure 8. In order to prevent the power supply from damaging the composite by burning out the piezos, a breaker was also developed. Testing was performed on the composite using a 5000lb load cell. This preliminary testing has been unable to show any measurable difference between the un-activated and activated composite states (Figure 7).

True Stress vs. Stretch for Dry Sample

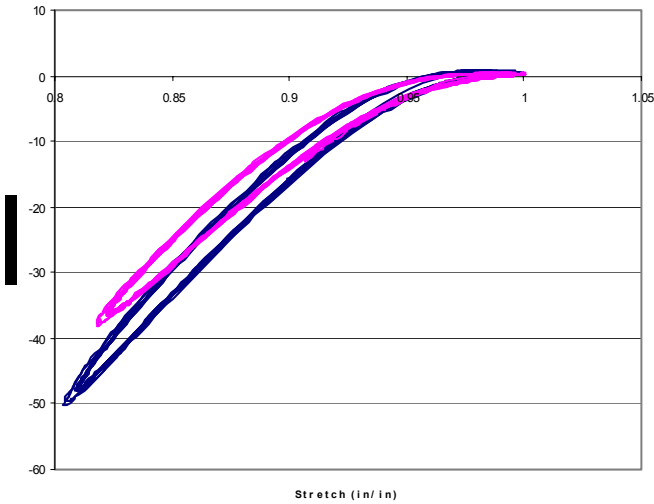


Figure 5: Initial Elastomer Testing Results

In order to eliminate this problem, Teflon sheets were attached to the platens and silicon grease was applied to the sample to allow it to slide more freely. The Teflon was much stiffer than the elastomer and only a very small amount of grease was added, so their effects were considered negligible. Several combinations of grease, Teflon, and testing frequency were made before repeatable results were obtained. In Figure 6, two

Composite Testing

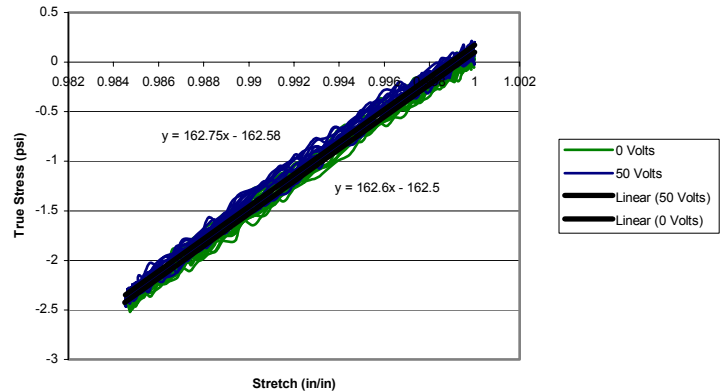


Figure 7: Composite Testing at 0.01Hz Actuators Up

Because there was no apparent change in modulus while using the 5000lb load cell, a more sensitive load cell was implemented. In order to perform this line of composite testing several other components needed to be manufactured. There were complications with performing the transfer to the 5 and 10lb load cells. An adapter had to be made to attach the 5/10lb load cell to the 5000lb load cell. This attachment was a steel converter with a 1/2-20 threaded end on one side and a 1/4-28 on the other. A second adapter had to be made to attach the smaller load cell to the platen without interfering with the center threads of the load cell. Once these adapters were completed, composite testing was again performed. In this case however, the load cells proved to be too sensitive in that they were only able to assess force at up to 1% strain before the load cell capacity was exceeded. At this small amount of strain, a recognizable difference in modulus was again not noticeable.

Switch and Limiter Details

The purpose of the switch is to flip between states without having to be rewired to the power supply. The design of the switch was to just use 2 DPDT switches, with one pole of the switch connected to the 500V power supply, and the other connected to ground. This setup provides 4 states for the actuators to be in, as shown in Figure 8.

