Courseware Material Sample

# INSTRUCTOR WORKBOOK

## SRV02 Base Unit Experiment For MATLAB®/Simulink® Users

Standardized for ABET* Evaluation Criteria

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SRV02 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. Among the most respected accreditation organizations in the U.S., ABET has provided 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 Quanser's control laboratory solutions come with proven practical exercises. The course materials are designed to save you time, give students a solid understanding of various control concepts and provide maximum value for your investment.

Quanser course materials are supplied in two formats:

1. Instructor Workbook – provides solutions for the pre-lab assignments and contains typical experimental results from the laboratory procedure. This version is not intended for the students.
2. Student Workbook – contains pre-lab assignments and in-lab procedures for students.

This course material is prepared for users of The MathWorks's **Matlab®/Simulink®** software in conjunction with Quanser's **QUARC®** real-time control software. A version of the course materials for National Instruments **LabVIEW™** users is also available.

This course material is **aligned with the requirements of the Accreditation Board for Engineering and Technology** (**ABET**), one of the most respected organizations specializing in accreditation of educational programs in applied science, computing, science and technology. The Instructor Workbook provides professors with a simple framework and set of templates to measure and document students' achievements of various performance criteria and their ability to:

- Apply knowledge of math, science and engineering
- Design and conduct experiments, and analyze and interpret data
- Communicate effectively
- Use techniques, skills and modern engineering tools necessary for engineering practice

Quanser, Inc. would like to thank Dr. Hakan Gurocak, from the Washington State University Vancouver, for rewriting the original material to include embedded outcomes assessment.

***The following material provides an abbreviated example of pre-lab assignments and in-lab procedures for the SRV02 Rotary Motion Servo Plant. 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 course materials you will receive with the plant.***

## COURSE MATERIALS SAMPLE TABLE OF CONTENTS

# 1. INTRODUCTION TO QUANSER ROTARY SERVO COURSE MATERIAL SAMPLE

Quanser course materials provide step-by-step pedagogy for a wide range of control challenges. Starting with the basic principles, students can progress to more advanced applications and cultivate a deep understanding of control theories. The Quanser Rotary Servo course materials covers **topics**, such as:

- How to design QUARC® controllers for Quanser's SRV02 system
- How to find a transfer function that describes the rotary motions of the SRV02 load shaft
- How to develop a feedback system that controls the position of the rotary servo load shaft
- How to develop a feedback system that controls the speed of the rotary servo load shaft

Every laboratory chapter in the Instructor's Manual is organized into four sections:

- **Background section** provides all the necessary theoretical background for the experiments. Students should read this section first to prepare for the Pre-Lab questions and for the actual lab experiments.
- **Pre-Lab Questions section** is not meant to be a comprehensive list of questions to examine understanding of the entire background material. Rather, it provides targeted questions for preliminary calculations that need to be done prior to the lab experiments. All or some of the questions in the Pre-Lab section can be assigned to the students as homework.
- **Lab Experiments section** provides step-by-step instructions to conduct the lab experiments and to record the collected data.
- **System Requirements section** describes all the details of how to configure the hardware and software to conduct the experiments. It is assumed that the hardware and software configuration have been completed by the instructor or the teaching assistant prior to the lab sessions. However, if the instructor chooses to, the students can also configure the systems by following the instructions given in this section.

Assessment of ABET outcomes is incorporated into the Instructor's Manual – look for indicators such as A-1, A-2. These indicators correspond to specific performance criteria for an outcome. **Appendix B** of the Instructor's Manual includes:

- details of the targeted ABET outcomes,
- list of performance criteria for each outcome,
- scoring rubrics and instructions on how to use them in assessment.

The outcomes targeted by the Pre-Lab questions can be assessed using the student work. The outcomes targeted by the lab experiments can be assessed from the lab reports submitted by the students. These reports should follow the specific template for content given at the end of each laboratory chapter. This will provide a basis to assess the outcomes easily.

