Report
on
BUILDING A COST-EFFECTIVE SEISMOMETER

submitted
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1.0 *Introduction*

1.1 Overview

We intend to address the lack of affordable seismometers in K-16 classrooms and to offer a viable solution to this problem. As our world becomes more technologically advanced, it is beneficial to provide children with technical skills at an early age. If seismometers can become reasonably priced for the public school system, students can expand their knowledge about earthquakes and gain experience with this type of technology.

The major constraints and limitations of this project include sensitivity, cost, and usability. It will:

- Cost no more than $150.
- Be sensitive enough to measure a magnitude 7 earthquake up to 180° away.
- Be easy to assemble and operate.
- Have a good signal-to-noise ratio.
- Have a period up to 20 s.
- Allow a computer to record data continuously if desired by the user.

1.2 Goals and Objectives

Our goal is meet the above listed requirements and build a working model; it must be effective and cost efficient for a school setting. Our seismometer must cost less than $150 for mass production ($50 for us to build a model), be sensitive to magnitude 7 earthquakes, and be safe for school-aged children.

2.0 *History*

Below is a basic timeline of the work we have done from the first concept to our final design proposal.

Table 1: Timeline

	September		October		November	December	
	9/2/02	9/16/02	10/7/02	10/28/02	11/11/02	12/2/02	12/5/02
Clarification Memo	•						
Letter of Understanding	•----	----•					
Submit Project Plan		•----	----•				
Subsystem Analysis			•----	----•			
Redline Drawings				•			
Draft of Final Report				•----	----•		
Submit Final Report					•----	--------	----•
Exhibit Final Product							•

To accomplish this task, we have researched several seismometer designs on the Internet, so as to cut our costs and to choose the most effective design. While visiting a website published by Infiltec, we discovered the basic layout for a Lehman seismometer using an inclined pendulum for the mechanical arm [1]. We also discovered the La Coste zero-length spring which is best described as a long weak spring. It was used in the Press Ewing seismometer in the physics section of the Mercer University website [2]. For sensors, we will choose between magnetic and optical.

2.1 Selection Criteria

In Table 2, we have developed a decision matrix with the possible designs presented above for both mechanical arms and sensing devices.

Table 2: General Seismometer Component Decision Matrix

Component	Design	Cost (2x)	Availability of parts	Durability (1.5x)	Ease of Construction	Sensitivity (1.5x)	Total
Mechanical Arm							
	Zero-length Spring (La Coste)	5	4	3	4	4	28.5
	Inclined Pendulum (Lehman)	5	5	4	4	4	31
Sensor Device							
	Optical	3	4	3	3	4	23.5
	Magnetic	4	5	4	4	3	27.5

Rated 1 to 6, with 6 being best

The two mechanical arm designs are similar in that the rod or spring to which the weight is attached is set at an angle in order to lengthen the period [1]. There is also a horizontal rod in both that is attached to the weight to hold it up. They vary because the La Coste oscillates vertically while the Lehman detects motion horizontally. Also, the Lehman differs from the La Coste seismometer and other pendulum designs in that the rod attached to the weight is restricted in its movement by a knife-edge [4].

For the decision matrix (Table 2), our criteria for making this evaluation were cost, availability of parts, durability, ease of construction, and sensitivity. Cost was weighted twice its numerical value as a result of the strict price limit imposed by the client. Sensitivity was weighted by a factor of 1.5. It was a major concern but takes lower priority than cost. Because children are not always careful with equipment, the final design must be able to handle classroom wear-and-tear; therefore durability was also weighted by a factor of 1.5.

2.2 Selection Process

2.2.1 Mechanical Arm:

When comparing the La Coste and the Lehman arms, we found the costs are roughly equivalent because their designs are similar. The main difference in required parts is the zero-length spring and the knife-edge. Costs for these items are relatively equivalent; therefore they received the same cost ranking.

The difference in design does affect the availability of parts. Finding a wire to support the pendulum for the Lehman would be easier than finding a long weak spring with the proper spring constant in order to build a La Coste seismometer.

