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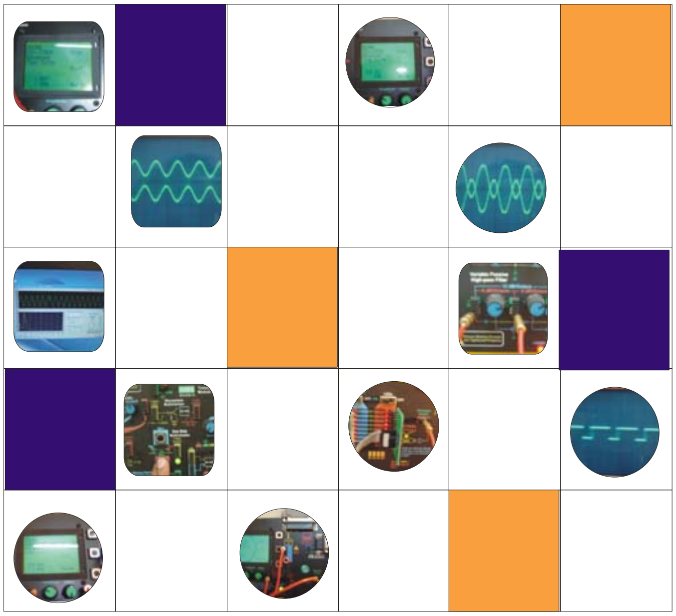
DEV-2752

Advanced Servo & DC Motor Control Trainer

EXPERIMENTS

PART NO. 2752-00-321



COMPREHENSIVE & ILLUSTRATED
EASY EXPERIMENTS STARTUP
LAB MANUAL

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LAB HANDBOOK

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Welcome to RIMS Advanced Servo & DC Motor Control Trainer

- ☑ MOTOR SPEED INPUT/TORQUE CHARACTERISTICS
- ☑ MOTOR TRANSIENT RESPONSE
- ☑ BASIC CLOSED LOOP CONTROL & SIMPLE SPEED CONTROL WITH INCREASED GAIN
- ☑ POSITION CONTROL SYSTEM

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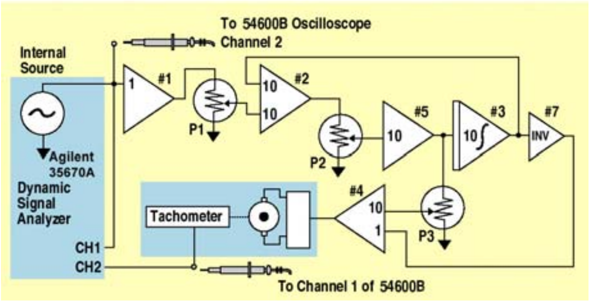
1

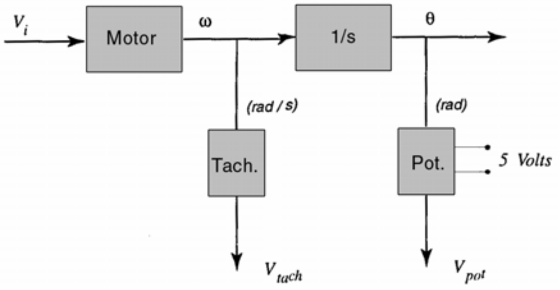
MOTOR SPEED INPUT/TORQUE CHARACTERISTICS

A diagram describing the motor dynamics is shown in Figure. This will be used to develop the motor transfer function.

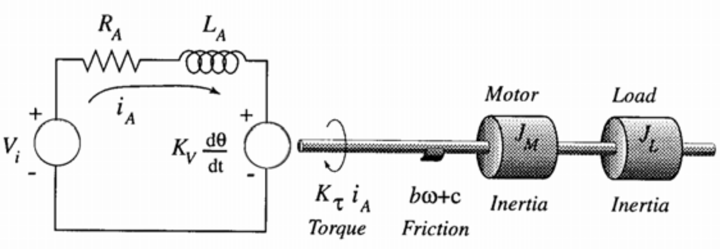


The DC Motor.

