Pendulum Seismometer

Equipment- Maple top, Two scissors jack stands, Air Pump, Computer, 850 interface, 4 inflatable rubber tubes , 2 long metal struts, Seismometer apparatus, Clear plexiglas enclosure, level

1 Background

A pendulum can be used as a detector of seismic activity or of any other activity that might cause a building or other structure to shake, such as a train passing in a nearby subway tunnel. The pendulum acts as an accelerometer that is capable of detecting low-frequency vibrations. In this lab, you use a "swinging gate" seismometer to detect building vibrations from passing subway trains and other sources.

As background, you should read §3.2.1 of the *Lecture Notes* for Classical and Quantum Waves, which provides the necessary theoretical background to understand how the seismometer works and how to extract meaningful information from measuring the noise spectru

2 Setting up the seismometer

To set up the seismometer for making measurements, follow the following procedures. See Fig. 1 on the next page for a picture of the apparatus.

Place the plexiglas cover over the seismometer to protect it from air currents in the room. Arrange the opening at the bottom side of the box so that you can access the lower parts of the seismometer.

Float the wooden table to isolate the seismometer from building vibrations. Use the bicycle pump to inflate the air supports and thus lift the wooden table supporting the seismometer a few millimeters off its rigid supports.

Level the seismometer using the leveling screw, shown in Fig. 1, so that the brass mass at the end of the seismometer pendulum is aligned with the long arm of the T-shaped support. This is most easily performed if the damping magnets are placed such that they surround the red aluminum damping plate, as shown in Fig. 1, which provides maximum damping of the pendulum.

Hookup the electronics for sensing the motion of the pendulum. This involves connecting the two wires from the sensing coil to the feed through mounted in the plexiglas box. Connect the other side of the feed through to a voltmeter. For this experiment, the voltmeter is provided by the voltage input of the *850 Interface*. Connect the cable from the feed through to Analog Channel A, which can measure voltages between ±10 volts. To use the voltage input, you will need to launch the *Capstone* software on the computer connected to the *850 Interface* box. To do this, follow the following steps:
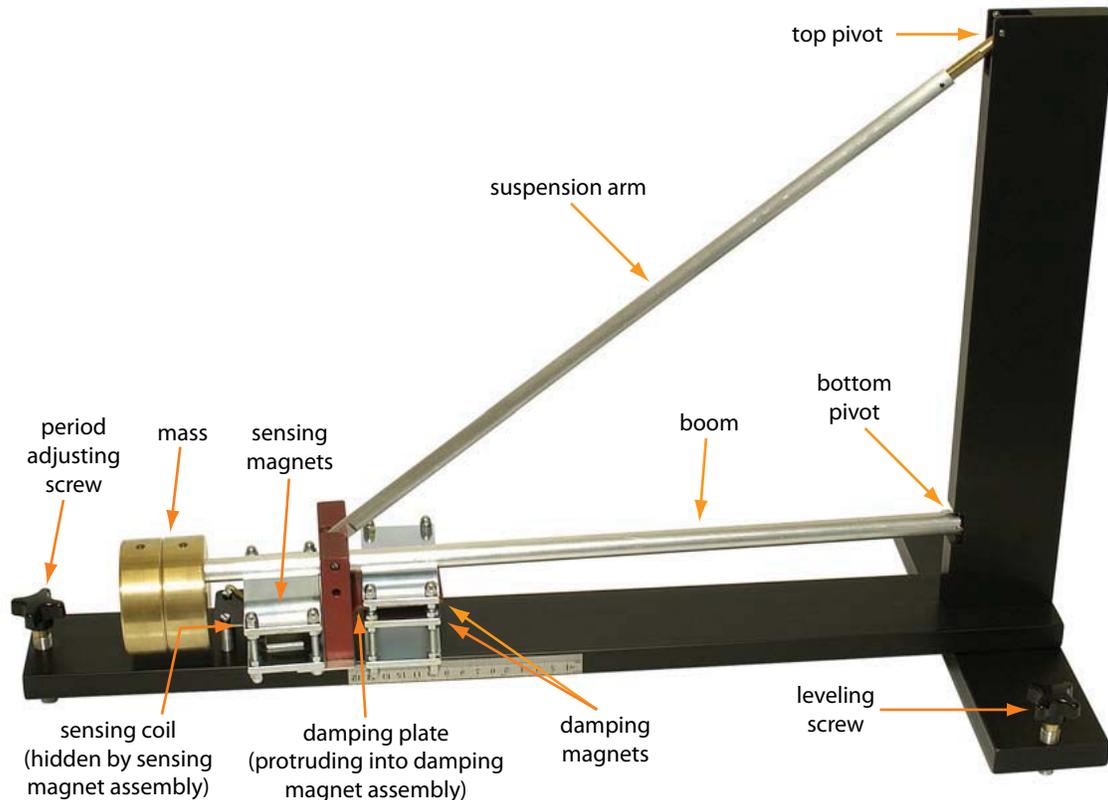
Figure 1: Swinging gate pendulum seismometer.

