AN APPARATUS FOR MONITORING THE HEALTH OF ELECTRICAL CABLES

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Keywords
Smart material, piezoelectric, health monitoring, ultrasonic waves, electrical cables

Prerequisite Knowledge
Introductory Physics

Objective
To create piezoelectric sensors that will detect a sound wave passing through an insulated wire.

Equipment and Materials
The supplies listed below are separated into two categories; General Supplies that can be found in most physics and instrumentation labs and Special Supplies that will need to be purchased specially for this experiment.

General Supplies:

Acetone	8 oz.
Aluminum foil	1 sheet
Cellophane tape	
Copper foil	
Digital oscilloscope	
Electrical tape	
Function generator	
Mechanical pencil	

Metal ruler	
Multi-meter	
pipe or rod	7ft.
Rubber cleaning gloves	
Sand paper 240 grit	
Scissors	
Screws, wood – 1-in.	12
Soldering	

iron/solder	
Toothpicks	
Twine	
Voltage amplifier	
Wire strippers	
Wire, copper 10 gauge single strand	48 ft.
Wire, copper black insulated 22 gauge	

Wire, copper red insulated 22 gauge	
Wood board 2in.x4in.x 12in	
X-Acto knife	

Special Supplies

	Supplier	Part#	Qty.	Cost
Piezoelectric Material 2in.x2in.	Piezo Systems Inc. 186 Massachusetts Ave. Cambridge, MA 02139 (617) 547-1777 www.piezo.com	T110-A4E-602	1	$150.00
BNC Jack	Radio Shack	Ug-1094	2	$4.00

Etching Solution	300 W. 3rd St. Suite 1400 Fort Worth, Texas 76102 (817) 415-3200 www.radioshack.com			
Conductive Epoxy	ITW Chemtronics 8125 Cobb Center Drive Kennesaw, GA 30152-4386 1-800-645-5244 www.chemtronics.com	CW2400	1	$20.00

* Optional materials and tools for mounting board

Board, pine12in. x 12in.x 0.75in.	Board, pine 2in.x 4in.x12in	Wood screws-1&3/4 in (12)	12in. Table saw

Introduction

As with most elements of infrastructure, electrical wiring is innocuous; usually hidden away and unnoticed until it fails. Failure of infrastructure, however, sometimes leads to serious health and safety hazards. Electrical wiring fails when the polymeric (usually rubber) insulation material that sheathes the conductor gets embrittled with age from exposure to pressure, temperature or radiation cycling or when the insulation gets removed by the chafing of wires against each other. Miles of such wiring can be found in typical aircraft, with significant lengths of the wiring immersed in aviation fuel – a recipe for an explosion if a spark were to occur. Diagnosing the health of wiring is thus an important aspect of monitoring the health of aging aircraft. Stress wave propagation through wiring affords a quick and non-invasive method for health monitoring. The extent to which a stress wave propagating through the cable core gets attenuated depends on the condition of the surrounding insulation. When the insulation is in good condition – supple and pliable, there is more damping or attenuation of the waveform. As the insulation gets embrittled and cracked, the attenuation is likely to reduce and the waveform of the propagating stress wave is likely to change. The monitoring of these changes provides a potential tool to evaluate wiring or cabling in service that is not accessible for visual inspection. 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 4 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.

Procedure

Mounting board (optional)

The 10 gauge wire can be mounted on a pipe and suspended using the wood blocks to support it. If this method is chosen skip to the section below 'Creating the Sensors.' An alternate method for a more compact apparatus is to mount the 10 gauge wire to a 12 in. square board.

Materials

- Board, pine – 1 pc. 12 in. x 12 in. x 0.75 in.
- Wire, copper 10 gauge 48 ft.
- Wood tiles (6) 2 in. x 2 in. x 0.25 in. (cut from the 2 in. x 4 in. board) (six one inch flat brackets may be substituted for the wood tiles)
- Wood screws (12) 1 in.