Although there are safety issues with the knife-edge, there are inexpensive ways around this issue. These will be discussed later in the section on the construction of the knife-edge. We found making a safe knife-edge for the Lehman would be more cost effective than the long, weak spring required for the La Coste [2].

The zero-length spring is less durable than the rigid rod used for the Lehman. If the La Coste seismometer is ever tampered with, such as children pulling and stretching it, the period of oscillation could be affected.

Because the two designs are so similar, construction should be equally simple for both designs presented.

Although the La Coste operates on a vertical axis and the Lehman on a horizontal, the likelihood of noise due to building vibrations and human interaction is equal for both axes.

Based on the above reasoning, we decided that the Lehman design was preferable to the La Coste.

2.2.2 Sensor:

In the comparison of the magnetic and the optical sensor, the magnet and coil are less costly, especially if surplus hard drive magnets such as those at the Wondermagnet website with proper lines of force can be obtained. [3]

Magnets and coils are more readily available, as they can be purchased from general hardware retailers, whereas the parts for an optical sensor would have to come from a more specialized electronics store.

The extra electronics involved in an optical sensor make it more susceptible to breakdown, giving it a lower durability than a magnetic sensor.

The AD converter we will be using is designed to work with the magnet and coil; therefore, rigging it to work with the optical sensor will take more effort, lowering the ease of construction score for that system. The increased difficulty in finding the necessary parts also lowers its ease of construction rating. Another important factor for ease of construction is the amount of background information available on each choice. Magnetic sensors are a very widely disseminated idea, and plans on how to use them for a Lehman design are readily available. Optical sensors are not as widely tested, and so it would be more difficult for us to incorporate them in our design.

The sole area in which the optical sensor outweighs the magnetic sensor is the sensitivity. Magnetic sensors lose some sensitivity at the required period because the slow motion produces little current. An optical sensor does not have this handicap. However, a stronger magnet and an electronic amplifier circuit can compensate for the loss.

Because of the above reasons, we found the magnet and coil the preferable option for a sensor.

3.0 *Cost Analysis*

3.1 Initial Cost Estimate

The costs for Infiltec's Lehman design using a magnetic sensor are shown in Table 3. We plan to cut costs on software and the AD converter. In the table below we have underlined the software we plan to eliminate because is not necessary for our application. We are not trying to build a professional seismometer, but rather something to enhance learning, therefore precise timing is not an issue. We will use an AD converter that costs only $25 instead of the $99 one listed in the table. These cuts in Infiltec's proposed costs will help us reach our goal within the budget constraint of $150.

Table 3: Sample Prices from Infiltec

Component	Cost
Pendulum (Home Depot)	$34
Pickup coil and magnet (Larry Cochrane)	$35
Preamp/filter/power (Andy Loomis design)	$30
AD converter: 12-bit DataQ	$25
Data collection software: Amaseis	$00
Total	$124

3.2 Final Cost Analysis

In Table 4 is the costs for the model that we built divided into the components outlined in section 4 of the report. Below this data are the additional costs outside the model and the total cost for our proposed design.

Table 4: Actual Prices for Model

Component	Part	Quantity	Cost
Magnet and Coil			
	Magnets	2	$2.01 ea
	220 V relay		$15.00
Mechanical Arm			
	Slotted Steel Angle		$4.29
	Eye Hook (8 pack)		$0.86
	Turnbuckle		$0.80
	Long Bolt (5.5 in)		$1.57
	Large Washers	16	$0.24 ea
	Small Washers	2	$0.17 ea
	3/8 in Nuts	3	$0.17 ea
	#8 Guitar String		$0.80
Damping Mechanism			
	Long Bolt (5.5 in)		$1.57
	3/8 in Nut		$0.17
	Ruler		$0.69
	Measuring Cup		$2.99
	10W-30 Motor Oil		$1.89
Base and Knife-Edge			
	Particle Board (2 ft x 2 ft)		$5.38
	Liquid Nails		$1.97
	PVC (16 in)		$0.29
	Leg Bolts (2.5 in)	3	$0.30 ea
	1/4 in Nuts	6	$0.11 ea
Total for model			$48.54
Other parts needed			
	AD converter		$25
	Amp/Filter/Power		$30
	AmaSeis Software		free
Overall Total			$103.54

From the above table we can see that our design meets the cost requirement with money to spare.