- Launch Capstone from the Desktop icon
- Go to the top left menu in Hardware Setup window
- Click on the analog channel of the Voltage Sensor from the drop down menu (you may need to scroll to the bottom of the menu to see the Voltage Sensor item). A Voltage Sensor icon should appear beneath the image of the *850 Interface* box. Under the Data Summary menu, Voltage sensor should also appear.
- Click on the gear icon next to the voltage sensor its the box that appears under the image of the *850 Interface* box. Set the Gain to (10x). This sets the sensitivity of the voltmeter. Leave the Sample Rate set to 20 Hz for now. Click Ok.
- Drag the graph icon from the far right side menu to the center of the screen. This brings up a graph to display your data.
- Click Record at the bottom-left of the display to begin acquiring data. Clicking Stop stops the data acquisition and clicking Record again begins a new data acquisition.

Ask your TA if you need help in launching and setting up the voltage measurement and recording.

Measure the period of the seismometer. To facilitate the measurement of the period, you should minimize the damping by sliding the damping magnets away from the damping plate. Set the pendulum into motion by blowing on the mass at the end of the boom. Blowing, rather

than touching the pendulum, provides an appropriately gentle push for exciting this sensitive instrument. You can record the oscillations of the pendulum using the electronics and software you set up in the previous step.

Adjust the period of the seismometer so that the period is 15–20 seconds. The period of this *swinging gate* pendulum is determined by the tilt of the boom below horizontal, meaning that the mass should be a few millimeters lower than the bottom pivot. You can change the tilt by turning the period adjusting screw, which is shown in Fig. 1.

Save a set of data that shows a nicely decaying set of oscillations. Your data set should show at least 10–12 complete oscillations. You will notice that the signal-to-noise ratio gets smaller (*i.e.* noise comprises a bigger fraction of the signal) as the signal decays. Nevertheless, you should try to obtain a signal such that the first 7-8 oscillations have a signal-to-noise ratio of at least 4 or 5 so that they are clearly visible over the background noise.

To save a data set, select File and then click on Export Data. Title the file and select Desktop before saving it. Now the file is saved to the desktop for easy transfer to a USB drive. Launch Python from the same computer that you are using to run Capstone. When the IPython (PyLab) terminal window appears, set the directory to that of the flash drive.

Use the program called ReadDataFitPlot.py, given below, to read in the voltage data you acquired and to plot it out together with a plot of a decaying sinusoidal function of the form

$$v(t) = A\,e^{-\gamma t/2}\sin(\omega_u t + \phi) \tag{1}$$

where $\omega_u = \omega_0\sqrt{1 - 1/4Q^2}$ and $Q = \omega_0/\gamma$. In the Python program, we have used the relation $\gamma = \omega_0/Q$ to eliminate γ from the analysis in favor of the more readily understood quality factor Q as a way of characterizing the decay of the oscillations.

```
# Reads in data from data file, plots it and compares it to
# an exponentially decaying sinusoidal signal

import numpy as np
import matplotlib.pyplot as plt


# Function defining exponentially decaying sinusoidal
def thetaU(t, A, w0, Q, phi):
    wu = w0 * np.sqrt(1.0-1.0/(4.0*Q*Q))
    return A * np.exp(-0.5*w0*t/Q) * np.sin(wu*t + phi)


# User sets these parameters to best match the data
A = 0.12                        # Amplitude
T = 17.0                        # Period (w0 = 2 pi / T)
Q = 10.0                        # Q = quality factor (determines damping)
phase = 90.                     # phase in degrees


# Convert phase in degrees to phase in radius for use in function
phi = np.pi * phase / 180.0     # phase in radians
```

```
time, theta = np.loadtxt('FreeDecay2.txt', skiprows=250 , unpack=True)

fit = thetaU(time, A, 2.0*np.pi/T, Q, phi)

plt.plot(time, fit)
plt.axhline(color='gray')
plt.plot(time, theta)

plt.show()
```

3   Measurements and analysis

Measure the Q of the seismometer for several different positions of the damping magnets, noting the positions by the ruler mounted to the seismometer base, such that you measure Q for at least a couple of significantly under-damped cases (which should have significantly different values of Q). Then determine the position of the damping magnets that correspond to critical damping, which should provide the best, or nearly the best, compromise between sensitivity to small building accelerations and resolution of changes in acceleration. In addition to using the above program to analyze your data, you may wish to develop other ways of analyzing your data, depending on any deficiencies you find in using the above method.

Once you have the seismometer set up, collect data so that you "see" several subway trains pass, at least 10-15 minutes. You should ask yourself what quantity does the pick-up coil measure and exactly what quantity or quantities is the instrument sensitive to? What are the characteristic frequencies of the vibrations? Analyze your data to see if you can actually determine the amplitudes of the accelerations, velocities, and displacements of the building. See if you can figure out what magnitude of earthquake would correspond the vibrations you measure due to the subway trains passing (obviously this depends on where the epicenter of the earthquake is).

Repeat your measurements both with and without the vibration isolation mounts for the wooden table. Do you see a difference? Why or why not?