The parameters under consideration have the following units: the pot. gain K_{pot} is in volts/rad; the tach. gain K_{tach} is in volts-s/rad.; Armature resistance R_a is measured in ohms; the back emf constant K_V is in volt-s/rad.; the torque constant K_T is in N-m/amp; the total inertia seen by the motor $J = J_M + J_L$ is in Kg-m^2; the viscous friction coefficient is b in N-m-sec/rad.; the Coulomb friction coefficient is c in N-m; and the armature inductance L_a is measured in Henries.



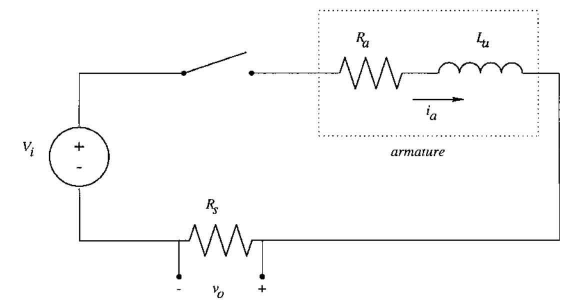
Motor Block Diagram.



Motor Schematic Diagram.

a. The dc motor, *with the flywheel clamped* ($\omega = 0$), is described by the electrical schematic of Fig. 4. The resistance R_s has been added to obtain voltage measurements, so that the current's time response can be viewed on an oscilloscope. Find $V_o(s)/V_i(s)$ in terms of R_a, R_s, and L_a, What is the *electrical time constant,* τ_e, for the motor?

Note: The final model of the motor we will develop will not have R_s. This is only used for identification.



Motor Electrical Diagram: Flywheel clamped.

b. The electrical parameters R_a and L_a (assuming R_s is known) can be determined from the step response of the motor with clamped flywheel. Describe how τ_e can now be found from a best-fit line of ln ($y_s s$ - $y(t)$) vs. t. This will give a reliable estimate in spite of noise. Load the MATLAB data in the file "f:\labs\Ee386\prelab4.mat." The variable "Elect" contains time points and voltage points from a step response in columns 1 and 2, respectively. Determine L_a from these data, after finding *tau*$_e$. Assume $R_s = 2.5\Omega$, $R_a = 3.3\Omega$, compare the value you find from the plots to the value used to generate them: 1 mH. (In the Laboratory Exercises below you will collect your own data points.)

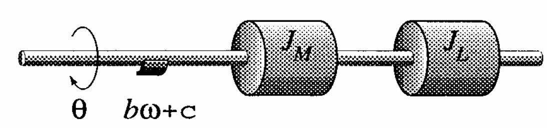
c. Now consider the dc motor with the rotor free to turn. The back emf constant, K_V, the torque constant, K_τ ($= K_V$ in SI units), the viscous friction coefficient, *b*, and the Coulomb friction coefficient, *c*, can be obtained from *steady-state* step response data, that is from measurements of $\omega(\infty)$ and $i_a(\infty)$, when a known constant input voltage V_i is applied. Explain how (more than one trial will be needed). If we perform two experiments, with following results:

V	Steady state I_a	steady state ω
5 Volts	0.249 A	77.0 rad/s
10 Volts	.304 A	163 rad/s

Measuring Motor Current

what are the values for $K_\tau = K_V$, *b* and *c* (R_s is not use measurement,
R_a and L_a are as above)?

d. The mechanical time constant, and hence the total moment of inertia, *J*, can be determined by opening the motor circuit ($I_a = 0$), when the motor is rotating, and observing the time-constant of the resulting decay of the motor speed. The situation is shown in Fig. 5.



Motor Mechanical Diagram: open electrical circuit.

With the motor spinning only in one direction, the Coulomb friction will not change sign, and we can consider it to be a constant. The dynamics are then described by the differential equation:

$$J\dot{\omega} + b\omega + c = 0$$

Find $\omega(t)$, in terms of J, b, c, and $\omega(0)$. Explain how to adjust the method used in part (b) so that we can find J if the other parameters are known. Illustrate your method on the data in the variable "Iner" in the MATLAB data file. Use the values for the friction coefficients from part (c). Compare the value you find to the value used to generate the plots, 4 x 10^{-5} Kg- m^2.

