Session 3264

The Use of Piezoelectric Materials in Smart Structures

D. M. Pai[1] and N. R. Sundaresan[2]
[1]Center for Advanced Materials and Smart Structures
[2]Summer Research Student, NASA Center for Aerospace Research
Department of Mechanical Engineering
North Carolina A&T State University
Greensboro, NC 27411

Abstract

A piezoelectric material is basically a ceramic that outputs a voltage upon being mechanically strained. Sensors made of this material are sensitive enough to generate signals when subjected to low-amplitude mechanical waves such as sound waves traveling through solids. This makes them candidate materials for all kinds of exciting applications. For example, sensors mounted on a wing surface could detect ice formation on the wing using surface active waves. Since the velocity of sound in a given medium is a function of temperature, such sensors are also being used to actually measure temperature. It is important for students to be aware of this new generation of materials and to be familiar with the use of these materials for measuring fundamental quantities such as the velocity of sound. This experiment has been designed for use in an introductory mechanical or materials engineering instrumentation lab. Initial setup (after procuring all the materials) should take the lab instructor about 2 hours. A single measurement can be initiated and saved to disk in less than 3 minutes, allowing for all the students in a typical lab section to take their own data rather than share a single set of data for the entire class. This experiment is offered to a sophomore-level laboratory class in mechanical engineering that focuses on measurements, instrumentation and manufacturing and addresses the first two topics in that course.

Introduction

A piezoelectric material is basically a ceramic that outputs a voltage upon being mechanically strained. Sensors made of this material are sensitive enough to generate signals when subjected to low-amplitude mechanical waves such as sound waves traveling through solids. This makes them candidate materials for all kinds of exciting applications. For example, sensors mounted on a wing surface could detect ice formation on the wing using surface active waves. Since the velocity of sound in a given medium is a function of temperature, such sensors are also being used to actually measure temperature. It is important for students to be aware of this new generation of materials and to be familiar with the use of these materials for measuring fundamental quantities such as the velocity of sound. This experiment has been designed for use in an introductory mechanical or materials engineering instrumentation lab. Initial setup (after procuring all the materials) should take the lab instructor about 2 hours. A single measurement can be initiated and saved to disk in less than 3 minutes, allowing for all the students in a typical lab section to take their own data rather than share a single set of data for the entire class.

Approach

Our experiment utilizes long single strand wire of different materials coiled on a cylindrical spool with the coils widely spaced to avoid interference. A piezosensor is connected to each coil at the same polar location and the electric signal is fed through an amplifier to an oscilloscope. A sound wavetrain is generated by a pencil lead break at one end of the wire and progresses through the length of the wire. The time lag between the wavetrain's arrival at successive coils, and the reduction of the signal's amplitude are a measure of fundamental material properties such as the velocity of sound and the attenuation factor for that material. The experiment enables students to interface concepts of physics, materials science and materials engineering and encourage them to develop scenarios for the practical application of novel materials.

Equipment and supplies

General supplies and measuring equipment commonly found in most physics/instrumentation labs are listed in Table 1. Materials/supplies that will need to be purchased specially for this experiment are listed in Table 2.

	General Purpose	
X-Acto Knife		240 Grit Sand Paper
6in. Metal Ruler		Soldering Iron and Supplies
Aluminum Backing Plate		Copper Foil
Pipe		Thread
Digital Oscilloscope (2 ch.) with necessary leads		Mechanical Pencil
Electric Insulating Tape		

Table 1. Generally available supplies and equipment

Experimental Procedure

Given that the experiment is offered in the first laboratory course taken by mechanical engineering students with no theoretical background in electrical circuits or mechanical measurements, there is a need for an explicit procedure, given below, that the students can emulate when they write their own procedures in more advanced laboratory experiments.

