PREFACE

Preparing laboratory experiments can be time-consuming. Quanser understands time constraints of teaching and research professors. That's why the QUBE-Servo 2 experiment comes with a new generation of mix-and-match courseware that allows easy adaptation of material to a specific course. The courseware is also aligned with requirements of ABET accreditation. All this allows professors to get their labs running faster, saving months of time typically required to develop lab materials and exercises.

Quanser QUBE-Servo 2 courseware provides step-by-step pedagogy for a wide range of control challenges. You can select a pre-defined lab sequence where students start with the basic principles and progress to more advanced applications of control theories. Or you can select a specific topic and use the exercises to supplement the theory students learnt in class with hands-on experience in lab.

To make the courseware easily adaptable to your specific course, Quanser also offers a comprehensive mapping of courseware topics to the most popular control engineering textbooks:

- Control Systems Engineering by Norman S. Nise
- Feedback Systems by K.J. Åström, R.M. Murray
- Feedback Control of Dynamic Systems by G.F. Franklin, J.D. Powell, A. Emai-Naeini
- Modern Control Systems by R.C. Dorf, R.H. Bishop
- Modern Control Engineering by K. Ogata
- Automatic Control Systems by F. Golnaraghi, B.C. Kuo
- Control Systems Engineering by I.J. Nagrath, M. Gopal
- Mechatronics by W. Bolton

This document provides an abbreviated example of background and in-lab exercise courseware sections for the QUBE-Servo 2 experiment. Please note that the examples are not complete as they are intended to give you a brief overview of the structure and content of the courseware you will receive with the QUBE-Servo 2.

This courseware sample based on the material prepared for users of LabVIEW™ software.

The QUBE-Servo courseware is aligned with requirements of ABET accreditation.

1. QUBE™-SERVO 2 COURSEWARE TABLE OF CONTENTS

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3. Background Section - Sample

Bump Test Modeling

The bump test is a simple test based on the step response of a stable system. A step input is given to the system and its response is recorded. As an example, consider a system given by the following transfer function:

$$\frac{Y(s)}{U(s)} = \frac{K}{\tau s+1} \tag{1.1}$$

The step response shown in Figure 1.1 is generated using this transfer function with K = 5 rad/V.s and τ = 0.05 s.

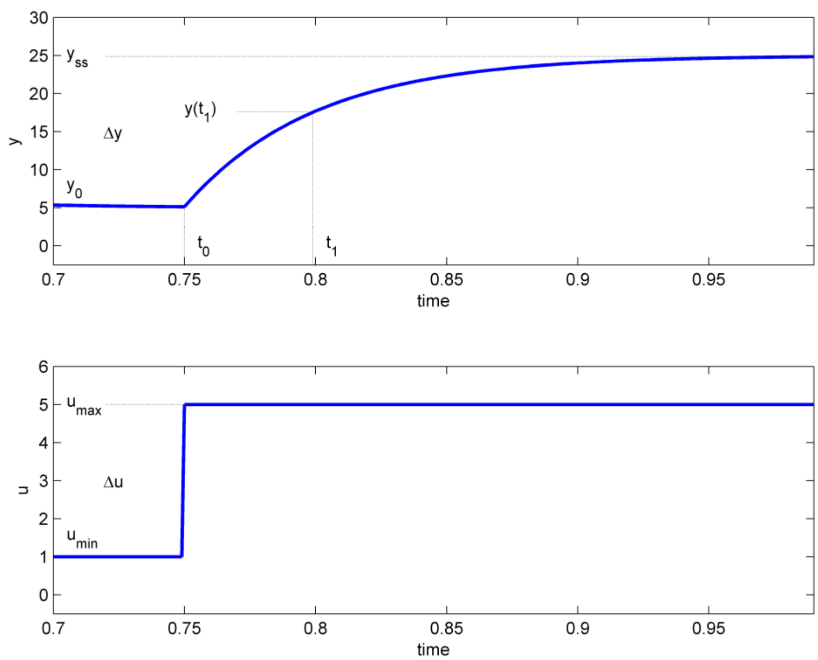


Figure 1.1: Input and output signal used in the bump test method

The step input begins at time t_0. The input signal has a minimum value of u_{min} and a maximum value of u_{max}. The resulting output signal is initially at y_0. Once the step is applied, the output tries to follow it and eventually settles at its steady-state value y_{ss}. From the output and input signals, the steady-state gain is

$$K = \frac{\Delta y}{\Delta u} \tag{1.2}$$

where $\Delta y = y_{ss}-y_0$ and $\Delta u = u_{max}-u_{min}$. The time constant of the system τ is defined as the time it takes the system to respond to the application of a step input to reach $1-1/e \approx 63.2\%$ of it's steady-state value, i.e. for Figure 1.1