(e) If we assume the motor has a strictly positive angular velocity, we can get a linear model by disregarding the Coulomb friction. (We'll address this again in lab 5.) Using the numerical values above, obtain the resulting second order transfer function, $\Omega(s)/V_i(s)$ for the motor. Compare this transfer function to the first order transfer function obtained in class with L_a = 0. Use MATLAB to produce step responses and Bode plots for both cases.

2	MOTOR TRANSIENT RESPONSE

I. Introduction

A second order system is studied in simulation and in hardware. The transient characteristics of the step response (i.e. Percent Overshoot, Rise Time, etc.) are examined in both situations. The effect of feedback gain on the transient characteristics is determined.

II. Simulation

A second order system can be obtained by cascading an integrator with the single pole motor model used in previous labs. Such a system is shown in Figure.

(a) Determine the closed loop transfer function V_{tach}/V_{ref}. Find the steady-state response for a unit step input. (Use the final value theorem.) What is the steady state error? Using the values of K_m, K_{tach}, and T_m determined from hardware in the last experiment, compute values for the damping ratio and the natural frequency of oscillation $_n$ for the amplifier gains: Ka = 0.5, 1, 2, 4, 6, 8.

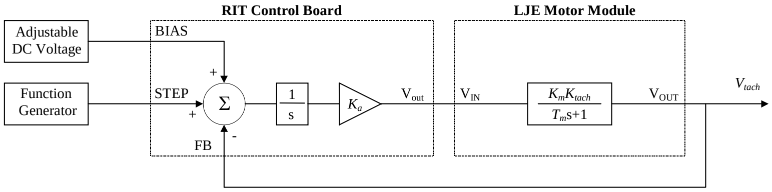
(b) Simulate the system shown in Figure for $K_a = 2$. Obtain plots for $V_{tach}(t)$ and $e(t)$ for a unit step input. What is the relationship between the two signals?

(c) Calculate the value of K_a to make the system critically damped. **Plot** the output V_{tach} for an over damped, an under damped, and the critically damped case on the **same graph**. **Specify** the value of K_a used for each case.

(d) Simulate the system using the values of gain Ka specified in part (a). Write a MATLAB function to determine the rise time, peak time, settling time, and percent overshoot from the step response vectors returned by the simulation. This MATLAB function will allow key performance indicators to be obtained very quickly from the simulation output. INCLUDE this m-file in Appendix of your report.

III. Hardware

Connect the hardware as shown in Figure. The integrator can be constructed using the spare op-amps on the control board. Wire one of the op-amps as an inverting integrator, and wire the other as an inverting unity gain follower. These op-amps can be switched in and out of the circuit using the *Ka/Compensated* switch on the control board. See the schematic of the control board.



(a) Set up the function generator to provide a square wave which oscillates between 0v and 1v at a low frequency.

(b) Adjust the gain of the control board such that K_a = 2 (See NOTE!!!). Adjust the BIAS input to give an initial speed of 500RPM. Capture the output V_{tach} and the error signal (output of the summing node) on the scope screen. Make a plot.

(c) Capture and plot the step response for the values of K_a used in part II (a) (0.5,1,2,4,6,8). After adjusting the gain each time (see NOTE), be sure to set the BIAS input to yield an initial speed of 500 RPM. For each response, determine rise time, settling time, and percent overshoot. Use the measurement features or the cursors to read these values.

NOTE: When adjusting the controller gain K_a, be sure to disconnect FB and STEP, and switch the integrator out of the circuit (put switch in K_a position). Doing so makes $K_a = V_{out}/BIAS$.