4.0 *Division of Components*

Following the guidelines set forth by our client and the criteria in our decision matrix, our team will construct a seismometer using a Lehman type pendulum and a magnet and coil for the sensing device. We have divided the components into four subsystems. They are as follows:

- Magnet and coil
- Mechanical arm (boom, wire, and mass)
- Damping component
- Base and knife-edge

We divided our components in this fashion because this division provided a logical separation of labor while keeping similar elements together. We have a sensing device, mechanical arm, damping unit, and basic support system.

4.1 General Functions and Relationships

The magnet and coil convert the motion of the mass into voltage that can be read by the AD converter.

The mechanical arm responds to the movement of the earth in an earthquake. The movement of the mass as a result of a quake is then converted to voltage by the magnetic sensor. The wire is placed at an angle to increase the pendulum's period of oscillation, and the boom holds up the mass.

The damping component is meant to restrict the motion of the pendulum so it follows the motion of the earth more closely. A mass will hang from the boom into a container of damping fluid.

The base levels the system accounting for any irregularities in the surface on which it sits. Also, the base holds the other three components. The knife-edge will be a razor blade that will serve to restrict vertical motion of the boom.

4.2 Magnetic Sensor

4.2.1 Assembly:

As stated above, the magnetic sensor will consist of two main components, a magnet and a transducer coil. In traditional Lehman type seismometers, the magnet is often an Alnico horseshoe. In our design, this single Alnico horseshoe will be replaced by two niobium magnets parallel to each other. The magnets are mounted at the end of the mechanical arm using a hot glue gun so that as the arm swings back and forth, the magnets move as well.

The transducer coil is the same design as that used by Larry Cochrane [5]; it is extracted from a 220 V relay using a screwdriver and a file. The coil is then mounted with a hot glue gun in a spindle arrangement to keep it upright. The coil setup is then placed between the two magnets. The leads from the AD converter are then soldered to the leads from the coil.

4.2.2 Operation:

As the pendulum oscillates, the changing magnetic flux through the coil generates a voltage according to the equation $V=n*v*B*l$, where V is the voltage; n is the number of turns of coil; v is the speed with which the magnet is moving; B is the strength of the magnetic field; and l is the length of one turn of wire. The AD converter reads this voltage and changes it into digital signals that the AmaSeis software interprets.

4.2.3 Technical Specifications:

Table 5: Dimensions of Magnet and Coil

Component	Dimensions
Niobium magnet	1.25 in x 0.5 in x 0.125 in
Pole faces	1.25 in x 0.5 in
Pickup coil	0.94 in dia, 0.69 in wide

As the magnets are surplus hard drive magnets from an online supplier, the quality and composition of the niobium is not precisely known. However, using the calculator at the Magnet Sales website [6], we have determined that the amount of pull generated by each magnet will range from 9.2 lb, using Nio 35, to 11.6 lb, using Nio 48. Using the equation: $F=.577*B^{2*}A$, where F is pull; B is the strength of the magnetic field; and A is the area of the pole face of the magnet. We have also calculated that each magnet will produce a magnetic field between 0.48 T (Nio 35) and 0.54 T (Nio 48) from each pole.

The magnets will be placed parallel to each other and 0.81 in apart (see Figure 1), allowing the coil setup to fit between them with 0.063 in to either side. This configuration allows the magnet to move freely about the coil. The transducer coil as described by Cochrane has more than 10,000 turns and results in the length of one turn being approximately 2.95 in.