Initial Setup

1. Insert the pipe through the galvanized wire and arrange the wire so that none of the coils are touching. Tie the coils to the pipe with string
2. Arrange the pipe with the coils on two wood supports so that the coils are suspended.
3. Create two sensors by cutting a 1/2in. x 1/4in. piece of piezoelectric material into several thin strands. Attach the ends of the piezoelectric material to two pieces of electrical tape so that the middle of the piezoelectric material is exposed. Attach a thin piece of copper foil to the exposed area of the piezoelectric material and tape them together.
4. The coil of wire specified in Table 2 has about 23 ½ coils. For this coil, clean two sections of the wire 8 coils from one end and 1 coil from the other end with sand paper. Number of coils will vary if you use other materials, and the suggested numbers should be adjusted appropriately.
5. Attach the sensors without cracking the piezoelectric material to the two cleaned areas. Make sure the copper is not touching the wire. Wrap the sensor tightly to the wire using

electrical tape.
6. Attach a ground to the wire using copper foil. Wrap it tightly using electrical tape.
7. Solder a wire to the sensor, and then solder the wire to the inside of a BNC jack.
8. Solder a wire to the ground, and then solder the wire to the outside of a BNC jack.
9. Attach the BNC jacks to coaxial cables and attach them to an oscilloscope.
10. Cover the sensor and ground areas with aluminum foil.
11. Check the continuity of the circuit with a multimeter.

	Supplier	Part #	Qty.	Cost
Piezo Electric Material	Piezo Systems Inc.	T110-A4E	1	$150
2 in. X 2 in. (enough for	186 Massachusetts Avenue	-602		
at least 10 sensors)	Cambridge, Massachusetts 02139			
	(617) 547-1777			
	www.piezo.com			
Galvanized Wire	Master Halco	5570	1	$10
(a 10 lb coil)	PO Box 365			
	La Habra, Ca 90631			
	(562) 694-6787			
	www.fenceonline.com			
BNC Jack	Radio Shack	UG-1094	2	$4.00
	300 West Third Street Suite 1400			
	Fort Worth, Texas 76102			
	(817) 415-3200			
	www.radioshack.com			
Wood Supports	Home Depot	2 X 4	1	$3
	2455 Paces Ferry Rd.	wood		
	Atlanta, GA 30339			
	(770) 433-8211			
	www.homedepot.com			

Table 2. Special supplies required for this experiment (piezoelectric material cost can be spread out over 5 sets of 2 sensors each)

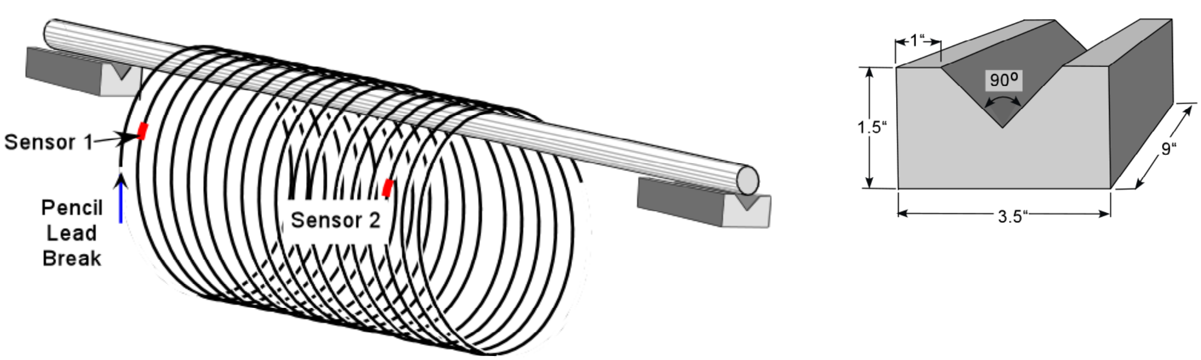

Figure 1 Coil setup & detail of wood support for pipe ends

Experiment

1. Measure/count and record the following data regarding the coil: total number of turns in the coil, number of turns between left sensor (Sensor 1) and right sensor (Sensor 2), mean coil diameter, wire diameter.
2. Set the oscilloscope to trigger and collect left sensor (Sensor 1) and right sensor (Sensor 2) data to disk (implementing an easy-to-understand file naming system is crucial!)
3. Using a mechanical pencil, break about a 1/16 in. piece of lead on the tip of the galvanized wire.
4. Observe the results on the oscilloscope and store the voltage-time data to disk.
5. Repeat steps 2 and 3, except break the pencil on the other tip of the galvanized wire.
6. Steps 3-5 can be repeated to replicate the data, if desired.

