ME352 QUBE Lab #4:

**Motor Position Control**

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Fall 2022

(last updated 9/20/22)

# 1 Objective

In this lab, you will regulate the position of the Qube motor shaft and disc using a PID controller. You will determine controller gains from time domain specifications and study the effects of derivative and integral action on the transient and steady-state response and disturbance effects.

# 2 Pre-lab Background Questions

A block diagram of the closed-loop system for control of motor position is shown in Fig. 1. Fig. 1 separates the motor plant model (dotted box) into electrical and mechanical inputs and outputs so that we can model different types of disturbance effects. The controller outputs a voltage, *u*, which produces a torque proportional to the armature current (*T* = *kt ia*), which causes the motor to rotate. Assuming negligible armature inductance, the motor model can be derived in terms of the back-emf motor constant ke, the electrical motor armature resistance Rm, and the equivalent moment of inertia of the motor pivot Jeq. A direct disturbance applied to the inertial wheel is represented by the disturbance torque variable Td and a simulated disturbance voltage is denoted by the variable Vsd.

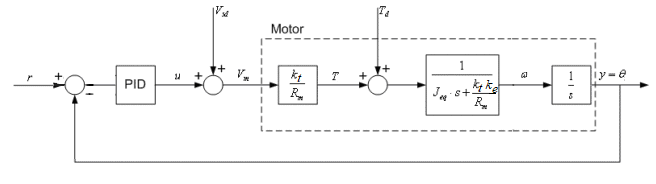
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Figure 1: DC Motor PID position control closed-loop block diagram.

The plant transfer function, , for the DC motor position system can be written in terms of the open-loop motor gain constant, *K*, and the time constant, *τ* :

Complete the following questions before attending the lab.

1. Consider PD Control and determine the closed-loop transfer function from the position reference, *r*, to the angular position output, *ϴ* in radians*,* i.e., *Y*(*s*)/ *R*(*s*), in terms of *K,* *τ*, *kp* and *kd*.
2. Determine *kp* and *kd* in terms of the closed-loop natural frequency, *ωn,* damping ratio, *ζ*, motor time constant, *τ*, and motor gain constant, *K.*
3. Determinethe steady-state error to a unit step input and the DC Gain of the closed-loop motor position system.
4. Now consider PID control. Determine the closed-loop disturbance to position transfer function, *Y(s)/Td(s)*, assuming zero reference input and zero disturbance torque (*Td*), in terms of *Jeq*, *K,* *τ*, *kp*, *ki* and *kd*. In this lab we will simulate the torque disturbance (*Td*), by applying a simulated voltage disturbance (Vsd), which is why we assume Td is zero. The voltage applied to the motor is Vm is equal to the controller output, *u*, plus the simulated disturbance voltage, Vsd:

*Hint: It is helpful to start by recognizing Y(s) = P(s) Vm(s) and U(s) = C(s) [R(s)-Y(s)] where R(s)=0 and then solve for Y(s)/Td(s). The algebra in the Laplace domain is less tedious if you leave the plant in the form: .*

1. Determine the steady-state error to a step disturbance of magnitude, *Tdo* , given PD (i.e. set ki = 0).
2. Determine the steady-state error to a step disturbance of magnitude, *Tdo* , given PID-Control.
3. Consider the standard characteristic equation for a third-order system:



Determine *kp,* ki, and *kd* in terms of the closed-loop natural frequency, *ωn*, the damping ratio, *ζ*, the motor gain constant, *K*, and the location of the pole, *p*o*. (Hint: You do not need to derive the closed-loop transfer function for PID Control. You already determined the characteristic equation for the system with PID Control in question #4.)*

**Before you begin the lab, you should check that you correctly determined *kp, ki*and *kd* !**

# 3 Position Control Simulink Model and Experiment Setup

## Outputting encoder position

Navigate to the QUBE\_STUDENT folder and open the lab2\_speed\_control.sltx Simulink template and Create Model. Save the template as a new Simulink file. Double click on the Qube\_Plant subsystem block.

Inside the subsystem block the motor encoder signal is converted from pulse count to radians, then to angular velocity using a low-pass derivative block. For this lab, we need to output the position, *ϴ*, for feedback control as shown in Fig. 2. To do this, delete the low-pass derivative block, reconnect the radian signal to the output block and rename the output from Omega to Theta.

Diagram

Description automatically generated

Figure : Qube Plant Subsystem Block

## Updating position control plant model

Navigate back to the Theoretical Model subsystem block and double-click on the Transfer Fcn block and add an integrator (pole at the origin) and rename the output to Theta as shown in Fig. 3. Note, this can also be accomplished by adding an integrator block after the existing first-order transfer function block. Change the names of the scopes from Omega or Velocity to Theta or Position in radians.

Diagram

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Figure 3: Theoretical Model Subsystem Block

## Adding derivative term to Controller Block

Modify the block diagram to add a derivative block and gain to the Controller Block. Do this by double clicking on the summation block and adding a “+”. In the Simulation tab, click on Library Brower, and search for the Derivative block. Rename the gain block to indicate “Derivative Gain”.