$$t_1 = t_o + \tau$$

where

$$y(t_1) = 0.632\Delta y + y_o \tag{1.3}$$

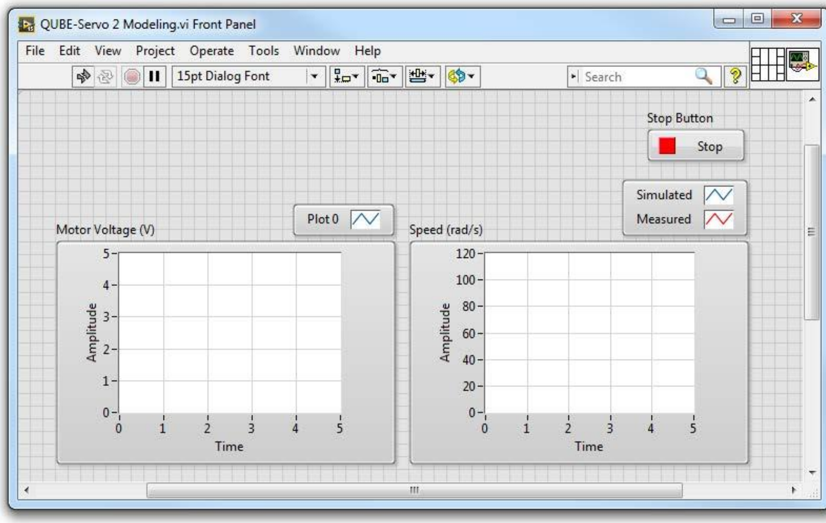
Then, we can read the time t_1 that corresponds to $y(t_1)$ from the response data in Figure 1.1. From this, the model time constant can be found as:

$$\tau = t_1 - t_0 \tag{1.4}$$

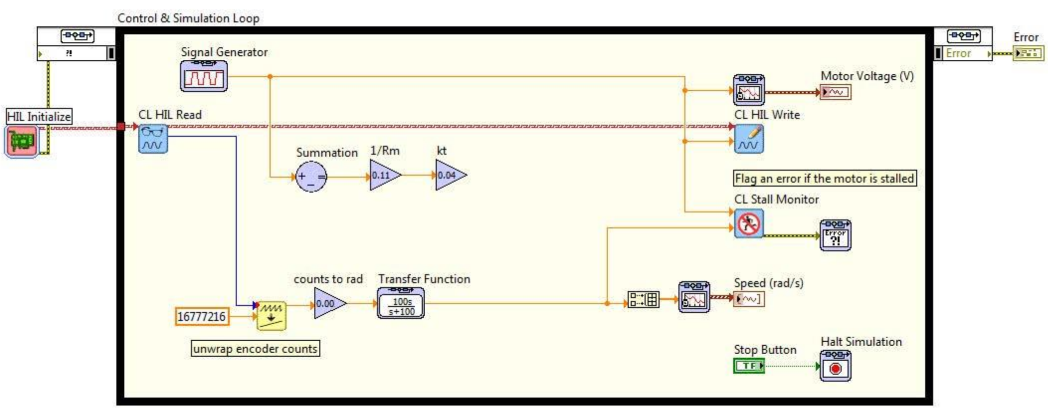
4. In-Lab Exercises - Sample

First Principle Modeling

Based on the Vis already designed in the Integration and Filtering laboratory experiment, design a VI that applies a *1-3 V 0.4 Hz* square wave to the motor and reads the servo velocity using the encoder as shown in Figure 2.1



(a) Front Panel



(b) Block Diagram

Figure 2.1: Applies a step voltage and displays measured and simulated QUBE-Servo 2 speed (incomplete block diagram).

Using the equations given above, assemble a simple block diagram in the block diagram of the VI to model the system. You'll need a few Gain blocks, a Subtract block, and an Integrator block (to go from acceleration to speed). Part of the solution is shown in the block diagram in Figure 2.1.

1. A-1, A-2 The motor shaft of the QUBE-Servo 2 is attached to a *load hub* and a disc load. Based on the parameters given in Table 1.1, calculate the equivalent moment of inertia that is acting on the motor shaft.

Answer 2.1

Outcome	**Solution**
A-1	From Figure 1.1, the total moment of inertia acting on the motor shaft is the sum of the motor armature / rotor inertia, J_m, the hub inertia, J_h, and the disc inertia, J_d. The equivalent moment of inertia is therefore

$$J_{eq} = J_m + J_h + J_d \qquad \text{(Ans. 2.1)}$$

Given the disc moment of inertia in Equation 1.7 and the parameters defined in Figure 1.1, the moment of inertia of the hub and disc load are:

$$J_h = \frac{1}{2} m_d r_h^2 \qquad \text{(Ans. 2.2)}$$

and

$$J_d = \frac{1}{2} m_d r_d^2 \qquad \text{(Ans. 2.3)}$$

A-2 Using the parameters from Table 1.1, evaluate Equation Ans.2.1 to obtain

$$J_{eq} = 4.0\ x\ 10^{-6} + \frac{1}{2} 0.0106(0.0111)^2 + \frac{1}{2} 0.053(0.0248)^2 = 2.09\ x\ 10^{-5} \qquad \text{(Ans. 2.4)}$$

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2. K-3 Design the QUBE-Servo 2 model using *Control & Simulation* blocks as described above. Attach a screen capture of your model.