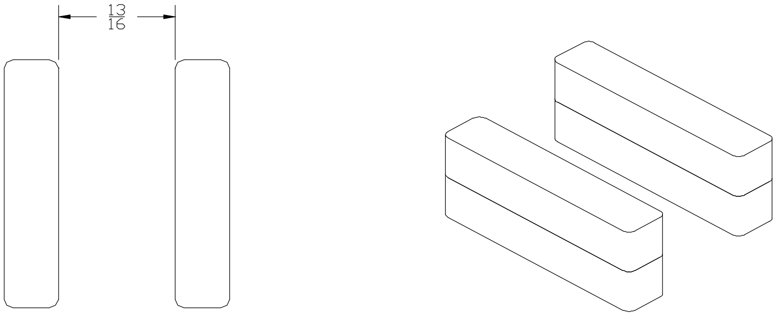

Figure 1: Combination of four household magnets designed to approximate the two niobium magnets described above.

If we assume a velocity of 6 µm/s (see Requirements for the justification) and 10,000 turns of wire, the voltage generated by the magnet and coil should range from 2.1 mV (Nio 35) to 2.4 mV (Nio 48). However, this does not take into account the 9000 Ω of internal resistance in the wire; this will reduce the voltage generated.

4.2.4 Meeting Requirements:

Since one of the major objectives set forth by our client was to provide a cost-effective yet sensitive seismometer, we had to find a way to reduce costs on the magnet and coil.

Niobium magnets are generally stronger than Alnico magnets of comparable size but less expensive. At the Wondermagnet website, the type of niobium magnet used in our design is only $2.01. [3] This alternative makes our niobium magnets a more cost-effective choice than the standard Alnico horseshoe. Stronger magnets also increase the voltage output, thereby increasing the sensitivity of the device.

Mounting the magnets as close to the end of the arm as possible maximizes their velocity due to the swing of the arm. This is also increasing the coil's voltage output and the overall sensitivity of the device.

We used a velocity of 6 µm/s because that value was given on the assumption that a large magnitude earthquake on the other side of the Earth should be detected by our seismometer. The resulting voltage is well within detectable limits, meaning our sensor is capable of picking up that type of quake.

4.3 Mechanical Arm

4.3.1 Assembly:

The boom, or horizontal pendulum, will be an aluminum bar, easily obtained at any hardware store. It will connect to a knife-edge mounted on the vertical side of the frame. The freely swinging side of the boom is threaded for 4 in. A nut is screwed onto the end of the threading, followed by a 5 lb fishing weight with a hole drilled through the center and another nut.

The pickup coil and magnet are located at the freely swinging end of the boom. Attached to the center of the boom will be a mass hanging in a container of damping fluid. The magnet is mounted on the boom, and the pickup coil is mounted on the base plate. A #8 guitar string will support the freely swinging side by connecting it at an angle of 30-40° to the top of the mounting frame. A hole will be drilled through the boom for this attachment. As a pivot point, a nozzle from an oil burner, without the inside filter, will be glued into the vertical frame. The wire will then go through this nozzle and the hole in the boom. The two ends are attached and tightened through a turnbuckle approximately halfway up.

4.3.2 Operation:

The turnbuckle on the wire will adjust the period of the oscillation. Every movement the boom makes is converted into an induced voltage in the coil. This will be amplified, filtered, and recorded after passing through an appropriate AD converter.

4.3.3 Technical Specifications:

Table 6: Dimensions of Mechanical Arm

Component	Dimensions
Aluminum Bar	18 in
Fishing Weight	~ 5 lb
#8 Guitar String	
Oil Burner Nozzle	0.5 in dia

