QUANSER COURSE MATERIALS SAMPLE

SRV02 ROTARY SERVO PLANT

FOR LabVIEW™ SOFTWARE USERS, with ABET Outcomes Assessment Embedded

DEVELOPED BY:

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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 National Instruments **LabVIEW™** software. A version of the course materials for The MathWorks MATLAB®/Simulink® users is also available.

The course materials for Quanser SRV02 Rotary Servo Plant 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 manual 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.

TABLE OF CONTENTS

1. Introduction to Quanser Rotary Servo Course Materials 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. Quanser Rotary Servo Curriculum covers **topics**, such as:

- How to design a proportional-derivative (PD) compensator that controls the position of the servo load shaft according to certain time-domain requirements
- How to simulate the PD controller using the developed model of the plant and ensure the specifications are met without any actuator saturation
- How to implement the controller on the Quanser SRV02 device and evaluate its performance

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 A** 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

Desired Position Control Response

The block diagram shown in Figure 2.1 is a general unity feedback system with compensator (controller) C(s) and a transfer function representing the plant, P(s). The measured output, Y(s), is supposed to track the reference signal R(s) and the tracking has to match to certain desired specifications.

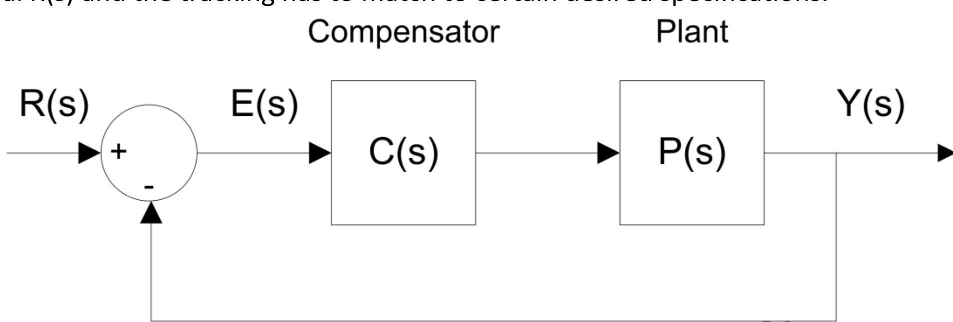

Figure 2.1: Unity feedback system.

The output of this system can be written as:

$$Y(s) = C(s)\,P(s)\,(R(s) - Y(s)) \tag{2.1}$$

By solving for Y (s), we can find the closed-loop transfer function:

$$\frac{Y(s)}{R(s)} = \frac{C(s)\,P(s)}{1 + C(s)\,P(s)} \tag{2.2}$$

Recall in the SRV02 modeling laboratory, the SRV02 voltage-to-speed transfer function was derived. To find the voltage-to-position transfer function, we can put an integrator (1/s) in series with the speed transfer function (effectively integrating the speed output to get position). Then, the resulting open-loop voltage-to-load gear position transfer function becomes:

$$P(s) = \frac{K}{s\,(\tau s + 1)} \tag{2.3}$$

As you can see from this equation, the plant is a second order system. In fact, when a second order system is placed in series with a proportional compensator in the feedback loop as in Figure 2.1, the resulting closed-loop transfer function can be expressed as:

$$\frac{Y(s)}{R(s)} = \frac{\omega_n^2}{s^2 + 2\zeta\,\omega_n\,s + \omega_n^2} \tag{2.4}$$

where ω_n is the natural frequency and ς is the damping ratio. This is called the standard second order transfer function. Its response properties depend on the values of ω_n and ς.

4. Pre-Lab Questions Section - Sample

1. A-1, A-2 The SRV02 closed-loop transfer function was derived in equation 2.18 in Section 2.2.1. Find the control gains k_p and k_d in terms of ω_n and ζ. **Hint:** Remember the standard second order system equation.

Answer 3.1

Outcome	Solution
A-1	The characteristic equation of the SRV02 closed-loop transfer function in 2.18 is

$$\tau s^2 + (1 + K k_d) s + K k_p \quad \text{(Ans.3.1)}$$

and can be re-structured into the form

$$s^2 + \frac{(1 + K k_d) s}{\tau} + \frac{K k_p}{\tau} \quad \text{(Ans.3.2)}$$

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

$$\frac{K k_p}{\tau} = \omega_n^2 \quad \text{(Ans.3.3)}$$

and

$$\frac{1 + K k_d}{\tau} = 2 \zeta \omega_n \quad \text{(Ans.3.4)}$$

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

$$k_p = \frac{\omega_n^2 \tau}{K} \quad \text{(Ans.3.5)}$$

and the velocity gain is

$$k_d = \frac{2\zeta\omega_n\tau - 1}{K} \quad \text{(Ans.3.6)}$$

□ □ □

2. B-3 Explain what approximation was made in order to find PD gains above (assume $k_d > 0$). **Hint:** Look at the structure of the equations used.

Answer 3.1

Outcome	Solution
A-1	Unless $k_d = 0$, the numerator of SRV02 closed loop equation 2.18 $\frac{K(k_p + k_d s)}{\tau}$ does not match the numerator of the standard second-order characteristic equation shown in 2.4, which is ω_n^2.

□ □ □

5. Lab Experiments Section - Sample

The main goal of this laboratory is to explore position control of the SRV02 load shaft using the PD controller. Students are asked to verify their control design and simulate the closed-loop PD response. Then, the PD controller is implemented on the actual SRV02. **Before starting**: Make sure your SRV02 is connected as described in [1]. If you are using the NI CompactRIO, then see the SRV02 cRIO User Manual ([3].