Data Analysis

1. Plot side-by-side the voltage – time curves for left and right sensors for the left pencil break event. You should see one distinct peak for the left sensor plot and two distinct peaks for the right sensor plot. The second peak for the right sensor plot is the reflection of the wavetrain from the right end of the coil.
2. Determine the time elapsed between the left sensor peak and the first right sensor peak. Call this t_L.
3. Plot side-by-side the voltage – time curves for left and right sensors for the right pencil break event. You should see one distinct peak for the right sensor plot and two distinct peaks for the left sensor plot. The second peak for the left sensor plot is the reflection of the wavetrain from the left end of the coil.
4. Determine the time elapsed between the left sensor peak and the first right sensor peak. Call this t_R.
5. From your coil dimensional data, calculate the circumference of one coil turn and therefore the distance L_{1-2} along the coil between left and right sensors.
6. The velocity of sound for left pencil break will be L_{1-2} / dt_L, and that for right pencil break will be L_{1-2} / dt_R.
7. Check that the two numbers match closely.
8. Also check how closely the numbers match with the theoretical velocity of a longitudinal sound wave propagating in a solid medium, given by the equation $v = (E/\rho)^{1/2}$.
9. Collect the velocity data from other class members and perform statistical analysis to determine the mean value and standard deviation of the data.
10. Present your results, graphs, calculations, discussions and conclusions in a report.

Typical Results

The results presented in Table 3 were obtained consistently by the student workers at NC A&T State University and are presented for the instructor's reference only. The authors found the data to be extremely repeatable and consistent. The result matched the theoretical calculation of longitudinal wave. Figure 2 shows the typical plots for left pencil break.

Dimensional calculations					
Wire diameter	0.125	in.			
Coil diameter	28	in.			
Coil circumference	87.96	in.			
Left sensor location	7.5	th turn	=	659.73	in.
Right sensor location	22.5	th turn	=	1979.20	in.
Right end of coil	23.5	turns	=	2067.17	in.
(all distances measured from left end of coil)					
Distance between					
Left end and left sensor			=	659.73	in
Left sensor and right sensor			=	1319.47	in.
Right sensor and right end			=	87.96	in.
Location of pencil break	**Trial #**	**t_L (s)**	**t_R (s)**	**dt (s)**	**v (ft/s)**
Left	1	0	0.0065613	0.0065613	16,758
Right	1	0.0065145	0	0.0065145	16,879
Specific weight of steel	0.283	lb/in^3			
Acceleration due to gravity	386.4	in/s^2			
Density of steel (rho)	0.0007324	lb.s^2/in^4			
Elastic modulus of steel E	3.00E+07	lb/in^2			
Velocity of longitudinal wave					
in steel v = (E/rho)$^{1/2}$	202,389	in/s			
=	16,866	ft/s			
=	5,140	m/s			

Table 3. Typical results of experiment

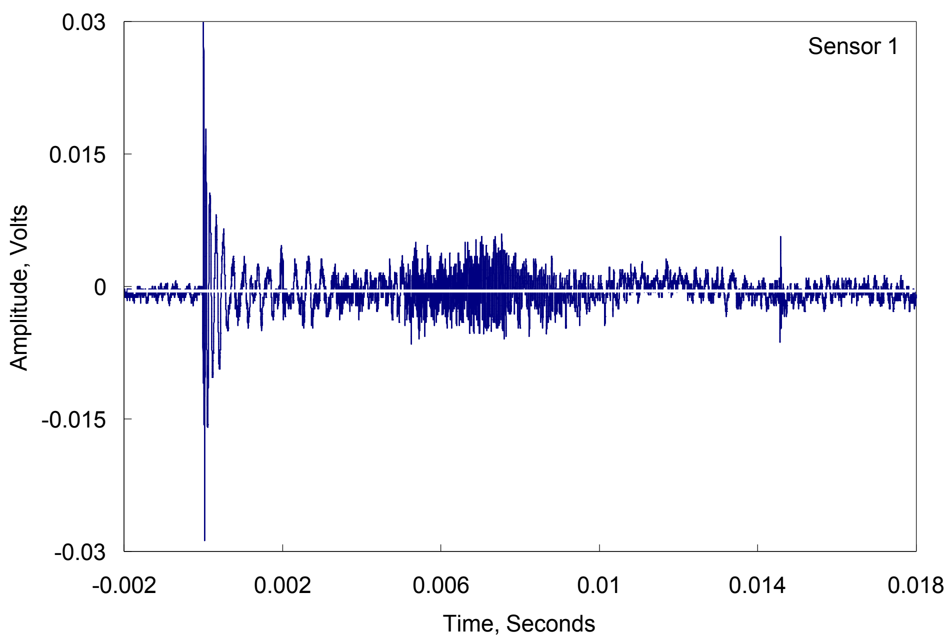

Figure 2 Left piezoelectric sensor signal for pencil break at left end of coil (peak location at 0 s and is the oscilloscope triggering event)