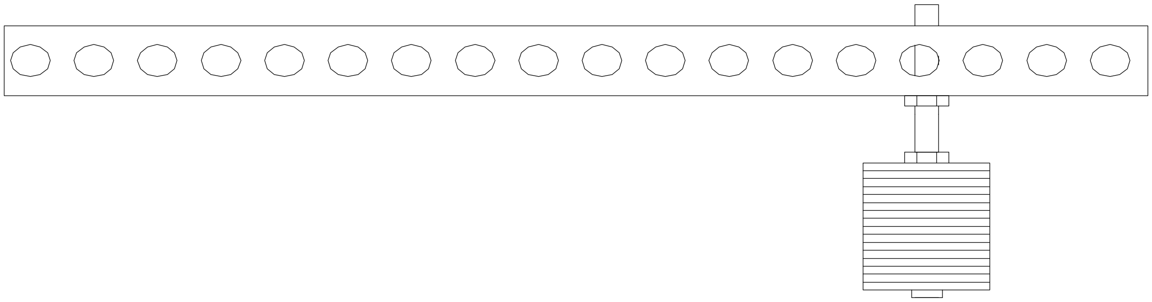

Figure 2: Mechanical arm with mass attached with a bolt. Knife-edge will be on the left side in this view.

4.3.4 Meeting Requirements:

The above assembly of the mechanical arm will be inexpensive, yet sensitive enough to meet the client’s requests. All of the materials are easy to obtain and easy to assemble. There are no components that would be questionable for the health of children, so the product is therefore ideal for the classroom environment.

4.4 Damping Mechanism

4.4.1 Assembly:

The damping unit will consist of a 6 in ruler attached to the middle of the boom by a threaded bolt (see Figure 4). The paddle will either be aluminum or steel. The ruler will then be placed into a small cup of oil. After attaching the ruler to the bolt, we will then secure it to the boom using a nut. The oil will be 10W-30 motor oil.

4.4.2 Operation:

The damping component is used to decrease the resonance of the pendulum. When an earthquake occurs, the pendulum will swing. As it returns to equilibrium, the paddle in the oil will cause the boom to slow down, thus decreasing the amplitude of motion of the pendulum.

To adjust damping, the volume of oil can be changed, the paddle can be raised or lowered, or the oil can be switched to one of a different viscosity [4]. The amplitude of motion being produced will change, as will the period of motion of the boom (see Figure 3). The damping unit is necessary to ensure accurate and meaningful data [7].

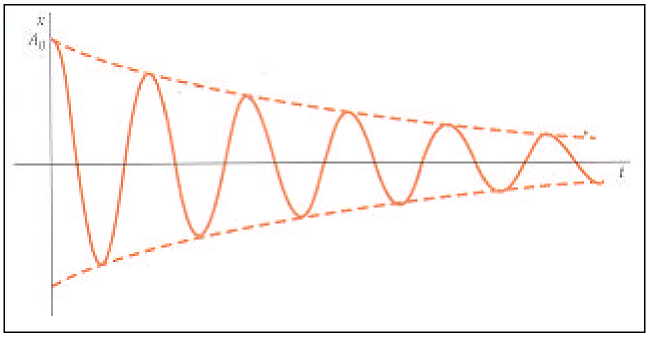

Figure 3: Amplitude of motion over time in a damped system, taken from Tipler Physics. [6:421]

4.4.3 Technical Specifications:

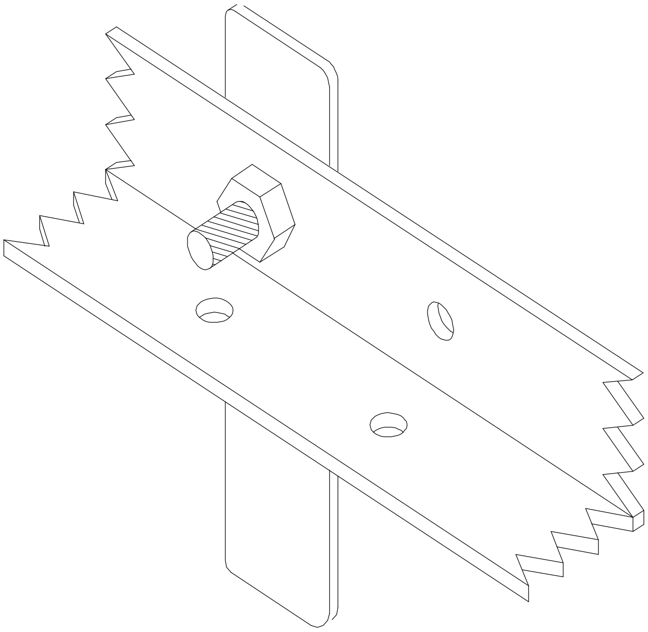

Figure 4: Damping component using paddle, shown attached to mechanical arm with bolt and nut.

