MCE441/541: Introduction to Linear Control Systems / Linear Control Systems

Final Project - Fall 2011

The final project report is due on December 16th
MCE541: Real-time controller deployment will be scheduled for finals week

1 Problem Description and Objectives

A cantilever beam fitted with a piezoelectric patch actuator will be the controlled plant. A DuraAct piezoelectric patch manufactured by Physik Instrumente (model P-876 A15) is bonded to the beam with epoxy. The patch is commanded from a power amplifier producing over 100V. The amplifier input (control signal for design) is restricted to the range -4 to 10V. The patch produces bending moments on the beam, resulting in deflection. The controlled variable is the deflection of the beam near its free end, where a piece of reflective tape has been attached.

An optical probe is used to measure the deflection of the beam at the target location (shining spot on reflective tape). Light is sent via optic fibers to a sensor head, which produces an output voltage proportional to beam deflection. This voltage constitutes the sensed variable. Figures 1 and 2 show a close-up of the beam and the complete measurement and control system.

As shown in class, a dynamic signal analyzer, or spectrum analyzer, was used to perform a frequency sweep on the plant. The analyzer provides an experimental Bode plot of the plant, from amplifier input to sensor output.

1.1 Control Objectives

The control objectives are:

1. Achieve offset-free following of a square reference profile for the plant output, with minimal overshoot and a reasonably-fast response time

2. Significantly reduce the oscillation decay time of the impulse response: without control, the beam will oscillate for more than one second when the free end is flicked. With control, we should see a significant reduction in the decay time.

3. Test the control system in real-time operation.

The following design requirements apply to the first objective. With a properly-designed controller, the second objective will be met automatically.