Manufacturing procedure

1. Set the height of the blade on the table saw to1/4 in. above the table deck. Use the pencil to divide the 12 in. x 12 in. board into three equal sections along the grain by drawing a line from one end to the other.
2. Cut a 1/4 in. deep groove along each line with the table saw. Label the middle groove 10 ft. and the other grooves 2 ft. and 20 ft.
3. Measure the insulated wire and use a magic marker to mark it at 2 ft., 10 ft. and 20 ft. from one end.
4. Measure 9 in. from the 2 ft. mark and place this section in the end of the groove marked 2 ft.
5. Place a 2 in. x 2 in. wood tile over the wire and groove and screw into place with two wood screws, securing the wire in the groove.
6. Bend the wire up at 90 degrees from the board, measure four inches from the wood tile and bend the wire at 90 degrees so that the section with the 2 ft. mark is parallel to the board.
7. Bend two more 90 degree angles in the wire at the other end so that the remaining wire fits into the groove at the other end of the board with enough room to secure it with a wood tile and screws. You should now have one section of wire secured to the board and elevated about 4 in. above it. The 2 ft. mark will be where you place one sensor.
8. Repeat these steps with the other two sections of wire labeled 10 ft. and 20 ft. using their respective grooves.
9. Neatly coil all excess wire. There should be approximately 20 ft. of excess wire beyond the mounting board.

<u>Creating the sensors</u>

Materials

- Copper foil 1in.x1in. 0.75 in. x 0.75 in. and 1/16 in x 1 in.
- Piezoelectric material 0.5 in. x 0.5 in. square

Cellophane tape 4 in. of 1 in. wide clear, cut into eight 1 in. x 0.5 in. strips.

- Etching solution
- Conductive epoxy

Manufacturing procedure

1. Remove the cap from the etching solution bottle and place a few drops of the solution in the cap.
2. Dip each edge of the PZT tile into the solution just enough to remove about a half millimeter of the PZT surface on each side, being careful not to remove more than half a millimeter. Blot the tile dry with a paper towel.
3. Place the 1 in. x 1 in. copper foil onto a sheet of white paper.
4. Center the PZT on the 1 in. x 1 in. copper foil and lightly trace the outline with a pencil.
5. Remove the PZT and paint a thin coat of epoxy into the outlined section of the copper foil, then place the PZT onto the epoxy and gently press into place. Clean up any epoxy that squeezes out from the edges using a tooth pick.
6. Place tape around the edges of the PZT being sure to cover the edges where the material was etched away but not cover the active section of the PZT. There should be enough excess tape to completely cover the foil and also secure it to the paper.
7. Using the X-Acto knife and a straight edge gently score the surface of the PZT vertically in half mm increments from one edge to the other.
8. Paint a thin coating of epoxy on the PZT being careful to leave a margin near the taped edges.
9. Press the 0.75 in. square of copper foil onto the PZT and tape the edges down.
10. Mark an arrow onto the exposed copper foil in the direction of the scored marks made on the PZT for future reference. The sensor should now be firmly taped to the sheet of paper.
11. Let the epoxy cure over night, then use the X-Acto knife to cut around the edges of the larger copper foil to remove the sensor from the paper.
12. Turn the sensor over and feel for the edge of the PZT tile and mark it with your finger nail on both edges of the PZT in the direction parallel with the arrow on the other side.
13. Use scissors to cut along these lines to trim off excess foil. These two edges of the sensor will be the two that meet when the sensor is wrapped around the wire. The arrow represents the direction of the wire.