Table 7: Dimensions of Damping Mechanism

Component	Dimensions
Cup	3 in
Ruler	6 in
Screw	0.25 in dia, 3 in long

4.4.4 Meeting Requirements:

The damping component will ensure correct measurement of the earth's movement. It will allow the pendulum to follow the earth's motion more closely, thus recording more accurate results. This meets the client's requests because the damping device keeps the system from oscillating too much and causing incorrect readings. The component will be safe to use in a school setting because the oil being used will be enclosed in the system's casing, ensuring that no one consumes or tampers with the oil.

4.5 Base and Knife-Edge

4.5.1 Assembly:

The base will be an L-shaped construction with particle board on the bottom and PVC piping on the vertical part (see Figure 5). The knife-edge will be a razor blade. A small crevice will be drilled in the pipe for the razor blade. The entire construction will rest on three screws placed in a triangular configuration on the particle board. These screws level the entire seismometer to correct for any imperfections in the surface on which it is resting. The PVC will be glued to the particle board with Liquid Nails.

4.5.2 Operation:

The horizontal part of the base will hold the magnet and coil sensing device and the damping device. The vertical part will house the knife edge and support the wire for the mechanical arm. The purpose of the base is to provide a level surface on which everything can rest. The razor blade will act as a hinge to restrict the motion of the boom so it can only move in one horizontal plane, either east-west or north-south.

4.5.3 Technical Specifications:

Table 8: Dimensions of Base and Knife-Edge

Component	Dimensions
Particle Board	12 in x 24 in x 1 in
PVC Piping	2 in dia, 11 in long
Razor Blade	
Leveling Screws	0.25 in dia, 2 in long

4.5.4 Meeting Requirements:

The main objective of this project is to design an affordable seismometer. Because all of these materials can be found at your local hardware store, they are not only easy to access, but are also cost effective. Because our seismometer must be suitable for children as young as kindergarteners, using a razor blade poses a possible safety hazard. To avoid this issue, the crevice housing the razor blade will be deep enough to cover the cutting edge.

Figure 5: Base and mechanical arm

5.0 *Final Thoughts*

Our seismometer is well suited for the requirements. It costs less than $150 to build; it is sensitive to earthquakes down to magnitude 7 and meets all other minor requirements.

5.1 Appeal and Educational Value

Our design for a classroom seismometer is suited perfectly for how it will be used. It takes up a minimal amount of space: it requires only a 1 ft by 2 ft table. It will connect easily to a classroom computer with the free software available online. All the components can either be easily ordered off of the Internet or obtained at a hardware, music, or electronics store. The entire unit can be assembled in a couple hours by a teacher with the use of a few simple tools, such as a drill with a 1 in drill bit and a hacksaw.

Putting seismometers in elementary and middle school classrooms is especially beneficial to the future of geophysics. If we can catch the interest of children at an early age, they are more likely to pursue this interest when they reach the age to choose a college and a major. We believe that our seismometer can spark this curiosity.

5.2 Details Concerning Our Model

For our model, we followed the specifications put forth in the subsections as closely as possible, but some changes were needed due to operational difficulties and problems obtaining supplies. A list of all the supplies we actually used can be found in the cost analysis section. In Figure 7 below is a basic drawing of our model.

