QUANSER
INNOVATE. EDUCATE.

INSTRUCTOR WORKBOOK

QUBE-Servo Experiment for MATLAB®/Simulink® Users

Standardized for ABET* Evaluation Criteria

Developed by:
Jacob Apkarian, Ph.D., Quanser
Michel Lévis, M.A.SC., Quanser

COURSEWARE SAMPLE

QUBE educational solutions are powered by:

MATLAB SIMULINK

Course material complies with:

ABET

CAPTIVATE. MOTIVATE. GRADUATE.

*ABET Inc., is the recognized accreditor for college and university programs in applied science, computing, engineering, and technology, providing leadership and quality assurance in higher education for over 75 years.

PREFACE

Preparing laboratory experiments can be time-consuming. Quanser understands time constraints of teaching and research professors. That's why the QUBE-Servo experiment comes with a new generation of mix-and-match, rich digital media 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 courseware provides step-by-step pedagogy for a wide range of control challenges. You can select a pre-defined lab section 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 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.

This courseware sample based on the material prepared for users of MATLAB®/Simulink® software.

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

1. QUBE™-SERVO COURSEWARE TABLE OF CONTENTS

The full Table of Contents of the Quanser QUBE-Servo courseware is shown here:

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:

$$\frac{Y(s)}{U(s)} = \frac{K}{\tau s+1} \tag{4.1}$$

The step response shown in Figure 4.1 is generated using this transfer function with K = 5 rad/V-s and τ = 0.05 s.

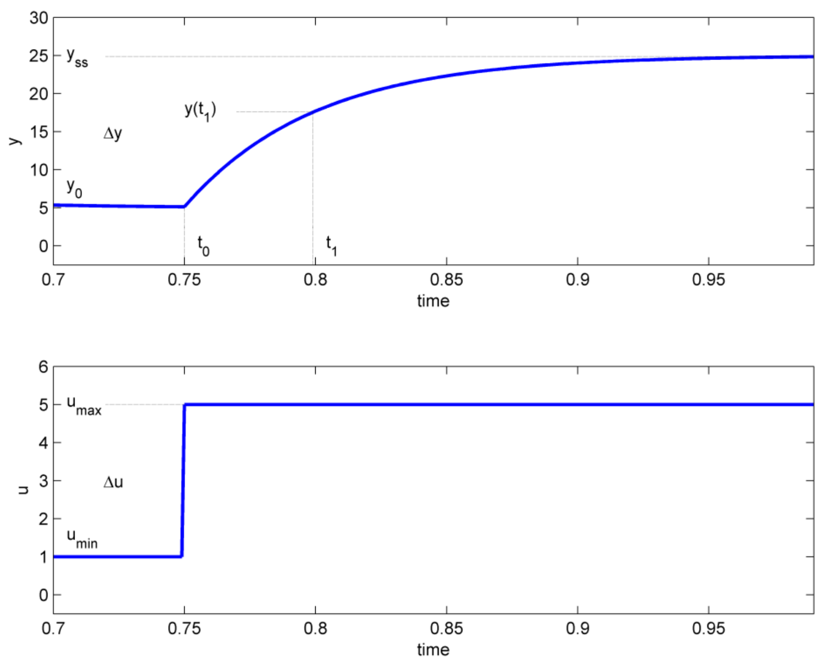


Figure 4.1: Input and output signal used in the bump test method

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

$$K = \frac{\Delta y}{\Delta u} \tag{4.2}$$

where $\Delta y = y_{ss}-y_0$ and $\Delta u = u_{max}-u_{min}$. In order to find the model time constant, τ, we can first calculate where the output is supposed to be at the time constant from:

$$y(t_1) = 0.632\Delta y + y_o \tag{4.3}$$

Then, we can read the time t_1 that corresponds to $y(t_1)$ from the response data in Figure 4.1. From the figure we can see that the time t_1 is equal to:

$$t_1 = t_o + \tau$$

From this, the model time constant can be found as:

$$\tau = t_1 - t_0 \tag{4.4}$$

4. In-Lab Exercises

First Principle Modeling

Based on the models already designed in QUBE-Servo Integration and Filtering labs, 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 5.2.