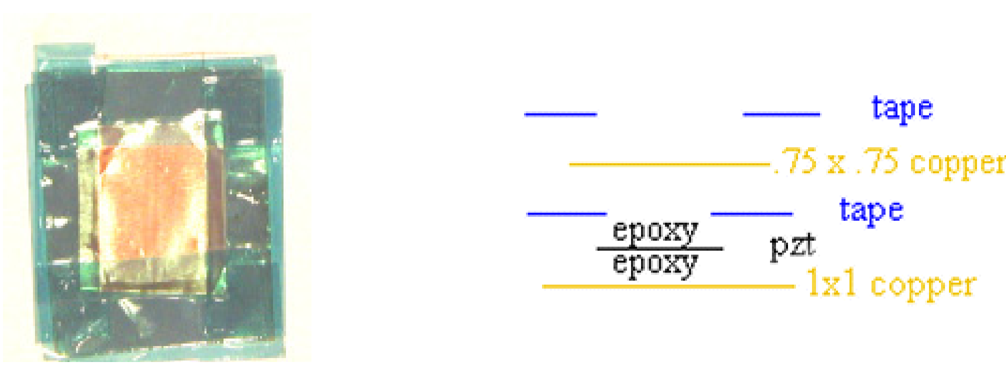


Figure 1. *Completed sensor (left) and side view diagram (right)*

Placing the sensors on the wire

If you have opted to hang the coil on a bar, measure the 10 gauge insulated wire and mark distances of 2 ft., 10 ft. and 20 ft. with a permanent marker. Coil the wire over the rod and hang in the wooden blocks so that the sections marked off are easily accessible. There will be a sensor placed at each mark so refer back to these directions for each sensor placement. Then continue with the following.

1. Straighten a segment of the wire near the mark so that the radius of the coil is taken out as much as possible for about 6 in.
2. Lightly sand the insulation at the marked sections just to scratch it a bit so that the epoxy will hold better.
3. Place a prepared sensor arrow side down on a hard surface.
4. Place the handle of the X-Acto knife along the same axis as the arrow and roll it from one side to the other using enough pressure to crack the PZT along the scored marks.
5. Paint a bead of epoxy along the center line of the sensor parallel with the arrow on the 1 in. x 1 in. copper side.
6. Place the sensor onto the marked section of the wire with the epoxy against the wire and pointing in the direction of the length of the wire and firmly bend the sensor around the wire so that the two meeting ends are clearly visible, making sure the sensor makes good contact all along the diameter of the wire. You should hear and feel the PZT material cracking as it is bent around the wire.
7. Remove any squeezed epoxy from the wire surface so as not to short out the ends of the sensor.
8. Insert the thin strip of copper foil 3 mm under the edge of the sensor so that it makes contact with the epoxy and copper on the bottom of the sensor and let the tag end stick out freely. This will be your ground contact for the bottom of the sensor.
9. Tape the sensor in place with electrical tape and let cure over night. Folder clips can be used to hold the sensor in place if desired.
10. To test the sensors connect them to oscilloscope (trigger set to single) and lightly tap the wire with a ruler. The oscilloscope should register a wave at each sensor.

Attaching the BNC jacks

Materials

- BNC jacks (3)
- Solder
- Wire, copper 22 gauge black and red
- Copper foil 1 in. x 0.25 in. (3)
- Electrical tape
- Aluminum foil

Manufacturing procedure

1. Cut 5 in. of black and red 22 gauge wire.
2. Strip the insulation from both ends of each wire.
3. Solder the red wire into the center post of the BNC jack and the black wire to the ground connection.
4. Cover both connections with electrical tape.
5. Solder the opposite ends of each wire to a separate 1 in. x 0.25 in. piece of copper foil.
6. Place the black wire connection onto the sensors ground connector (copper tag) and tape into place with electrical tape.
7. Place the red wire connection onto the exposed copper section of the top of the sensor and tape into place.
8. Secure all loose wires with electrical tape.
9. Attach the coaxial cable to the BNC jack and tape the cable to the 10 gauge wire for support.
10. Cover the entire sensor and all connections with aluminum foil to shield it from external noise.
11. Use a clip to insure that there is a solid connection between the aluminum foil shield and the BNC jack.
12. Use a multi meter to make sure there is no short circuit at the end of the coaxial cable between the pin and the ground.