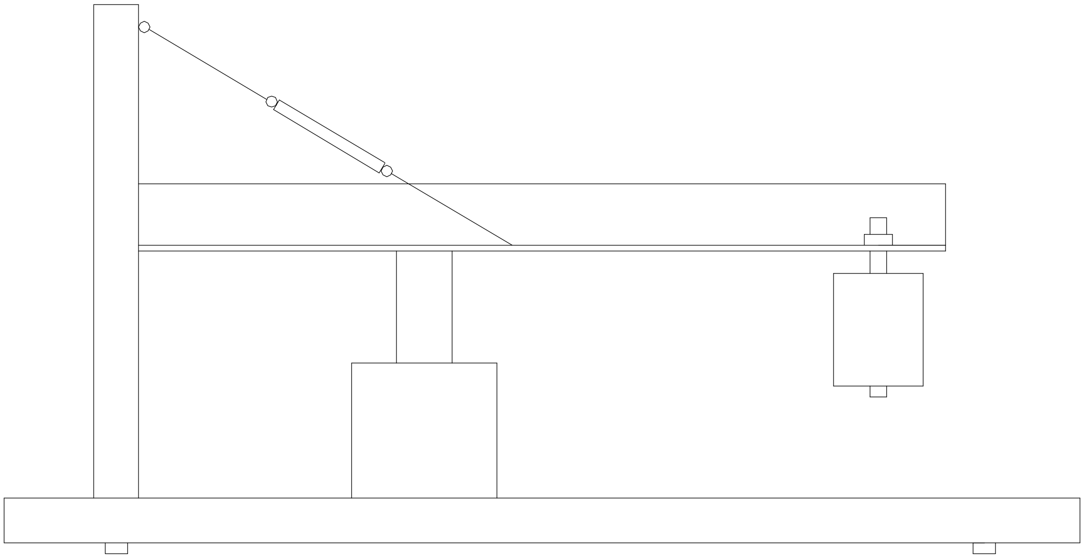

Figure 7: View of the entire system without the magnet and sensor. If included, they would be at the bottom of the mass on the far right.

5.2.1 Magnet and Coil

The magnet and coil supplier on the Internet that we had hoped to use was out of the parts that we needed. Instead of using surplus hard drive magnets, we used household magnets found at Home Depot. Instead of using the wiring from a 220 V relay for our coil, we purchased a coil of magnet wire at Radio Shack. We are not completely certain of the composition of these magnets or the number of turns in this coil so we are unable to provide numbers for the magnetic field produced. We still plan on using the hard drive magnets and relay coil when they are in stock.

5.2.2 Mechanical Arm

While constructing our model, we realized that an aluminum bar would not be sturdy enough to support everything that needed to hang from it without bending. We replaced the aluminum bar with a slotted steel angle bar. The angle prevents it from bending and the predrilled holes came in very handy to bolt in the damping and mass. We were not able to find a five pound fishing weight. Instead we used a series of heavy washers on a long bolt. We were unsure where to obtain an oil burner nozzle, so we used an eye screw to support the wire. These changes should be considered for future improvements.

5.2.3 Damping Mechanism

Because our pendulum is intended to move horizontally, we decided that a paddle style damping system would be more effective than the horizontal washer at creating drag and bringing the system back to equilibrium.

5.2.4 Base and Knife-Edge

In order to make the vertical PVC assembly sturdier, we did not drill all the way through the particle board base. We used a 1 in paddle bit and left enough particle board in the bottom of the hole to put Liquid Nails on the bottom as well as the sides to help hold it together. We could not determine a sound way to secure the razor blade to the mechanical arm, so we used the end of the mechanical arm as the knife edge. For future production, a better solution to this issue will be necessary.

6.0 ***Documentation***

6.1 References

[1] D. Saum, “How to Build an Inexpensive Seismometer,” *Infiltec*, http://www.infiltec.com/seismo/ (October 9, 2002).

[2] R.D. Peters, “Physics of the Zero-Length Spring of Geoscience,” Mercer University, http://physics.mercer.edu/earthwaves/zero.html (October 12, 2002).

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6.2 Resources

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7.0 *Appendix*

Magnet and Coil – Jared Dabling
Mechanical Arm – Amy Kurtz
Damping Mechanism – Jeremy Sell
Base and Knife-Edge – Megan Taylor

Report redacted by Megan Taylor