1. QNET DC MOTOR BOARD COURSEWARE

Dedicating over two decades to the development of systems and solutions for control education and research, Quanser understands curricular needs and time constraints of teaching and research professors. That's why Quanser's QNET boards for NI ELVIS come with courseware 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.

The courseware is supplied in two formats:

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

The **QNET DC Motor Board courseware** provides step-by-step pedagogy for a wide range of control challenges. Starting at basic principles, students can progress to more advanced applications and cultivate a deep understanding of control theories through real-life applications of the QNET DC Motor board. The courseware covers topics, such as:

- Modeling a DC motor experimentally
- PID control
- Position control
- Speed control
- Disturbance rejection

The courseware is prepared for users of National Instruments **LabVIEW™** software.

The courseware 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 courseware materials provide 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

The following material provides an abbreviated example of pre-lab assignments and in-lab procedures for the QNET DC Motor Board. 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 plant.

2. QNET DC MOTOR BOARD COURSEWARE CONTENTS

The Table of Contents of the QNET DC Motor Control Board Courseware is shown here:

MODELING

QUALITATIVE PI SPEED CONTROL

PI SPEED CONTROL ACCORDING TO SPECIFICATIONS

QUALITATIVE PD POSITION CONTROL

PD POSITION CONTROL ACCORDING TO SPECIFICATIONS

TRACKING AND DISTURBANCE REJECTION

3. BACKGROUND SECTION- EXAMPLE

Qualitative PI Speed Control

The speed of the QNET DC Motor is controlled using a proportional-integral control system. The block diagram of the closed-loop system is shown in Figure 1.1.

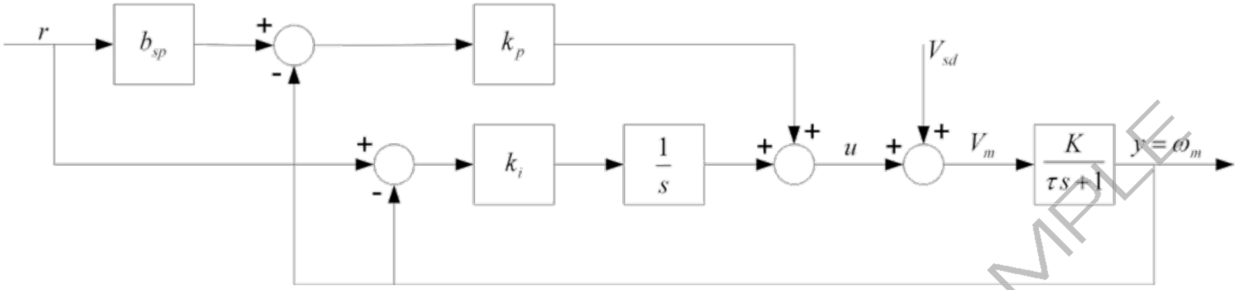


Figure 1.1: QNET DC Motor PI closed-loop diagram

The transfer function representing the DC motor speed - voltage relation with steady-state gain *K* and time constant τ is

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

and will be used to design the PI controller. The input-output relation in the time-domain for a PI controller with set-point weighting is

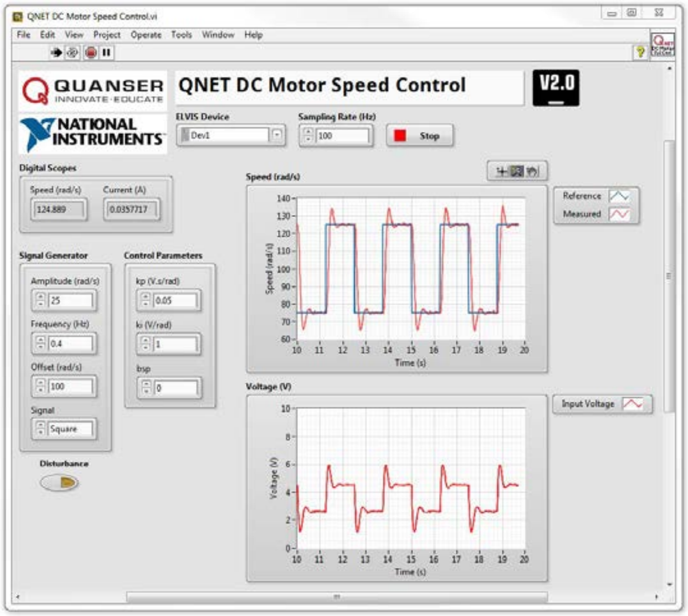
$$u=\;k_p\left(b_{sp}r-y\right)+\frac{k_i(r-y)}{s} \tag{1.2}$$

where k_p is the proportional gain, k_i is the integral gain, and b_{sp} is the set-point weight. The closed loop transfer function from the speed reference *r* to the angular motor speed output ω_m is

$$G_{\omega,r}(s)\;=\;\frac{K(k_p b_{sp}s+k_i}{\tau s^2+(Kk_p+1)s+Kk_i} \tag{1.3}$$

Speed Control Virtual Instrument

The LabVIEW virtual instrument for speed control laboratory experiment is shown in Figure 1.2.