The sensor is now ready. Repeat steps above for the other two sensors

Figure 2. *An assembled BNC jack with leads*

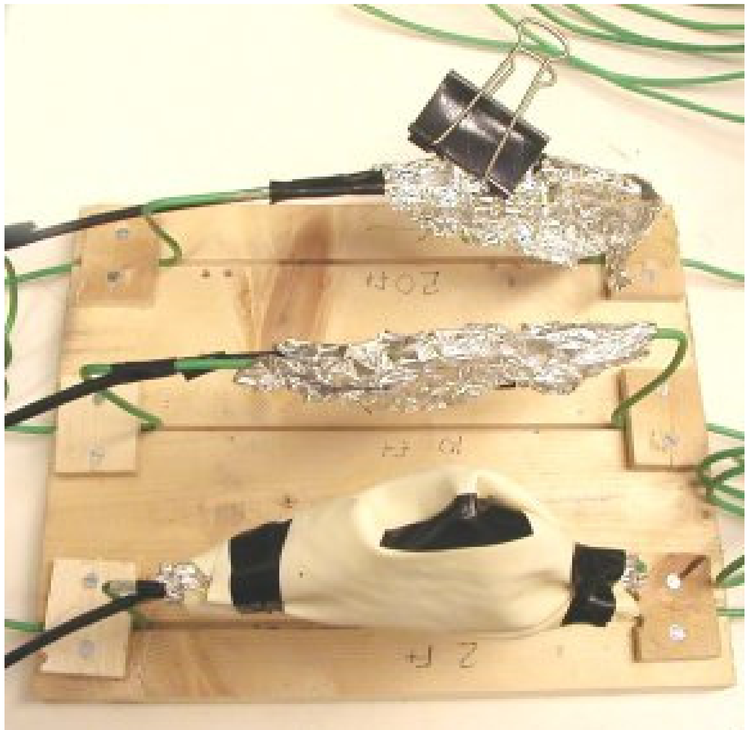


Figure 3. *Completed setup with mounting board*

Figure 4 *Diagram of the completed apparatus with sensors at 2 ft., 10 ft. and 20 ft.*

<u>Connecting the function generator, amplifier and oscilloscope</u>

Warning: Care should be taken when using the voltage amplifier. A direct connection between the output of the voltage amplifier and one of the sensors can cause serious damage to the oscilloscope.

1. Using coaxial cables (or appropriate connectors for your oscilloscope) connect the 10ft. sensor to channel 1 and the 20 ft. sensor to channel 2.
2. Connect the EXT. jack on the function generator to the EXT. jack on the oscilloscope and set the oscilloscope trigger to EXT.
3. Connect the function generator OUTPUT to the voltage amplifier INPUT.
4. Connect the voltage amplifier OUTPUT to the sensor located at the 2 ft. mark. This sensor will now be referred to as the actuator as it will be generating the wave from the inputted voltage. *IMPORTANT! Once the cable is connected to the actuator cover all metal on the actuator with rubber cut from the rubber cleaning glove (or other insulating material) and tape securely into place.* Should the metal of the actuator touch the aluminum foil of the sensor at the 10 ft. mark it could cause serious damage to the oscilloscope.

5. Set the oscilloscope to trace channel 1 to A and channel 2 to B.

You are now ready to begin testing the wire.

NOTE: to test that the sensors are functioning properly you can connect each sensors cable directly to the function generators OUTPUT, then using a constant sine wave set between 4 kHz and 15 kHz at 9 $V_{p\text{-}p}$ listen for a tone. The sensors will create an audible tone when working properly.