Diagram

Description automatically generated with low confidence

Figure 4: Controller Block with PID Control

## Changing reference input

Change the input to vary the desired position from 0 to 360 (one rotation).  Double click on the gain after the square wave and change the name to theta. Change the labels on the input gain to indicate position. Make sure the square wave signal block generates an amplitude of 0.5 V and frequency of 0.2 Hz with the offset of 0.5 added to the summation block.

Diagram

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Figure 5: Square Wave Reference Input with offset and Theta Gain Block

## Running parameter file and Simulink model

Open the lab2\_params.m file. Change the input name from w to theta and change the theta to 2(theta = 2\*pi).Save the parameter file as lab4\_params.m and run the parameter file.

Align the disc so that the etching aligns with the 0-degree marking so you can observe the disc as it rotates 360.

Set the proportional gain to 0.5 and derivative and integral gains to 0. Click Monitor & Tune and observe the disc and desired vs. actual position in the scope. *Change the default scope settings in the “Configure Parameters” menu to limit logging data points from 5K to 20K.*

# 4 Position Control Lab Assignment

## Qualitative PD Control

1. Examine the desired vs. actual position scope and describe the behavior of the measured position with respect to the reference position. *Click View then Legend to display the scope legend.* Indicate the approximate overshoot and steady-state error in rad and percent.
2. Increment the proportional gain and observe the change in behavior. Determine the overshoot and steady-state error when *kp* = 3.85.
3. Increment the derivative gain, *kd*, by steps of 0.01 V.s/rad. Describe the changes in the measured signal with respect to the reference signal. Explain the performance difference of changing kd.

## PD Control according to Specifications

1. Calculate *kp* and *kd* necessary for ζ = 0.6 , ωn = 20 rad/s. This corresponds to an approximate overshoot of 10% and rise time less than 1/10 second. Implement the controller gains. Examine the measured position response. Explain why there is an error between the reference and measured position. *Use the K and τ calculated using the QUBE Servo 2 motor specifications.*
2. Calculate *kp* and *kd* if the damping ratio, ζ , is increased to 0.7 (keep ωn = 20 rad/s). Implement the controller gains. What effect does changing the specification for ζ have on the calculated controller gains and the experimental measured position response.
3. With ζ = 0.6, calculate the controller gains for natural frequencies of 15 rad/s and 30 rad/s . Implement the controller gains. What effect does changing the specification ωn have on the calculated controller gains and the measured position response?

## Response to Load Disturbance

1. In the signal block set the Amplitude = 0 rad and for the offset set *Constant value* = 0 rad. With *kp* = 1.54 V/rad and *kd* =0.054 V-s/rad (ζ = 0.6 , ωn = 20 rad/s), observe the disc position and desired and actual position scope, which should show a reference of 0 Gently try to move the disc with your finger causing a small torque disturbance of no more than 1 radian. Describe the effect of the disturbance on the measured position.

## Response to Simulated Voltage Disturbance

Now modify the Simulink model to be able to systematically apply a disturbance by applying a voltage disturbance to simulate a torque disturbance. Stop the hardware and navigate to the Library Browser in the Simulation tab. In the Library search for a *Manual Switch*. Add two constant blocks to the inputs of the switch – one labeled “Voltage Disturbance” with a *Constant Value* = 1 and one labeled “No Disturbance” with a *Constant Value* = 0. Connect the output of the switch to a summation block that you add to the output of the controller block as show in Fig. 6.

Diagram, schematic

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Figure6: Position Control Simulink with Simulated Voltage Disturbance Switch

*Note, in Fig. 6, a saturation block was added to saturate the modeled motor voltage since the Quanser motor controller is only able to output a maximum of +/-18V even if the controller requests more. Note adding this block is not absolutely necessary since it will not change the experimental results but saturating the motor voltage will allow the modeled results to reflect the hardware limitations more accurately. If you decide to add this block in your model make sure to change the saturation limits to +/-18V.*

1. Start with the Disturbance switch to input zero disturbance. Then toggle the switch to input a simulated 1 Volt disturbance and observe the resulting steady-state angle. Now calculate *kp, ki,* and *kd* for a PID Controller where the pole, *p*o = 1. Implement the controller gains and then switch on the disturbance. Explain the difference in the disturbance response with the integral action added.
2. Calculate the controller gains if you move the pole location, *p*o, from 1 to 3. Before you implement the new gains, switch the disturbance off. Once the new gains are implemented, switch the disturbance on and examine the disturbance response. Explain what happens to the disturbance response when the pole is placed further into the left-hand plane.

Extra Credit

In your homework #4 MATLAB problem #7 you modeled the Quanser Qube motor position control system. You should have observed from the simulated closed-loop unit step response that the steady-state error for a P Controller is zero (Type 1 system!) even though your experimental results showed some steady-state error.

1. For extra credit, with the disturbance switched off in Simulink and *kp*=3.85, *kd*=0.1, *ki*=0, change the Signal type in the Signal Generator block to a Triangle wave. Submit a plot of the experimental desired vs. actual measured position and determine the steady-state offset. Compare the offset to calculations of the error to a ramp input using the final value theorem. Show your calculations. Then implement a PID Controller and show whether you are able to eliminate the offset.