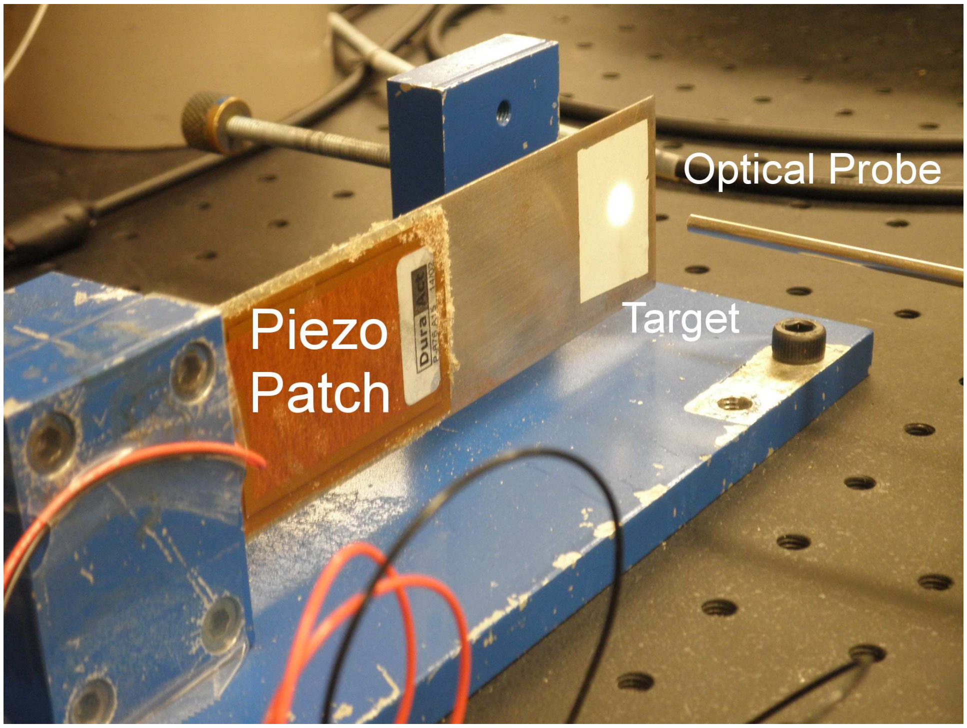

Figure 1: Close-up view of piezo-beam

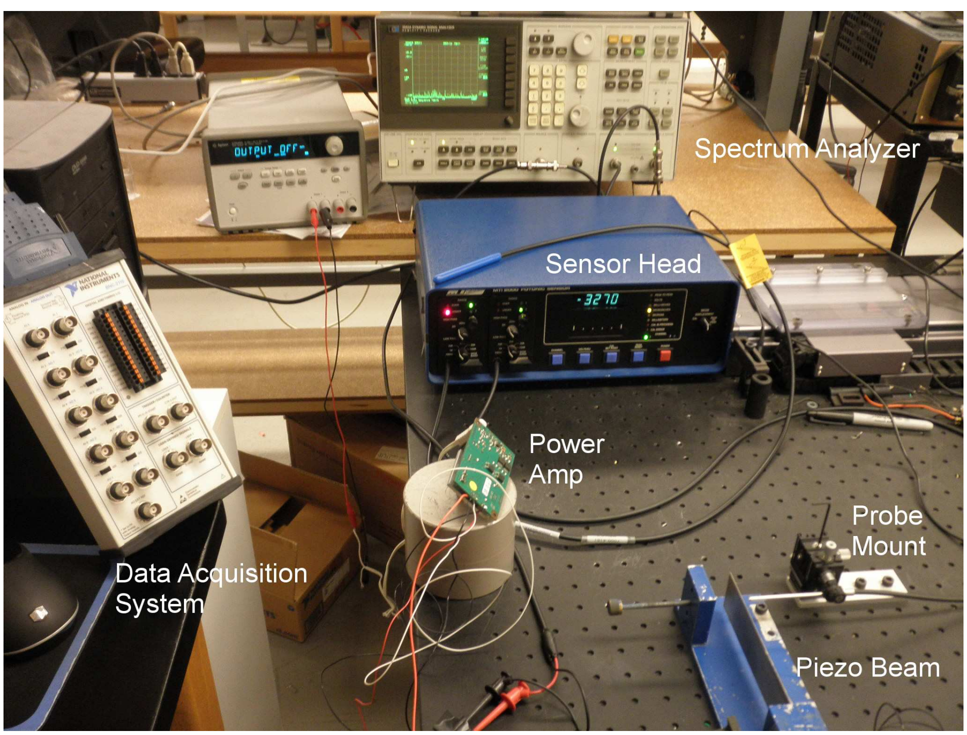

Figure 2: Control and measurement system

1.1.1 Design Specifications: MCE441

Design a controller with the following requirements:

1. Zero steady-state error to step commands
2. Settling time: 0.25 seconds
3. Maximum overshoot: 5%
4. The reference input will be a 0.05 V step. The control voltage must remain within the -4 to 10 V limits at all times.
5. The controller must be robust against the un-modeled second resonance. Verify by simulation against a more realistic model (including 2 resonances and 1 antiresonance).
6. The control transfer function $K(s)$ must be proper (no more zeroes than poles) and stable (no right-half plane poles in the denominator of $K(s)$).

1.1.2 Design Specifications: MCE541

Design a controller with the following requirements:

1. Zero steady-state error to step commands
2. Settling time: 0.1 seconds
3. Maximum overshoot: 1%
4. The reference input will be a 0.05 V step. The control voltage must remain within the -4 to 10 V limits at all times.
5. The design plant will be the more realistic model (including 2 resonances and 1 antiresonance).
6. The control transfer function $K(s)$ must be proper (no more zeroes than poles) and stable (no right-half plane poles in the denominator of $K(s)$).

2 Frequency-Based Model Fit

A frequency sweep was carried out for the piezo-beam system using a frequency range of 1 Hz to 1kHz. Data corresponds to a vector of 801 logarithmically-spaced frequencies. The two data sets will be posted to the course website.

1. Fit a continuous-time second-order transfer function to include the first resonance. This will be called Model 1-CT.
2. Fit a continuous-time transfer function to include the first and second resonances and the anti-resonance between them. This will be called Model 2-CT.
3. Generate a plot showing how 1-CT and 2-CT fit the data.

Data has been posted on the course website under `beamfreqdata.mat`. Download the file to your computer and load in Matlab as follows:

- `>> load beamfreqdata`

- Two variables will be created in the workspace: `f` (frequency vector in Hz) and `mag` (decibel magnitudes). Plot using `>> semilogx(f,mag);grid`.
- To verify that your fitted transfer functions match the data, plot the original data as above but using `2*pi*f` (radian frequency). Hold the plot. If your fitted TF is `sysG`, plot with `bodemag(sysG,'r')`

3 Control Design

Do the following

1. Translate the step response specifications to the frequency domain: bandwidth, crossover frequency, phase margin, certain gain slopes. Sketch the target loop and boundary regions.
2. Import the plant model in SISOtool (1-CT for MCE441, 2-CT for MCE541). Follow the same directions as for the midterm project. This time, change the prefilter gain F to 0.05.
3. Proceed interactively, trying to achieve the target loop shape, and monitoring the current step responses for the output and the control. *Hint: use notch filters (complex zero pairs) to achieve approximate cancellation of resonances.*
4. Once SISOtool shows that the design requirements have been met, export the compensator to the workspace.

4 Verification Simulations

Cascade the final controller and the plant using `series`. Then find the closed-loop TF using `feedback`. Also find the control TF by dividing the closed-loop TF by the plant TF. If they are `sysT` and `sysG`, simply divide as follows: `>>sysU=sysT/sysG`. Use the `step` command to display the final step responses (use `step(0.05*sysT)` and `step(0.05*sysU)`. Note that the plants used in this task depend on whether you are 441 or 541, as follows:

4.1 MCE441:

Control design was done in SISOtool using Model 1-CT. For the final verification, find the closed-loop TF and the control TF using your final controller and Model 2-CT as a plant TF.

4.2 MCE541:

Control design was done in SISOtool using Model 2-CT. For the final verification, find the closed-loop TF and the control TF using your final controller and Model 2-CT as a plant TF. You should get the same results as in SISOtool. The true verification will come when we deploy the controller in real time.

5 Reporting

Write a short report allowing a technical person knowledgeable in controls to understand the project without having participated.