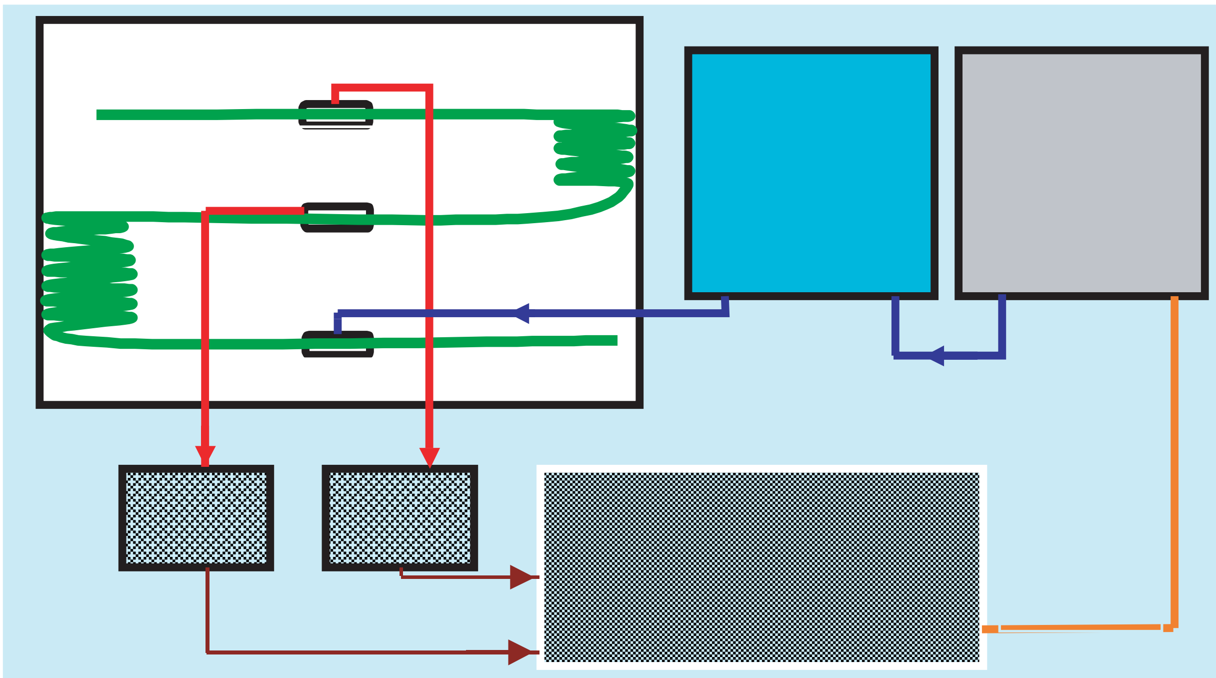
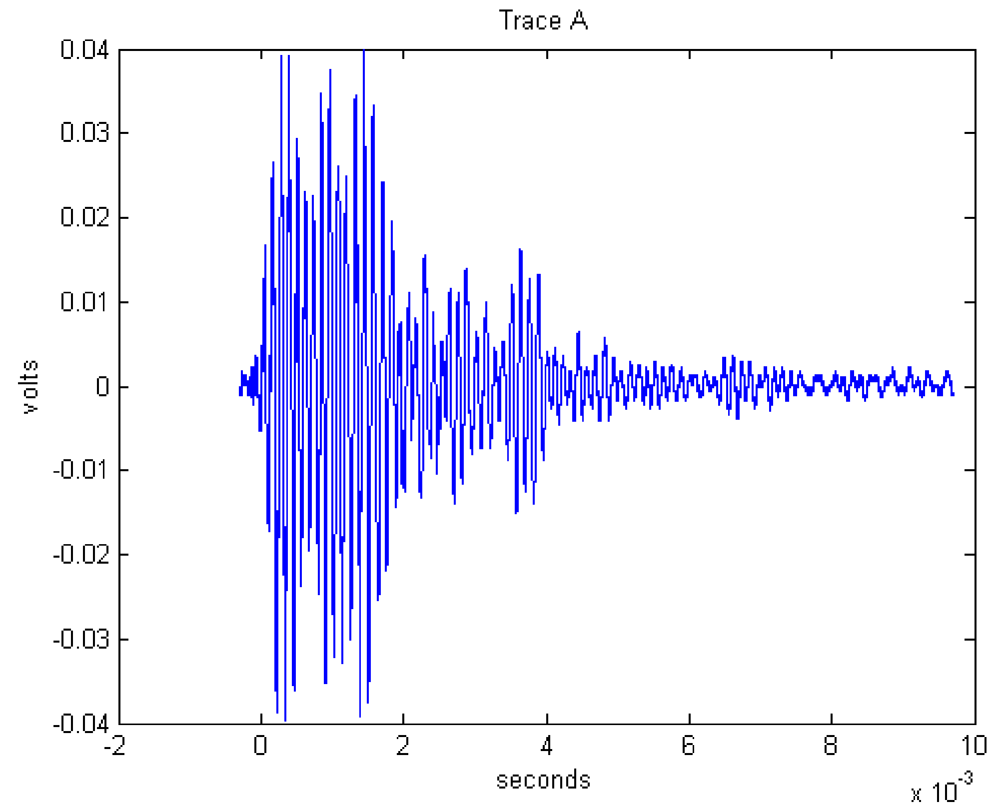


