Strain on an oscillating beam: Procedure

ME 240: Fundamentals of Instrumentation & Measurement • D. H. Kelley and I. Mohammad

Introduction

Mechanical structures — from buildings to bikes to beams — bear loads which cause stresses and induce strains. Being able to measure strain is crucial for characterizing the operation of any mechanical structure and avoiding failure. Your goal is to measure the strain on a beam oscillating at its lowest natural frequency, determine the frequency, and compare the frequency to a theoretical prediction. To do so, you will attach a strain gage to a beam and record measurements with a data acquisition system (DAQ) and computer.

Strain gages are passive transducers whose resistance varies linearly with strain. They are delicate, and using them requires attaching them securely to the object whose strain is to be measured, via a process of careful surface preparation and adhesion. Plan to spend substantial time and effort in that process; rushing will lead to mistakes and waste time. The resistance of a strain gage is typically 120 Ω and varies by only $\sim 0.1\% = 0.1\ \Omega$ under typical strains. That small variation is typically extracted via a Wheatstone bridge, which in this case is built into the DAQ.

A cantilevered beam has many natural frequencies, and the n^{th} frequency f_n is given by

$$f_n = \frac{2\pi}{\lambda_n^2}\sqrt{\frac{EI}{\rho A}}, \tag{1}$$

where E is Young's modulus, ρ is the density of the beam material, and A is the beam's cross-sectional area. The beam's area moment of inertia is

$$I = \frac{bT^3}{12},$$

where b is the width of the beam and T is its thickness (see Fig. 1). The wavelength of the n^{th} mode is λ_n, which is the n^{th} solution of

$$\cos\left(2\pi\frac{L}{\lambda_n}\right)\cosh\left(2\pi\frac{L}{\lambda_n}\right) = -1, \tag{2}$$

where L is the beam's length. If an impulse is applied to the tip of the beam, the strongest vibrations occur at the lowest natural frequency, for which $n = 1$.

Learning goals

- Properly attach a strain gage.
- Measure strain using a strain gage and a data acquisition system.
- Compare the measured natural frequency of a cantilevered beam to a theoretical prediction.

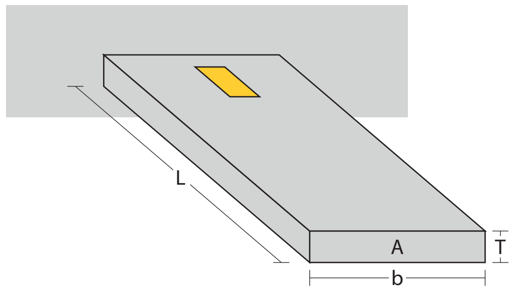

Figure 1: *Left,* A strain gage glued on a cantilevered beam with length L, width b, thickness T, and cross-sectional area A. *Right,* QR code linking to strain gage installation manual.

Materials

- **Attaching the strain gage:** metal beam, strain gage, CSM degreaser or GC-6 isopropyl alcohol, silicon carbide paper, M-Prep Conditioner A, M-Prep Neutralizer 5A, gauze sponges, cotton applicators, tweezers, gage installation tape, M-Bond 200 adhesive and catalyst, tape measure, electrical tape, wire strippers, wire cutters
- **Measuring variation of strain:** cantilevered beam with strain gage attached, data acquisition system (National Instruments NI 9235)

Safety

Closed-toed shoes and eye protection are required. Protective gloves are required when handling chemicals (e.g., for surface preparation and adhesion of strain gages). Work in a fume hood when producing fumes whose inhalation is to be minimized.

Attaching the strain gage

Attach a strain gage about 5 cm from one end of an aluminum beam, oriented with its traces parallel to the beam. Use the instructions in the “Installation of Micro-Measurements Strain Gage with M-Bond 200 and AE-10 Adhesive Systems” section of “Student manual for strain gage technology” by Vishay Measurements group, Inc. (available here and by using the QR code in Fig. 1). Proceed methodically and cautiously — strain gages are finicky, and the fastest way to attach one is by working slowly, to avoid mistakes. Consider reading the instructions more than once before beginning the procedure! Consider setting out all the supplies, in order, before starting. Other parts of the exercise will be quick, after this part is complete. Some tips are below.