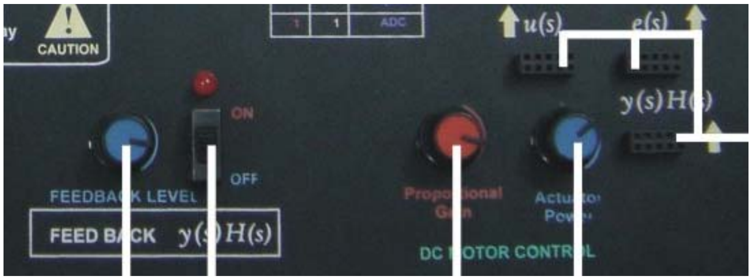
IV. Report

Include the following in the report:

- **All** derivations, calculations, and plots requested throughout the lab experiment.
- **Tabulate** and compare the values of percent overshoot, rise time, and settling time for the theoretical, simulation, and hardware results for each value of K_a. Discuss reasons for differences between theoretical, simulation, and hardware.
- Include a graph of percent overshoot versus ζ for theoretical, simulation, and hardware.
- Explain qualitatively how the forward gain (Ka) affects the transient performance of the system.
- How does the cascade integrator affect steady state response?
- Properly labeled hardware plots
- M-file from Simulation part II (d)

3

BASIC CLOSED LOOP CONTROL & SIMPLE SPEED CONTROL WITH INCREASED GAIN



I. Introduction

In this assignment, the step response of a DC motor will be shaped using a cascade compensator. A proportional plus integral (PI) compensator will be designed to yield given step response specifications. Simulation and hardware experiments will be used to verify the performance of the compensator in a velocity control loop. An integral lag (I-Lag) compensator will also be examined in simulation and will be shown to be ineffective in meeting the desired step response specifications.

II. Design (Pre-Lab)

A. PI Compensator

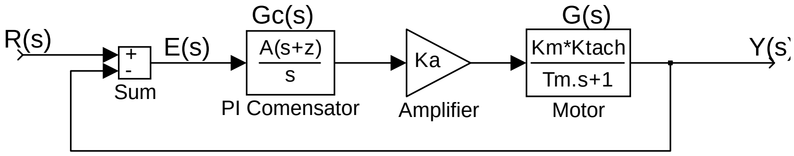
The proportional plus integral compensator has a transfer function of the form,

$$G_c(s) = K_p + \frac{K_i}{s}$$

Note that the PI compensator consists of a proportional gain plus a gain times an integrator. The transfer function can be rearranged in a more useful form as follows,

$$G_c(s) = \frac{A(s+z)}{s}$$

Figure shows the velocity control loop with a feed-forward (cascade) PI compensator Gc(s).



1. Derive the closed loop transfer function Y(s)/R(s)
2. Use the Routh-Herwitz criterion to determine the conditions on A and z such that the closed loop system will be stable.
3. Assuming the closed loop poles to be dominant, determine the values of A and z such that the system will have 15% overshoot and a settling time of 1.25 seconds for a step input.
4. Simulate the system given in Figure using the values of A and z determined in (3). Determine the overshoot and settling time from the simulated response, and compare with the desired values.

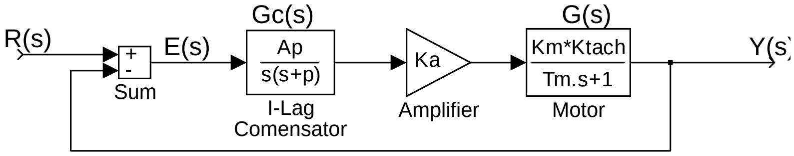
Why might the simulation results differ from the theoretical values?

B. I-Lag Compensator

The integral plus first order lag compensator has a transfer function of the form,

$$G_c(s) = \frac{Ap}{s(s+p)}$$

Figure shows the velocity control loop with a feed-forward I-Lag compensator Gc(s).