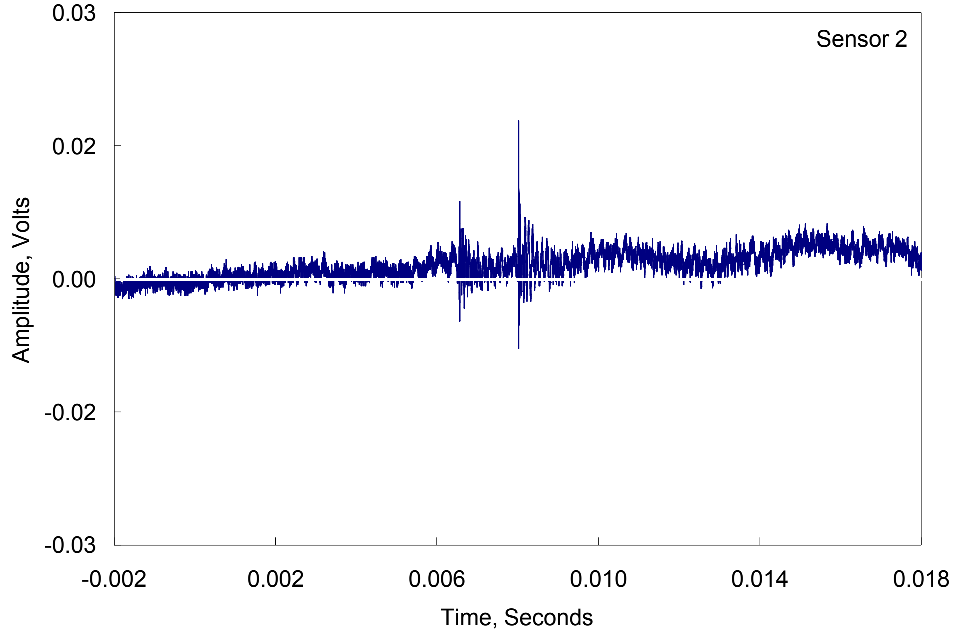

Figure 3 Right piezoelectric sensor signal for pencil break at left end of coil (notice initial peak at about 0.007 s and a second peak at about 0.008 s, a result of reflection of the wavetrain at the right end of the coil)

Conclusions

This paper reports on a fairly inexpensive test setup to expose students to a very sophisticated new generation of smart materials. Students are able to measure micro-timescale physical events and calculate meaningful values for physical properties and relate them to analytical quantities. Further, the nature of the experiment allows for generation of data by individual students and further statistical analysis of class data. The experiment meets the ABET course objectives of leading students through a logical experimentation process, with systematic data recording and analysis. Students respond well to being able to related commonly defined terms such as velocity to harder to measure quantities such as the speed of sound in a wire.

Acknowledgment

The authors wish to gratefully acknowledge financial, equipment and computing support for this project from the Center for Advanced Materials and Smart Structures, the NASA Center for Aerospace Research and the NASA PAIR program at NC A&T State University. This work was initially presented orally at the NEW: Update 2002 National Educators Workshop.

Biographies

DEVDAS M. PAI is Associate Professor of Mechanical Engineering at NC A&T State University. He received his M.S. and Ph.D. from Arizona State University. He teaches manufacturing processes and machine design. A registered Professional Engineer in North Carolina, he serves on the Professional Licensure Committees of the NCEES and SME and is active in the Manufacturing Division of ASEE and the Materials Division of ASME.

NARESH R. SUNDARESAN was a Summer Research Student in 2002 at NC A&T State University. With support from the NASA Center for Aerospace Research, he worked with Dr. Pai on developing this experiment in the Intelligent Structures and Mechanisms Lab. A senior at Northwest High School in Greensboro, NC, he will graduate in 2003.