Figure 5. *Experimental setup*

<u>Collecting Data</u>

1. Set the function generator to burst mode to generate 5 pulses of 8 kHz frequency with an amplitude of 1 $V_{p\text{-}p}$.
2. Attach a coaxial cable connecting the EXT jacks on the function generator and the oscilloscope. Making sure the oscilloscope trigger is set to EXT and that channel 1 and 2 are set at 2 ms and 6 V.
3. Use the trigger on the function generator to send a five wave burst to the actuator.
4. Confirm that a signal is registering on both channels.
5. Adjust the voltage on the oscilloscope as needed and increase the voltage of the function generator as needed using increments of 1 kHz.
6. Fine tuning of the signal can be done by adjusting the frequency in small increments until the best signal is received from each sensor. The individual sensors may get peak signals at different frequencies. Once an adequate signal is registered set the trace channels A and B to collect 20 sweeps averaged to eliminate noise.



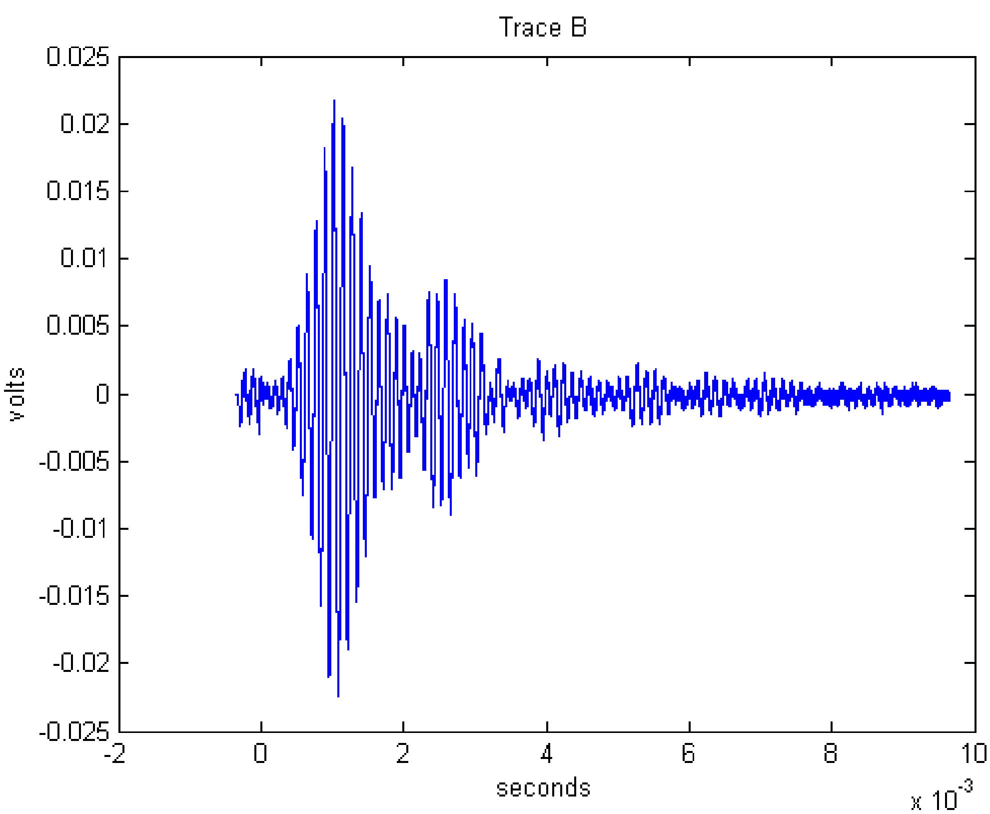


Figure 6. *A typical signal from channel 1 (top) and channel 2 (bottom)*

Comments

This paper demonstrates the manufacture and use of piezoelectric sensors attached to a common insulated electrical wire to monitor sound waves passing through the wire. It is a moderately inexpensive and compact apparatus that can be used to demonstrate how sound waves behave in an insulated wire.

Acknowledgement

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