# 2. Instructor's Manual Table of Contents

The full Table of Contents of the Quanser Rotary Servo Instructor's Manual is shown here:

# 3. Background Section - Sample

## SRV 02 Modeling

The angular rate of the SRV02 load shaft with respect to the input motor voltage can be described by the following first-order transfer function

$$\frac{\Omega_l(s)}{V_m(s)} = \frac{K}{\tau s + 1} \quad [1.1]$$

where the $\Omega_l(s)$ is the Laplace transform of the load shaft rate $\omega_l(t)$, $V_m(s)$ is the Laplace transform of motor input voltage $v_m(t)$, *K* is the steady-state gain, τ is the time constant, and *s* is the Laplace operator.

The SRV02 transfer function model is derived analytically in Section 1.1.1 and its K and τ parameters are evaluated. These are known as the *nominal* model parameter values. The model parameters can also be found experimentally. Section 1.1.2.1 and 1.1.2.2 describe how to use the frequency response and bump-test methods to find K and τ. These methods are useful when the dynamics of a system are not known, for example in a more complex system. After the lab experiments, the experimental model parameters are compared with the nominal values.

### Modeling Using First Principles: *Electrical Equations*

The DC motor armature circuit schematic and gear train is illustrated in Figure 1.1. As specified in [6], recall that $R_m$ is the motor resistance, $L_m$ is the inductance, and $k_m$ is the back – emf constant.

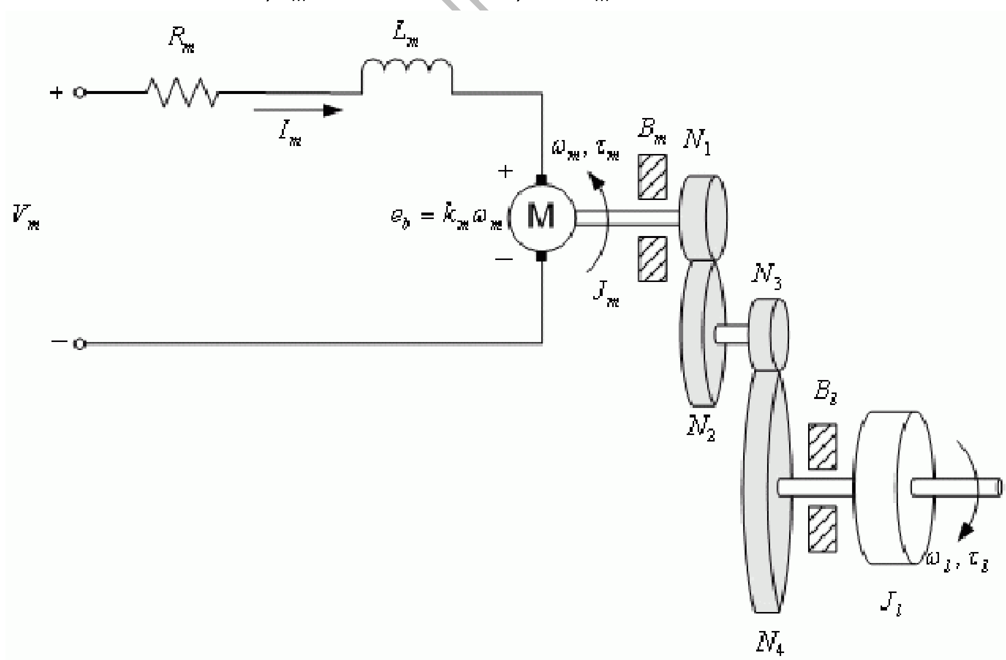



Figure 1: SRV02 DC motor armature circuit and gear train.

The back-emf (electromotive) voltage $e_b(t)$ depends on the speed of the motor shaft $\omega_m$ and the back-emf constant of the motor, $k_m$. It opposes the current flow. The back emf voltage is given by:

$$e_b(t) = k_m \omega_m(t) \tag{1.2}$$

Using Kirchoff's Voltage Law, we can write the following equation:

$$V_m(t) - R_m I_m(t) - L_m \frac{dI_m(t)}{dt} - k_m \omega_m(t) = 0 \tag{1.3}$$

Since the i motor inductance $L_m$ is much less than its resistance, it can be ignored. Then, the equation becomes:

$$V_m(t) - R_m I_m(t) - k_m \omega_m(t) = 0 \tag{1.4}$$

Solving for $I_m(t)$, the motor current can be found as:

$$I_m(t) = \frac{V_m(t) - k_m \omega_m(t)}{R_m} \tag{1.5}$$

# 4. PRE-LAB QUESTIONS SECTION - SAMPLE

### SRV 02 Position Control

Before you start the lab experiments given in Section 2.3, you should study the background materials provided in Section 2.1 and work through the questions in this Section.