FBD Control Simulation

1. Open Quanser SRV02 Project | SRV02 Control Design and Simulation | SRV02 Manual Control PD.vi shown in Figure 4.8.

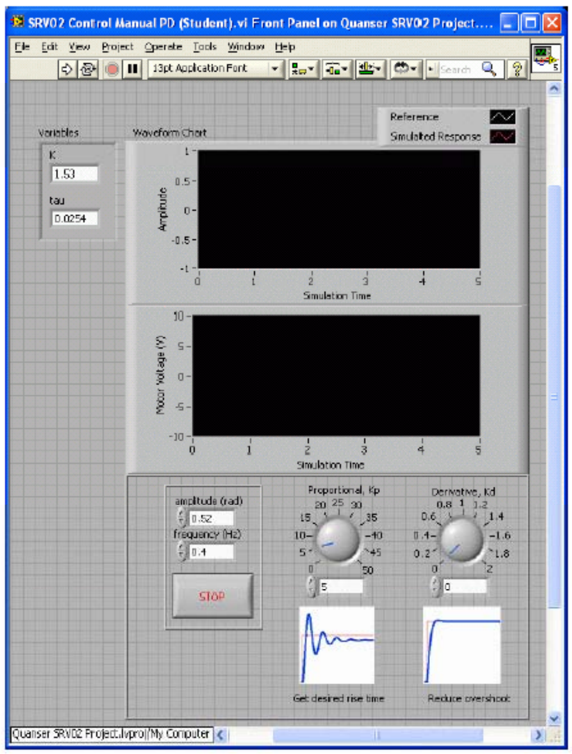

Figure 4.8: SRV02 PD Control VI

2. As shown in Figure 4.9, the block diagram is incomplete.

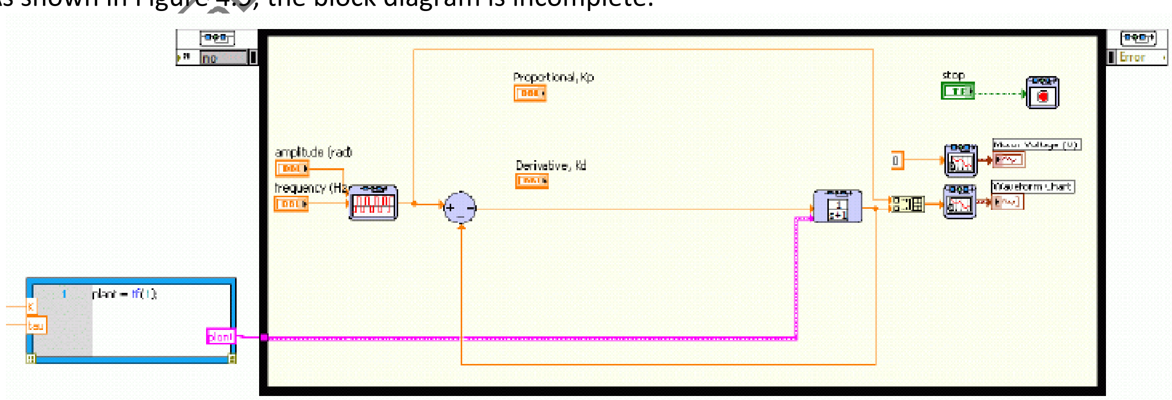

Figure 4.9: Incomplete block diagram in SRV02 PD Control VI

3. K-3 We want to simulate the position control of the SRV02 using a PD controller using the FBD gains you found in Section 4.1.1. First, enter the SRV02 plant in the MathScript node, as done in the previous procedure.

Answer 4.5

Outcome	***Solution***
K-3	*The MathScript node should appear as shown in Figure 4.7 when the transfer function is entered.*

4.. K-3 Using the Gain and Summation VIs from the Control Design and Simulation palette, build a PD controller as shown in Figure 2.3. Use the existing proportional and derivative gain controls already in the VI.

Answer 4.6

Outcome	***Solution***
K-3	*The completed block diagram should be similarly as shown in Figure* 4.15.

5.. B-5 Run the VI with the following parameters:

$$k_p = 5$$

$$k_d = 0$$

The response should be as shown in Figure 4.11. Both the output response, i.e. the servo angle, and the control input, i.e. the dc motor voltage, are being simulated.

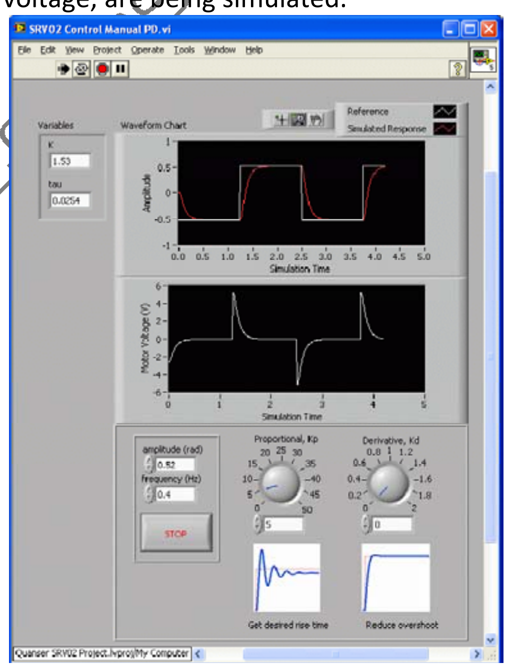

Figure 4.11: SRV02 PD Control VI shown when running with k_p= 5 and k_d = 0