ELE320 - Aero

Laboratory Assignment 2

Topics Covered

- Aero pitch control.
- Proportional-integral-derivative (PID) compensator.
- Manual PID tuning.
- Second-order system approximation.
- Controlling second-order systems.
- PID design by specification.

Prerequisites

- First Principles Modeling laboratory experiment.
- System Identification laboratory experiment.

Questions are marked with * and answers to them should be included in your hand-in. The steps without marker are necessary steps to obtain the results

4. Qualitative PID Control

Proportional Control

4.1 Open `q_aero_qualitative_PID_Control.slx`. As shown in Figure 4.1. This model implements basic command and unity feedback for the Quanser Aero.

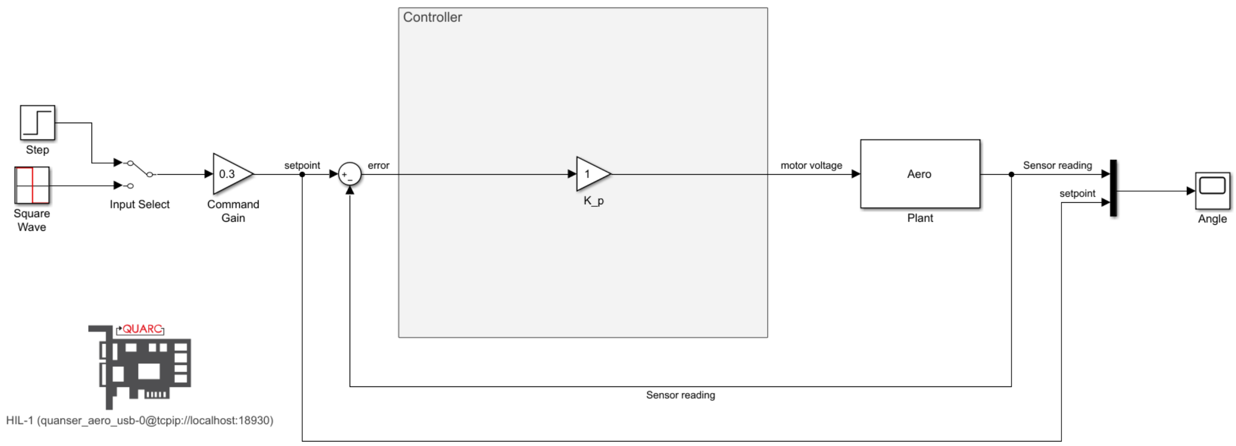


Figure 4.1: Unity feedback block diagram.