1. A-2 Calculate the maximum overshoot of the response (in radians) given a step setpoint of 45 degrees. **Hint:** By substituting $y_{max}$ = $\theta(tp)$ and step setpoint $R_0$ = $\theta_d$(t) into equation 2.6, we can obtain $\theta(t_p) = \theta_d(t)\ \left(1 + \frac{PO}{100}\right)$ Recall that the desired response specifications include 20% overshoot.

***Answer 2.1***

| Outcome | Solution |
|---|---|
| A-2 | *Substituting a step reference of* $\theta_d$(t) = 0.785 [rad] *and* PO = 20[%] *intothis equation gives the maximum overshoot as* $\theta$(tp) = 0.823 [rad]. |

□ □ □

2. A-1, A-2 The SRV02 closed-loop transfer function was derived in equation 2.23 in Section 2.1.2.1. Find the control gains $k_p$ and $k_v$ in terms of $\omega_n$ and $\zeta$. **Hint:** Remember the standard second order system equation.

***Answer 2.1***

***Outcome*** ***Solution***

**A-1** *The characteristic equation of the SRV02 closed-loop transfer function in* 2.7 *is*

$$\tau\, s^2 + (1 + K\, k_v)\, s + K\, k_p \qquad \text{(Ans.2.1)}$$

*and can be re-structured into the form*

$$s^2 + \frac{(1 + K\, k_v)\, s}{\tau} + \frac{K\, k_p}{\tau} \qquad \text{(Ans.2.2)}$$

*Equating this with the standard second order system equation gives the expressions*

$$\frac{K\, k_p}{\tau} = \omega_n^2 \qquad \text{(Ans.2.3)}$$

*and*

$$\frac{1 + K\, k_v}{\tau} = 2\,\zeta\,\omega_n \qquad \text{(Ans.2.4)}$$

**A-2** *Solve for* $k_p$ and $k_v$ *to obtain the control gains equations*

$$k_p = \frac{\omega_n^2\,\tau}{K} \qquad \text{(Ans.2.5)}$$

*and the velocity gain is*

$$k_v = \frac{2\zeta\omega_n\tau - 1}{K} \qquad \text{(Ans.2.6)}$$

□ □ □

# 5. Lab Experiments Section - Sample

### SRV 02 Speed Control - Step Response with LEAD Control, Simulation

You will simulate the closed-loop speed response of the SRV02 with a Lead controller to step input. Our goals are to confirm that the desired response specifications in an ideal situation are satisfied and to verify that the motor is not saturated.

As in the step response with PI control experiment in Section 3.3.1.1, in this experiment you need to use the q_srv02_spd SIMULINK® diagram shown in Figure 3.13 again.

1. Enter the $K_c$, a, and T lead control parameters found in Section 3.1.3.2.
2. In the *SRV02 Signal Generator* block, set the *Signal Type* to square and the *Frequency* to 0.4 Hz.
3. In the Speed Control SIMULINK® model, set the *Amplitude (rad/s)* gain block to 2.5 rad/s and the *Offset (rad/s)* constant block to 5.0 rad/s.
4. To engage the lead control, set the *Manual Switch* to the downward position.
5. Open the load shaft position scope, *w_l (rad)*, and the motor input voltage scope, *Vm (V)*.
6. B-5 Start the simulation. By default, the simulation runs for 5 seconds. The scopes should be displaying responses similar to Figures 3.10 and 3.11.
7. K-1, B-9 Verify if the time-domain specifications in Section 3.1.1.1 are satisfied and that the motor is not being saturated. To calculate the steady-state error, peak time, and percent overshoot, use the simulated response data stored in the *data_spd* variable.