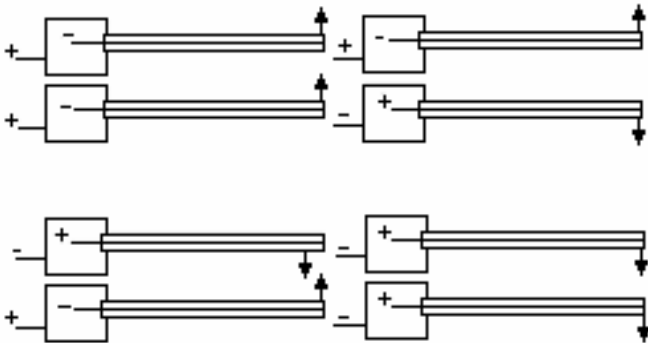


Figure 8: The four states of the two actuators

This design requires a voltage limiter to reduce the voltage coming from the power supply to the voltage level desired at the input of the actuators. This limiter consists of a 250K potentiometer and an NPN transistor. The 500V supply will be coupled in parallel with the potentiometer and the source of the transistor. The other end of the potentiometer gets connected to the gate of the transistor. The amount of voltage that passes through the circuit depends on how much voltage is dropped across the potentiometer. The potentiometer allows excess voltage to be dropped to ground. Adjusting the voltage and current at the base of the transistor, will in turn adjust current at the collector. The gain of the transistor can be determined by using the equation below:

$$i_C = \beta \cdot i_B$$

Control Algorithm

The purpose is to get a control of the actuator so that it will hopefully counter act the force acting upon it. The control algorithm will use Matlab to link the power supply to a Keithley multimeter and an Arbitrary Waveform generator. Theoretically, the multimeter will read in a voltage and send it to MatLab where this value will get put into a transfer function. This transfer function is then sent to the waveform generator, which is hooked up to the power supply. The generator will then change the voltage sent to the actuators, such that they sill counteract the force acting upon them. This will cause the system to be damped. Then, whole process will cycle over again.

Future Work

If a recognizable effect is obtained using the sensitive load cell, then the constitutive model can be validated. If this is not possible, then a new composite will have to be fabricated. For this new composite, piezoelectric actuators will be adhered to the elastomer using RTV 3145 Silicon Adhesive purchased from Dow Corning. The actuators will be exposed on the outer surfaces and tested to determine if they demonstrate a measurable effect. Once testing is complete, the model can be validated and the control algorithm can be instituted. This semester’s work focuses primarily on this testing. In addition, a constitutive model of the composite will be developed and validated with the collected test data, and finally a control algorithm will be designed to implement the tunable absorber.

TECHNICAL IMPACT STATEMENT

Economic

- The materials purchased in this and previous semesters include:
- Gelest OE™ 41
- Piezoelectric Actuators
- Load Cells (5lb, 10lb, 50lb, 5000lb)
- Platens
- Power Supply
- Switch and Limiter Equipment
- Material for Adapters
- Grease and Teflon Sheets
- RTV Silicon

Thus far, above list has been funded from previous projects, or from NSF.

Environmental

In general, the materials used are non-toxic. The composites were fabricated under a protective fume hood, and proper waste disposal was followed.

Sustainability

Silicon and oxygen are the two key elements used in making the synthetic polymer silicone. Silicon is the second most abundant element in the earth’s crust. It comprises about 28%

of the crust. Oxygen of course, is readily available for use in making the silicone. Though silicone is not found naturally, the mass production of the composites would not deplete the supplies of the elements needed substantially.

3. B. Arkles, Silicon, Germanium, Tin, and Lead Components, Tullytown,PA: Gelest, Inc., 1998.

Manufacturing

A mold for the composite was previously manufactured from aluminum using lathes and milling machines found in Rowan's machine shop. The procedure for creating the composite has been outlined by previous clinic teams and can be followed for future composite production.

Social/Societal

The National Science Foundation has provided the funding for this project, therefore this project should ultimately be able to influence and enlighten the field of science and engineering technology. By investigating tunable absorber technology, a better understanding of smart composites will be attained. In addition, because of the device's functionality, there are numerous applications that will be enhanced by tunable absorber technology including: engine cylinder covers, soundproofing of windows, automotive soundproofing, and general vibration damping. In addition, the development of this tunable absorber device can be used for in class demonstrations.

Health and Safety

The polymer alone is not a very dangerous substance. However, it is recommended that the user handle the substance in a well-ventilated area. Gelest does not specify if any extremely toxic chemicals are present within the kit.

ACKNOWLEDGMENTS

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