

## 1. What would I tell someone who was considering making one?

Plan ahead. Make sure you have the resources required to see the project through before you begin. Although this design is a great advance in simplicity for instruments of this precision, it's still complicated. If you've never built a seismometer, this might not be the project to start with.

This project will involve more than just some machining and building electronics. To get decent data you will need a pressure vessel, recording device, suitable pier, and a good site. Except for the pier and site, much of this can be purchased but there will be quite a bit of work to get it all put together. If you plan to build it yourself, you should have some experience machining aluminum and brass, and experience building and testing precision electronic circuits. One could certainly pay to have all of these things done by someone else, but investigate the cost first if you plan to go that way.

This is a rewarding project, and your chances of success are good if you stick with it. Plan on it taking a couple of months if you have lots of time to spend and some experience building seismometers, longer if not. There are many resources available to help you, and a wealth of experience among those who designed the instrument.

There are on-line sources for all of the materials, although it may be less expensive if you can find them locally.

This seismometer is the result of literally years of engineering, analysis, and testing by its designers, and has been optimized in many subtle ways. Deviations from the design should be carefully considered, and in many cases the designers should be consulted to be sure the results will be satisfactory.

In building one you will likely find that there will be problems to overcome. Although the design is very well thought out and extensively tested, as yet this is not entirely a plug-n-play type of project. Tenacity and patience are by far the biggest assets to solving problems that come up. Verifying solutions to some problems can take hours or days, so they should be well thought-out before trying them. Even so, some solutions may be little more than educated guesses and may amount to trial and error.

## 2. What problems did I have and how did I solve them?

The biggest challenges I've had so far have centered around reducing noise after I initially got it running. The solution to some of it

involved taking the instrument apart, cleaning debris from the magnet, or replacing the hinges. In my experience, the hinges should be inspected each time it is taken apart.

### 3. What surprised me?

How relatively easy this is to make, given the resulting performance.

Air buoyancy noise. I was going to have the seismometer in the wine cellar. There would be 2 doors to the outside and I thought the air pressure changes would be minimal by the time they got to the cellar. I was wrong.

### 4. Who shouldn't try to make one?

Those with little patience and those who have never built a seismometer. There are lots of aspects to this other than just machining metal and assembling electronics. Try a simpler project first.

You need to be familiar with a drill press, mechanical parts, and keeping things clean. If this is not you, forget it.

### 5. What resources should someone have to be successful?

Resources to machine aluminum and brass. The precision needed is such that a hack saw, a file, and a lot of care, and some trial and error will do. Having a small mill would make it much faster and easier.

A caliper for measuring the size of the machined parts is probably required.

For the electronics, experience with assembly and soldering of small through-hole electronic components is needed. Very likely some electronic troubleshooting skills will be required. Electronic test equipment should include a portable DMM at the least, and an oscilloscope may be helpful.

Drill press, band saw, PCB soldering tools. PCB soldering tools may mean a new iron and use the non-conductive flux solder. An oscilloscope would be good for showing the circuit is working. I used 2 outside machine shops for building the parts I couldn't make myself. One shop for the sheet-metal part and the other for regular machined parts. An arc welder for welding the magnet return path together.

## 6. What tips and tricks did I discover as I was making it?

The two pairs of hinge clamps need to be made such that they don't hang over the edge of the piece they are fastened to (the hinge tower in one case, and the boom in the other), or it will interfere with setting the hinge spacing. After tightening the hinge clamps but before removing the shims, make sure a piece of paper can be slipped in between the shims and the hinge clamps.

After the magnet assembly is assembled, cover the gap with tape until ready for use. This is very important as small pieces of debris can find their way into the gap and, if magnetic, stick in the magnetic field. The clearance between the coil bobbin and the magnet are small, and even very small debris can cause sticking. When ready to use the magnet, remove the tape and carefully inspect the gap for any foreign particles.

Be very protective the instrument to keep debris out of the gap. It can save hours of troubleshooting. And it is much easier to keep it out initially than to disassemble the instrument later on for cleaning.

If the instrument is sitting uncovered, place something over it to keep out dust and debris.

I installed the connector to the position sensor on the bottom side of the board, so the wires to the sensor could be shorter.

For the coil wires that run along the boom, I used small magnet wire and used superglue to fasten it to the top surface of the boom in several places.

With the mechanical parts assembled, the spring adjusted, and the magnet not installed, check the freedom of movement of the boom. Set it to moving and watch it swing as the oscillations die down. A bent hinge can still allow it to move the full range, but the motion will not be sinusoidal and will appear to be slightly non-uniform. Also watch that the center of the travel remains the same as the oscillation dies down.

Do this again with the magnet installed and the coil wires open. The oscillations will die down much more quickly due to energy loss of the coil moving air in and out of the magnet gap, but the movement should still be very smooth over the entire range. Anything other than very smooth movement is cause to suspect bent hinges or debris in the magnetic gap.

To help detect debris in the magnetic gap or bent hinges, first have the unit running without the pressure cover but protected from airflow. Measure the voltage on the centering force output and make sure it is fairly stable. Then remove the cover and gently push up on the boom. Let go and allow the centering force to stabilize again (several minutes). The centering force should be close to the same as it was before (within 50 millivolts). Repeat the process by pushing down on the boom.