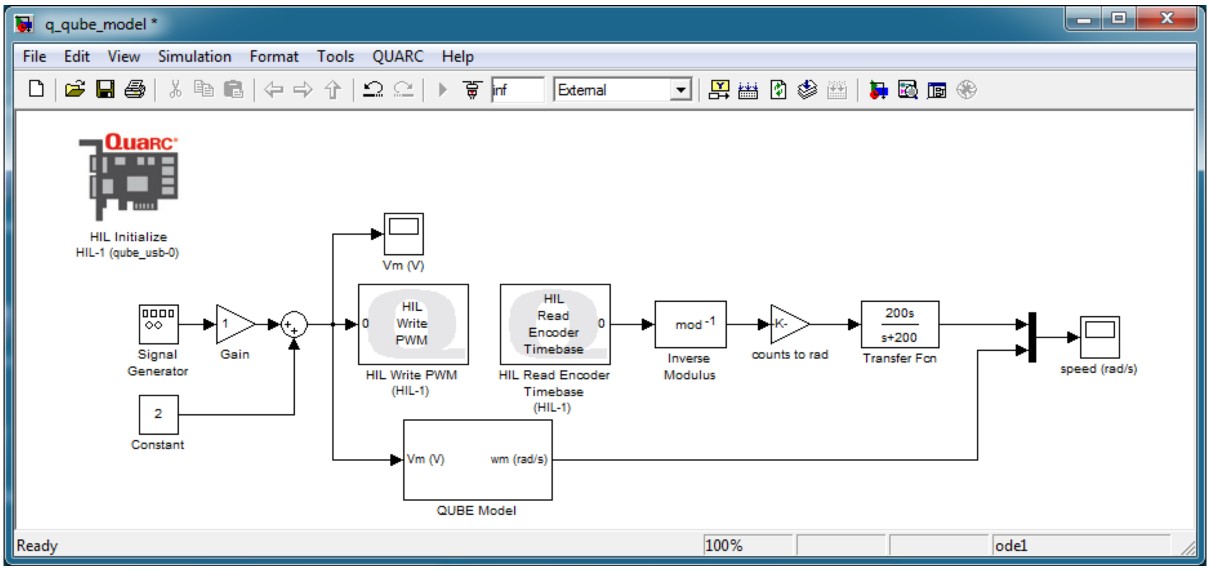


Figure 5.2: Applies a step voltage and displays measured and simulated QUBE-Servo speed.

Create subsystem called *QUBE-Servo Model*, as shown in Figure 5.2, that contains blocks to model the QUBE-Servo system. Thus using the equations given above, assemble a simple block diagram in Simulink 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 Figure 5.3.

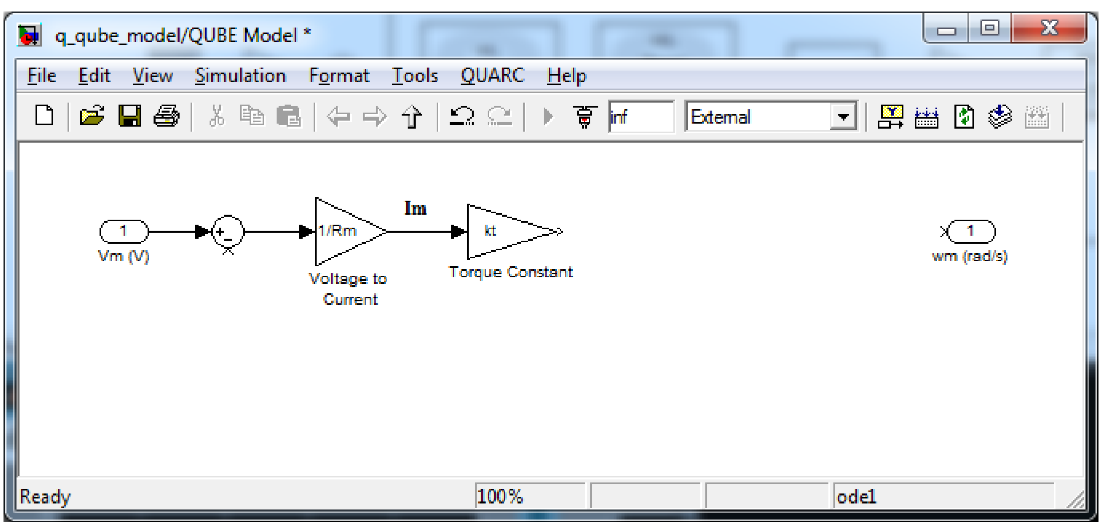


Figure 5.3: Incomplete QUBE-Servo Model subsystem.