***Answer 3.12***

***Outcome*** ***Solution***

***K-1*** *The steady-state error, peak time, and percent overshoot measured from the simulated lead speed response are*

$$e_{ss} = 0 \quad \text{(Ans.3.19)}$$

$$t_p = 0.036\ [s] \quad \text{(Ans.3.20)}$$

*and*

$$PO = 1.9\ [\%] \quad \text{(Ans.3.21)}$$

***B-9*** *Note also that the steady-state error, peak time, and percent overshoot are found automatically in the sample_meas_tp_os.m script using the response saved in the data_spd variable (after running s_srv02_spd). Even though the phase margin requirement was not met with the designed lead parameters, the response with the lead compensator satisfies the specifications given in Section* 3.1.1.1 *while maintaining an input voltage less than 10 V, i.e. the motor is not saturated.*

# 6. System Requirements Section - Sample

## SRV 02 Speed Control - Set up for Speed Control Simulation

Follow these steps to configure the MATLAB® setup script and the SIMULINK® diagram for the Speed Control simulation laboratory:

1. Load the MATLAB® software.
2. Browse through the Current Directory window in MATLAB and find the folder that contains the SRV02 speed controller files, e.g. s_srv02_spd.mdl.
3. Double-click on the s_srv02_spd.mdl file to open the SRV02 Speed Control Simulation Simulink diagram shown in Figure 3.9.
4. Double-click on the setup_srv02_exp03_spd.m file to open the setup script for the position control Simulink models.
5. Configure setup script: The controllers will be run on the SRV02 in the high-gear configuration with the disc load, as in Section 1. In order to simulate SRV02 properly, make sure the script is setup to match this configuration, i.e. the EXT_GEAR_CONFIG should be set to 'HIGH' and the LOAD_TYPE should be set to 'DISC'. Also, ensure the ENCODER_TYPE, TACH_OPTION, K_CABLE, AMP_TYPE, and VMAX_DAC parameters are set according to the SRV02 system that is to be used in the laboratory. Next, set CONTROL_TYPE to 'MANUAL'.

   ***Answer 3.17***
   *Set CONTROL_TYPE = 'AUTO' to load the PI and Lead control parameters that meet the specifications.*

   □ □ □

6. Run the script by selecting the Debug|Run item from the menu bar or clicking on the Run button in the tool bar. The messages shown below should be generated in the MATLAB Command Window. The correct model parameters are loaded, but the control gains and related parameters loaded are default values that need to be changed. That is, the PI control gains are all set to zero, the lead compensator parameters $a$ and $T$ are both set to 1, and the compensator proportional gain $K_c$ is set to zero.

```
SRV02 model parameters:
   K = 1.53 rad/s/V
   tau = 0.0254 s
PI control gains
   kp = 0 V/rad
   ki = 0 V/rad/s
Lead compensator parameters:
   Kc = 0 v/rad/s
   1/(a*T) = 1 rad/s
   1/T = 1 rad/s
Display message shown in Matlab Command Window after
running setup \_srv02|exp03\_spd.m
```

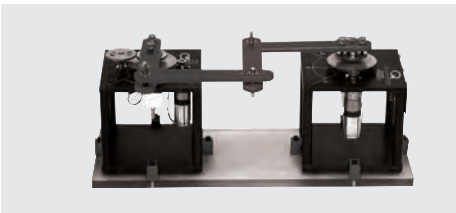
## Ten modules to teach controls from the basic to advanced level

SRV02 Base Unit

Flexible Link

Inverted Pendulum

Ball and Beam



2 DOF Robot

2 DOF Inverted Pendulum

Multi-DOF Torsion

Flexible Joint

Gyro/Stable Platform

Double Inverted Pendulum

2 DOF Ball Balancer

With the SRV02 Base Unit, you can select from 10 add-on modules to create experiments of varying complexity across a wide range of topics, disciplines and courses. All of the experiments/workstations are compatible with MATLAB®/Simulink®.

To request a demonstration or a quote, please email info@quanser.com.



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