- Degrease the beam surface in the fume hood, then clamp the beam to a table outside the hood.
- Strain gages are fragile, so handle yours carefully, using tweezers.

- Never let bare skin touch the back of the gage or the part of the beam where you will glue the gage, because skin oil can prevent proper adhesion.
- When sanding the surface to prepare it, keep it wet with conditioner to eliminate dust that could prevent proper adhesion.
- When applying neutralizer, again, keep the surface wet as you wipe it.
- The parts of the procedure involving tape may be easier if you do not wear gloves, and if you have trimmed the lead wires to 6 inches.
- When attaching the gage to the tape, use 4-5 inches of tape and fold each end of the tape over on itself, so you have a tab at each end to hold without sticking.
- A gage that is misaligned on the tape can cause measurement error.
- When attaching the gage to the tape, attach the wires, too, for extra stability.
- You will have about ten seconds to adhere the gage, once you have applied catalyst. Before applying catalyst, run a 10-second timer to get a sense for how much time you will have.
- After the strain gage is glued to the beam, do not flex the beam more than 1 mm, or you may break the glue and/or gage.

When you are finished, be sure that the attached gage is flush against the beam by gently ensuring that a piece of paper will not slide behind it. Use tape to anchor the wires against the beam for strain relief, so that accidental tugs on the wires will not break any solder joints. Verify that the resistance from the end of one wire, through the gage, and to the end of the other wire is 120 Ω; substantially higher resistance suggests a bad solder connection. Verify that the resistance between each wire and the beam itself is large enough to indicate an open circuit. Photograph your strain gage, glued in place.

Measuring strain of an oscillating beam

First, set up to acquire strain measurements. Using a National Instruments NI 9235 DAQ, connect the red strain gage wire to the `Exc0` terminal and the white strain gage wire to the `RC0` terminal. If your strain gage also has a black wire, connect it to the `AI0` terminal; if not, use a wire to connect the `RC0` and `AI0` terminals.

Open Matlab and set up data acquisition using these commands:

```
d = daqlist('ni'); % list available data acquisition devices
deviceInfo = d{1,'DeviceInfo'} % see info about the device
```

Note the DeviceID, which is probably something like `cDAQ1Mod1`; you will need it. Continue with these commands:

```
dq = daq('ni');
addinput(dq,'DeviceID','ai1','Bridge'); % add channel
dq.Channels(i).BridgeMode = 'Quarter';
dq.Channels(i).NominalBridgeResistance = 120; % strain gage resistance
```

If something goes wrong, you can use `daqreset` to start over.

Next, insert the beam into the cantilever clamp and measure the beam's dimensions. When determining its length, measure only the part of the beam that extends out from the clamp. To make the beam oscillate at its lowest natural frequency, gently tap the tip with a small screwdriver or similar tool, displacing the tip no more than 1 mm (a greater displacement might break the gage). Record the strain, starting before you tap the beam and continuing until its oscillations have basically stopped, using a command like

```
data = read(dq, seconds(15));
```

Plot your data with commands like these:

```
GF = 2.04; % gage factor
figure; plot(data.Time, data.DeviceID_ai1/GF)
```

Oscillations should be evident; if they are not, stop to troubleshoot. Then, calculate the power spectrum using `fft.m` or `pwelch.m`, plotting your results. From the plot, determine the beam's oscillation frequency and mark that frequency on the plot.

Comparing your measurements to theory

Solve Eq. 2 to determine λ_1, the wavelength of the beam's lowest natural frequency ($n = 1$). The equation is transcendental, so you will not be able to solve it by hand. However, you can accurately estimate λ_1 by plotting both sides of Eq. 2 to see where the plots cross, or else by using a tool like MATLAB's `fzero.m`, which finds roots of nonlinear functions. (You can enter `doc fzero` to read more.) There are many roots, and by definition, λ_1 is the smallest one. To avoid numerical challenges, determine the first root of $\cos x \cosh x = -1$, then calculate λ_1 from that root. Record your value of λ_1, along with your plot and/or code. Then use that value in Eq. 1 to predict the lowest natural frequency f_1. Record your answer and calculate the percent difference between the value you predicted and the value you measured. Name two likely sources of error.