4.2 Build and run the model. The response should look similarly as shown in Figure 4.2.

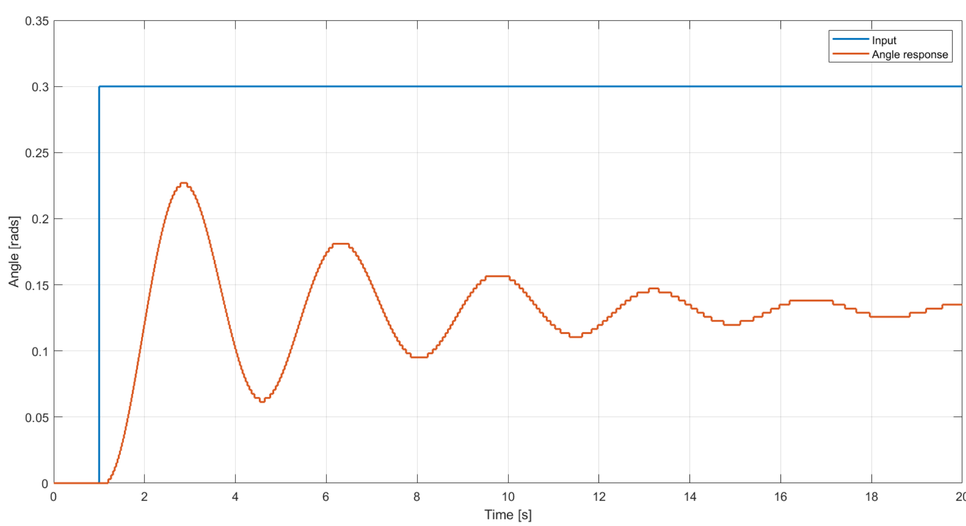


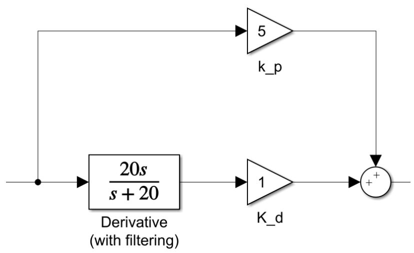
Figure 4.2: Quanser Aero unity feedback step response.

* 4.3 Vary the proportional gain between 1 and 5. Run the model with different proportional gains. What effects does increasing the proportional gain have on the system response?

* 4.4 Given the specification that the controlled system has a peak time of less than 1.2 seconds, is it practical to use purely proportional control? Why or why not?

Derivative Control

4.5 Add a transfer function and derivative gain block k_d in parallel with the proportional gain. Because the angle data from the encoder is a discrete signal, some filtering will have to be added to the derivative to smooth out discontinuities when the encoder count changes. Set the transfer function for the derivative filter to



$$F(s) = \frac{20s}{s + 20} \tag{4.1}$$

✱ 4.6 Set the proportional gain to 15 and vary the derivative gain between 0 and 6. What effects does increasing the derivative gain have on the system response? How does the system response differ when the derivative gain is very small (e.g. <0.25)

4.7 Change the Input Select switch to select the square wave input

✱ 4.8 It is desired that the system with PD controller has a peak pitch which does not exceed $\pm 0.35\ rads$ when commanded with a $0.3\ rad$s square wave. What is the minimum value of k_d which produces a system with acceptable overshoot?

Integral Control

4.9 The response should now approach the commanded value quickly and settle in a short time. However even with a large proportional gain, the final position of the Aero still differs from the command value by approximately 0.3 radians. To remove this steady state error, add an integrator with an integral gain k_i in parallel with the other two gains.

✱ 4.10 Keeping the proportional and derivative gain at the values identified in step 4.8, vary the integral gain between 0 and 5. Run the model with various integral gains. What effects does increasing the integral gain have on the system response? What happens when the integral gain is increased too much?

✱ 4.11 Given the specification that the output settles within 3% of the reference value (for the 0.3 radians square wave this means that the steady state value must be in the range from 0.291 to 0.309 radians). Given that the square wave has a frequency of $0.1\ Hz$, the system should have a maximum settling time of 3.5s to be able to settle before the next reference command. What integral gain results in a system which meets this requirement?

Response Tuning

* 4.12 If your response does not match the overshoot (<0.35 radians peak pitch) and peak time (<1.2 seconds) specifications from previous steps, try tuning your control gains until your response satisfies all three requirements (including steady-state error). Keep in mind the effects of the individual parameters states in Table (4.1). Plot the resulting system response overlaid with the reference signal. Add a horizontal and a vertical line representing the maximum allowed overshoot and peak time according to the specifications. Record the final PID gains and comment on how you modified your controller to arrive at your final results.

↑ parameter	Rise time	Overshoot	Settling time	Steady-state error	Stability
K_p	Decrease	Increase	Small change	Decrease	Degrade
K_i	Decrease	Increase	Increase	Eliminate	Degrade
K_d	Minor change	Decrease	Decrease	No effect	Improve (if K_d small)

Table 4.1: Effect of increasing PID parameters.

5. PID Control to Specification

Second-order system approximation

Modeling the Quanser Aero precisely would require a nonlinear system model, comprising different types of nonlinearites, such as "hard" ones as in the case of Coulumb friction. Even when focusing on the behavior about an operating point, a precise description of the linearized model would require a third or fourth-order model. However analytical design of a controller for such high-order systems is generally prohibitively complex. Instead, the Quanser Aero will be subjected to a step input and the response will be used to identify a second-order transfer function which, by virtue of the dominant pole approximation, describes satisfactorily the systems behavior.