It may also help to write a short Matlab script that sets the various system parameters in Matlab, so you can use the symbol instead of entering the value numerically in the Gain blocks. In the example shown in Figure 5.3, we are using Rm for motor resistance and kt for the current-torque constant. To define these, write a script like:

```
% Resistance
Rm = 8.4;
% Current-torque (N-m/A)
kt = 0.042;
```

1. A-1, A-2 The motor shaft of the QUBE-Servo is attached to a *load hub* and a disc load. Based on the parameters given in Table 5.1, calculate the equivalent moment of inertia that is acting on the motor shaft.

Answer 5.1

Outcome	**Solution**
A-1	From Figure 5.1, 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 $$J_{eq} = J_m + J_h + J_d \quad \text{(Ans. 5.1)}$$ Given the disc moment of inertia in Equation 5.3 and the parameters defined in Figure 5.1, the moment of inertia of the hub and disc load are: $$J_h = \frac{1}{2} m_d r_h^2$$ and $$J_d = \frac{1}{2} m_d r_d^2$$
A-2	Using the parameters from Table 5.1, evaluate Ans.5.1 to obtain $$J_{eq} = 4.0\ x\ 10^{-6} + \frac{1}{2} 0.0106(0.0111)^2 + \frac{1}{2} 0.053(0.0248)^2 = 2.09\ x\ 10^{-5}$$

□ □ □

2. K-3 Design the *QUBE-Servo Model* subsystem as described above. Attach a screen capture of your model and the Matlab script (if you used one)..

Answer 5.2

Outcome	Solution
K-3	The completed model is shown in Figure 5.4. The current depends on the angular rate of the shaft and the applied voltage, as expressed in Equation 5.1. The acceleration of the shaft equals the torque divided by the equivalent moment of inertia, as described in Equation 5.2. The Matlab script used for this is:

```
Rm = 8.4;
kt = 0.042;
km = 0.042;
Jr = 4e-6;
mh = 0.0106;
rh = 22.2/1000/2;
Jh = 0.5*mh*rh^2;
md = 0.053;
rd = 49.5/1000/2;
Jd = 0.5*md*rd^2;
Jeq = Jr + Jh + Jd;
```