If the centering force voltage is different by more than 50 millivolts, it may mean something is sticking or the hinges are bent.

The shim stock for the hinges has a natural curvature. To avoid oil-canning, cut the hinges so the curve is along the length of the hinge, not across it.

When adjusting period, I noticed a different period for small amplitude oscillations than for large ones. This could indicate a non-linearity in the hinge spring constant due to oil-canning. Cutting out the hinges as above fixed the problem.

Mark a line across the midpoint on the cut-out hinges with a felt marker. This will aid in positioning them under the clamps.

Put lines on the spring and hinge clamps to mark the edges of the spring and hinges. This will aid in centering the spring and hinges under the clamps.

Put small pieces of spring material under the outer ends of the spring clamp on the base to help even the clamping force. This clamp bends significantly when tightened since the screws are outboard of the edges of the spring. I noticed a slight increase in spring constant after I did this, suggesting the center of the spring wasn't clamped as tightly as it could have been.

If the spring width is known in advance, it might make sense to position the clamp screws closer together.

Loop7 design tool was indispensable for determining the various resistor and capacitor values. I built the airtight case out of 3/8" polycarbonate sheet. I determined the part sizes I needed and went to Tap Plastics and in just a few minutes, the parts were ready. I asked about gluing the parts and they suggested a solvent type system. I knew I would need to practice this process so I ordered 3 extra small pieces, just to practice. I got the hang of it and was ready. I tied a bunch of rubber bands together to hold the pieces together while using the hypodermic syringe dispenser to add the solvent to weld the parts together. It worked great with no problems.

7. How does my site affect performance and what is necessary for success?

Very much. Nearby tall trees or buildings can move the ground with wind. Even a person walking nearby can be seen if there isn't a good connection to bedrock.

I don't have personal experience with this, but I'm sure being close to a busy street, freeway, or railroad tracks can seriously

degrade an otherwise reasonably good site. Being on fill or sediment is not as good as bedrock.

The seismometer is installed in the basement wine cellar. The floor is terracotta tile on 4" concrete. This location seems to work well. I also have a 2" thick Styrofoam box surrounding the seismometer. Since adding the foam box, just walking into the cellar causes much less disturbance than before.

8. What sort of documentation will be most helpful?

- \* Machining aids. What's critical and what's not. Tolerances on drawings.
- \* Mechanical assembly instructions.
- \* Instructions for determining spring width.
- \* Instructions for initial turn on.
  
- \* A guide to the overall process. Here's a start:
  - a. Gather materials and documentation together. Make sure everything that will be needed is available. Note that the value of several of the electronic components will need to be determined based on results of testing and measurements.
  - b. Determine if deviations from the reference design will be made, and consider the consequences of these.
  - c. Do the needed machining of the metal pieces. Consider required tolerances.
  - d. Assemble the mechanical section including the hinges and magnet.
  - e. Measure the coil/magnet force constant. Compute or measure the boom weight and moment of inertia.
  - f. Tip the instrument up on end and install enough out-of-plane trim mass so that the boom hangs vertically.
  - g. Cut a trial spring.
  - h. Install the spring and try to get it to balance with the right period. If needed, cut another spring and repeat.
  - i. Heat treat the final spring.
  - j. Install the heat-treated spring and adjust balance and period.
  - k. Plug values into the loop7 spreadsheet, and follow the instructions to finalize the design.
  - l. Procure any needed electronic components according to the loop7 spreadsheet.
  - m. Assemble the PCB.
  - n. Complete the mechanical and electronic assembly and do initial turn on.
  - o. Put the instrument on a stable work surface to check centering force and position error. Adjust trim mass to balance centering force.
  - p. Install pressure cover. Check noise level and gain.

Part drawings would be good. Explanation on loop7 is very useful.

9. How much time will it take?

Two months if you have lots of time and decent skill level. Otherwise more.

Originally I gave myself one year. I took 15 months. But would be much quicker if you follow the original design.

10. What do you feel would be most useful, if we could provide some of the parts for sale?

- a. Springs, cut to size and heat treated. This may not be feasible if variations in boom weight and spring tolerance are too great.
- b. Assembled and tested electronic boards. Difficult due to parts selected to match mechanical characteristics.
- c. Coils.
- d. The boom1 piece. Probably the most difficult to machine due to its geometry, and the one with the tightest tolerances.

The machined parts.

11. How important will cost be?

One can easily trade cost for time & skill. It can probably be done for \$200-\$300 if one has access to surplus electronic parts, machining and electronic skills, and time. This does not include the A/D and computers.

As one who has several hobbies, keeping the cost down for a project like this is important. But I'm eager to trade my time to save some \$\$ and have fun in the process.

I'm sure one needs about \$500.

12. My general thoughts in hindsight.

This was/is a fun project.

Going into it I didn't have a good idea of the overall steps to build one.

The available documentation, for both background and specifically for this design, was a bit overwhelming. It was hard to get a handle on all of it at first. What I finally did was to categorize the documentation to separate background information from what was important to the actual construction. Although there is some overlap, this helped me to be able to look things up more quickly.