ELVIS Device: Dev1
Sampling Rate (Hz): 100
Speed (rad/s): 124.889
Current (A): 0.0357717
Amplitude (rad/s): 25
Frequency (Hz): 0.4
Offset (rad/s): 100
Signal: Square
kp (V.s/rad): 0.05
ki (V/rad): 1
bsp: 0

Figure 1.2: Virtual instrument for QNET DC Motor speed control

5. IN-LAB EXPERIMENT EXAMPLE

PD Control According to Specifications

1. **A-2** Calculate the expected peak time *tp* and percentage overshoot *PO* give
   - $\zeta = 0.60$
   - $\omega_0 = 25.0$ rad/s

   Optional: You can also design a VI that simulates the DC motor first-order model with a PD control and have it calculate the peak time and overshoot.

Answer 2.1

Outcome	Solution
A-2	Substituting the ζ above in Equation 1.10 yields PO = 9.45% (Ans.2.1) Using Equation 1.12, the peak time equation with the ω_0 and ζ given above equates to .$t_p = 0.16$ s (Ans. 2.2) You can also run the `DCMC_Position_PD_CD_Instructor.vi` to simulate the step response and find the peak time and percentage overshoot.

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2. **A-2** Assuming the model steady-state gain is K = 26 V/rad and time constant is $\tau = 0.145$ s, calculate the proportional and derivative control gains k_p and k_d respectively, to meet the specifications above.

Answer 2.2

Outcome	Solution
A-2	Substituting the model parameters and natural frequency given above into Equation 1.5 generates the proportional control gain $k_p = 3.486$ V/rad (Ans.2.3) The derivative control gain is obtained by applying the model parameters with the natural frequency and damping ratio specifications to Equation 1.6 $k_d = 0.1296$ V/rad.s (Ans.2.4) You can also run the `DCMC_Speed_PI_CD_Instructor.vi` to find the PI gains. Italso generates the set-point weight parameter.

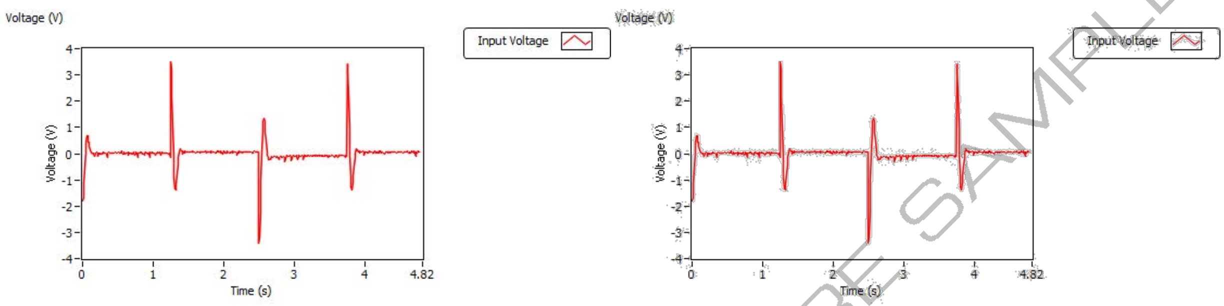
3. Run the QNET_DC Motor Position Control.vi. Make sure the correct Device is chosen.
4. Run the VI. You should see the DC motor rotating back and forth.
5. In the *Signal Generator* section set:
   - Amplitude (rad) = 0.50
   - Frequency(Hz) = 0.40
   - Offset (rad) = 0.00
6. In the *Control Parameters* section, set the PD gains to the values found in Step 2.The controller is implemented with $b_{sd} = 0$.
7. **B-5, K-2** Capture the position response found in the *Position (rad)* scope and control signal used in the *Voltage (V)* scope.

Answer 2.3

Outcome **Solution**

B-5 If the experimental procedure is followed correctly, the measured QNET DC Motor closed-loop position step response should be similar to Figure Ans. 2.1.

K-2 The closed-loop position response when using the PD control gains Equation Ans.2.3 and Equation Ans.2.4 with $b_{sd} = 0$ is shown in Figure Ans.2.1.



(a) Motor Position (b) Motor Voltage

Figure Ans.2.1: Measured PD position control response

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8. [redacted] Measure the peak time and percentage overshoot of the measured position response. Are the specifications satisfied?

Answer 2.4

Outcome **Solution**

K-1 Looking at the two cycles in the response in Figure Ans. 2.1, the peak of transient occurs about 0.125 seconds after the rising edge of the step, thus

$t_p = 0.1$ s (Ans.2.5)

As shown in Figure Ans. 2.1, when tracking the square reference, the motor position does not go over 0.52 rad, so the overshoot is approximately less than

$PO = 2.0$ % (Ans.2.6)

Note that there is a steady-state error of ≅ 3%. This is due to a relatively small error signal that results in an input voltage in the deadband of the DC MOtor. Adding an integral gain would increase the tracking performance, see the laboratory experiment on Tracking and Disturbance Rejection.

B-9 The specifications computed in Equation Ans.2.1 and Equation Ans.2.2 are satisfied.

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