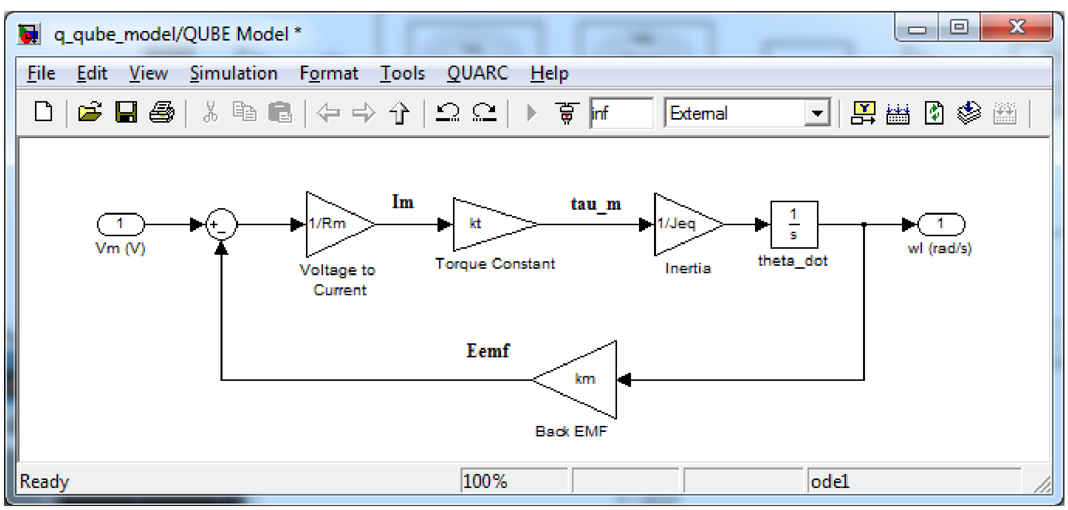
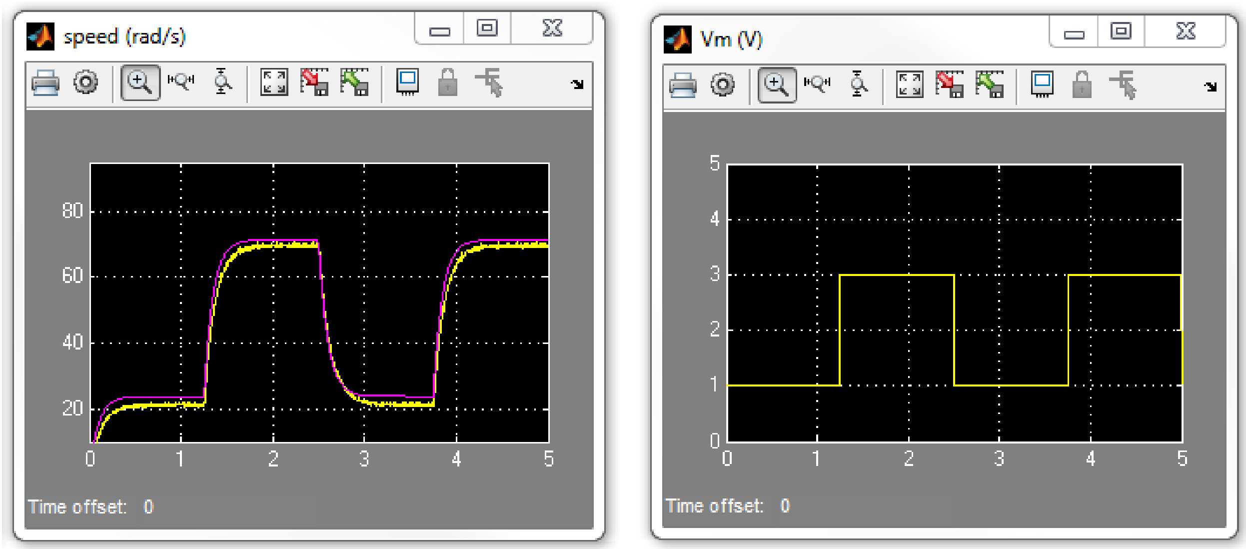


Figure 5.4: Completed *QUBE-Servo Model* subsystem.

3. B-5, B-9 Build and run the QUARC controller with your QUBE-Servo model. The scope response should be similar to Figure 5.5. Attach a screen capture of your scopes. Does your model represent the QUBE-Servo well? Explain.



(a) Motor Speed (b) Motor Voltage

Figure 5.5: QUBE Response

Answer 5.3

Outcome	Solution
B-5	If the experimental procedure was followed correctly, the user should be able to run the QUARC controller and obtain a response similar to Figure 5.5.
B-9	The model represents the actual QUBE-Servo system accurately because in the simulated response (purple) matches the measured response (yellow) quite well in Figure 5.5.

QUANSER
INNOVATE. EDUCATE.

YOU CAN RELY ON QUANSER TO ADVANCE CONTROL EDUCATION

For over two decades Quanser has focused solely on the development of solutions for advanced control education and research. Today, over 2,500 universities, colleges and research institutions around the world rely on a growing portfolio of Quanser control systems.

Our Rotary Control solutions offer quality, convenience, ease of use, ongoing technical support and affordability. They are part of a wider range of Quanser control lab solutions designed to enhance students' academic experience. They come as complete workstations and can captivate undergraduate and graduate students, motivate them to study further and encourage them to innovate.

Engineering educators worldwide agree that Quanser workstations are reliable and robust. Choose from a variety of mechatronics experiments and control design tools appropriate for teaching at all levels as well as advanced research. Take advantage of engineering expertise that includes mechatronics, electronics, software development and control system design. Leverage the accompanying **ABET-aligned courseware** which have been developed to the highest academic standards. Last but not least, rely on Quanser's engineers for ongoing technical support as your teaching or research requirements evolve over time.

Learn more at www.quanser.com or contact us at info@quanser.com

Follow us on:

ABET, Inc., is the recognized accreditor for college and university programs in applied science, computing, engineering, and technology. Among the most respected accreditation organizations in the U.S., ABET has provided leadership and quality assurance in higher education for over 75 years.