Answer 2.2

Outcome	**Solution**
K-3	The completed model is shown in Figure Ans. 2.1. The current depends on the angular rate of the shaft and the applied voltage, as expressed in Equation 1.4. The acceleration of the shaft equals the torque divided by the equivalent moment of inertia, as described in Equation 1.5. The Matlab script used for this is:

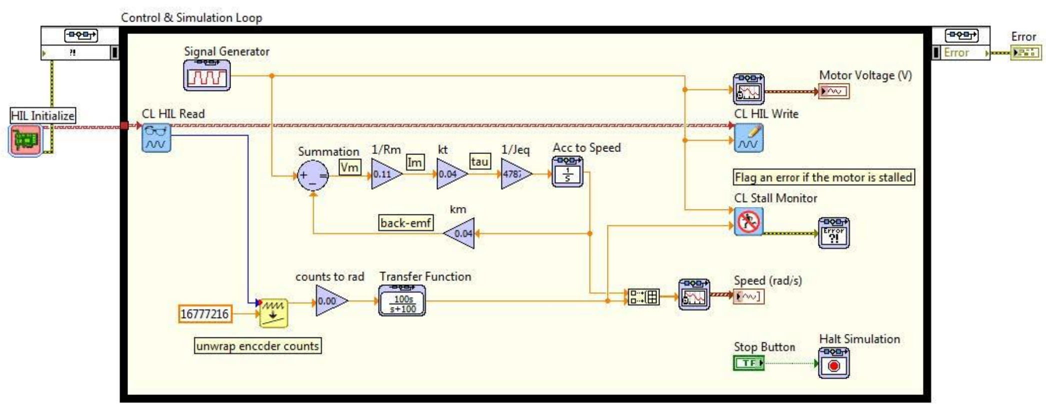

Figure Ans. 2.1: Completed *QUBE-Servo 2 Model*.

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3. B-5, B-9 Run the VI with your QUBE-Servo 2 model. The waveform chart response should be similar to Figure 2.2. Attach a screen capture of your waveform charts. Does your model represent the QUBE-Servo 2 well? Explain.

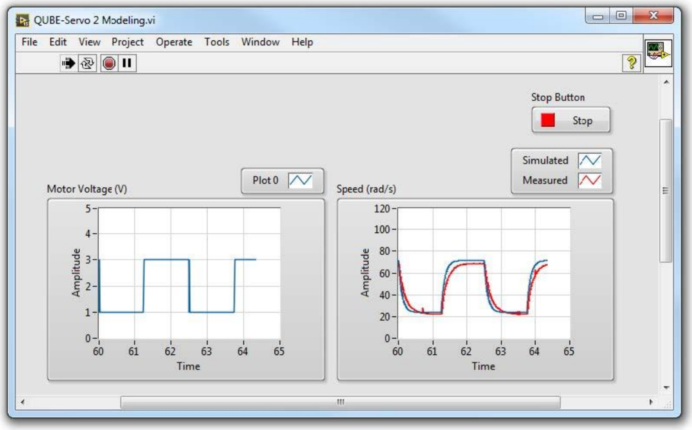

Figure 2.3: QUBE-Servo 2 Measured and Simulated Responses

Answer 2.3

Outcome	**Solution**
B-5	If the experimental procedure was followed correctly, the user should be able to run the VI and obtain a response similar to Figure 2.2.
B-9	The model represents the actual QUBE-Servo 2 system accurately because in the simulated response (cyan) matches the measured response (red) quite well in Figure 2.2.

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4. A-1, A-2, B-9 Formulate the differential equation for ω_m using Equation 1.4 to Equation 1.6. Compare your result with the transfer function obtained from the Bump Test Modeling laboratory experiment. (**Hint:** Obtain the Voltage $V_m(s)$ to Speed $\Omega_m(s)$ transfer function by applying Laplace Transform to the derived differential equation).

Answer 2.4

Outcome **Solution**

A-1 The differential equation for $\omega_m(t)$ can be derived starting from the following:

$$J_{eq}\dot{\omega}_m(t) = \tau_m(t) \tag{Ans.2.5}$$

and, using Equation 1.4 and Equation 1.6 to get:

$$\dot{\omega}_m(t) = \frac{k_t}{J_{eq}R_m}v_m(t) - \frac{k_t k_m}{J_{eq}R_m}\omega_m(t) \tag{Ans.2.6}$$

A-1 Taking the Laplace Transform,

$$s\Omega_m(s) = \frac{k_t}{J_{eq}R_m}V_m(s) - \frac{k_t k_m}{J_{eq}R_m}\Omega_m(s) \tag{Ans.2.7}$$

which simplifies to

$$\frac{\Omega_m(s)}{V_m(s)} = \frac{\frac{1}{k_m}}{\frac{J_{eq}R_m}{k_t k_m}s + 1} \tag{Ans.2.8}$$

A-2 Evaluating the transfer function from parameters in Table 1.1,

$$\frac{\Omega_m(s)}{V_m(s)} = \frac{23.8}{0.1\,s+1} \qquad \text{(Ans.2.9)}$$

B-9 This is the derivation for the Voltage $V_m(s)$ to Speed $\Omega_m(s)$ transfer function as presented in the Bump Test Modeling laboratory experiment.

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5. Click on the Stop button to stop the VI.