5.1 Open `q_aero_PID_specification.slx`.

5.2 Set the *OL/CL Select* and *Reference Select* switches to the *OL step* signal.

5.3 Run the model. The response should look similar to that shown in Figure 5.1.

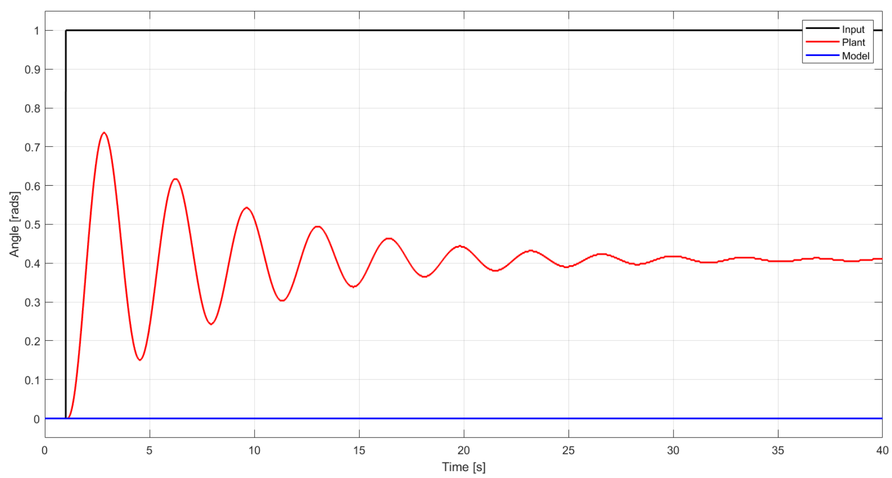


Figure 5.1: Open-loop step response of the Aero.

* 5.4 Analyze the plotted angle data to find the peak time (t_p), the maximum value of the response (y_{max}), the steady-state value (y_f), the percent overshoot (PO).

* 5.5 Using Equation 5.3 and Equation 5.5 in the `AERO2_Preparaton.pdf` document, find values of ω_n and ζ which define a second-order system with a similar behavior.

* 5.6 Using the prototypical transfer function

$$\frac{Y(s)}{R(s)} = \frac{y_f \omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

and the values calculated in step 5.5, find the transfer function of the second-order approximation of the Aero plant.

5.7 Change the values in the Model Transfer Function block to match the calculated second-order approximation.

* 5.8 Build and run the model. How closely does the second-order approximation model the behavior of the Aero plant? What physical dynamics in the Aero might contribute to the difference between the model and the plant behavior.

Calculating PID Gains

* 5.9 The desired response for the compensated Aero system is a critically damped system with a 2% settling time of 2 seconds. Given that critical damping requires $\zeta = 1$, Equation 5.6 in the `AERO2_Prepation.pdf` document gives a natural frequency of approximately $\omega_n = 2\ {}^{rads}/_{s}$. Using these values along with the values for a, b, and c from the second-order transfer function in step 5.6 and the third pole position $p_0 = 1$, calculate the PID gains using the formulas given in Section 5.2 of the `AERO2_Prepation.pdf` document.

5.10 Set the `Model Enable` switch to zero since the model will not be needed for testing the controller.

5.11 The normal operating range of the Quanser Aero is ±0.5 radians. Change the *OL/CL Select* and the *Reference select* switches to the square wave.

5.12 Update the control gains to match those found in step 5.9.

5.13 Build and run the model. Observe the response of the compensated system to the square wave.

* 5.14 Does the compensated system meet the requirements for damping and settling time?

* 5.15 Increase the speed of the filter by setting it to

$$F(s) = \frac{200s}{s+200}$$

What effect does this have on the response, and why?

* 5.16 Reduce the speed of the filter by setting it to:

$$F(s) = \frac{2s}{s+2}$$

What effect does this have on the response, and why?

5.17 Stop the model.

5.18 Power OFF the Quanser Aero.

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