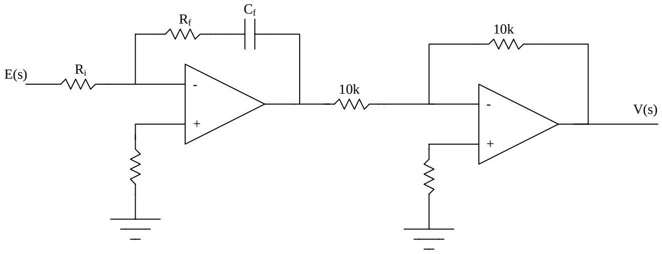
1. Derive the closed loop transfer function Y(s)/R(s).
2. Use the Routh-Herwitz criterion to determine the conditions on A and p such that the closed loop system will be stable.
3. Plot the root locus of the compensated system for p = 5, 10, 100. Is there a value of A and p such that the percent overshoot and settling time specifications given in part A-(3) can be met?

What happens if A becomes very large?

(4) Use p = 5 and simulate the step response of the system for A = 2, 4, 8, 16. How is the response affected by the gain?

III. Hardware

Figure shows an op-amp implementation of the PI compensator.



Which has a transfer function?

$$G_c(s) = \frac{V(s)}{E(s)} = \frac{R_f}{R_i}\,\frac{s + {}^{1}\!/_{R_f C_f}}{s}$$

(1) Obtain values for R_i, R_f, and C_f to meet the specifications given in section II A-(3).

(2) Use the spare op-amps on the control board to implement the PI compensator. Adjust the gain K_a to 1.0, and place the compensator in the velocity control loop.

(3) Capture the step response of the system and measure the overshoot and settling time.

(4) Attempt to meet the desired specifications by adjusting the compensator gain. Capture the step response for at least two additional values of gain. What effect does the gain seem to have on the overshoot and settling time? Is this expected by theory?

IV. Report

This lab requires more of an in depth write up than the past reports.

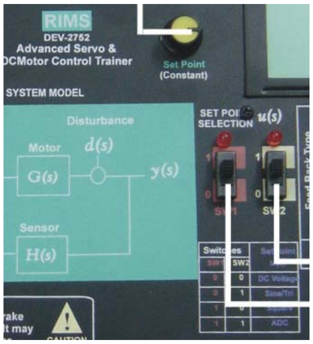
Include the following in the report:

- All derivations and proofs required throughout the lab exercise.
- Tables of theoretical, simulation, and hardware

results with comparisons. Also, note differences between the three.

- Compare the PI compensator and the I-Lag compensator in terms of meeting the given overshoot and settling time specifications
- What general effects does the I-lag compensator have on the system?
- Compare the simulation and hardware results for the PI compensator.

What adjustments were needed to obtain performance closer to the desired specifications with the PI compensator?



Reversible motor speed control
The set-point allows the user to control the direction of the motor. The other mechanism remains the same. Please remember the speed control setup is not intended for position control and do not expect the system to have fine speed control from the hysterisis based dc motor drive.

4

POSITION CONTROL SYSTEM

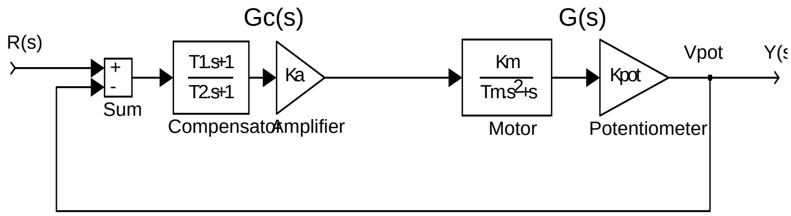
I. Introduction

Root locus techniques are used to design a compensator for a DC motor position control loop such that given step response specifications are met. The resulting compensator is evaluated through simulation. Root locus methods are also used to examine the robustness of the control scheme with respect to variations in the motor’s mechanical time constant.

II. Design Specifications

Design a compensator Gc(s) to be placed in the position control loop shown in Figure such that the following specifications are met:

Percent Overshoot: $12 < P.O. < 15$ for a unit step input
Settling Time: $.7 < TS < .9$ for a unit step input
Steady-State Error: ess. < 15 % for a unit ramp input



III. Design

Recall that the position model of the motor is given by,

$$\frac{\theta(s)}{V_{in}(s)} = \frac{K_m}{s(T_m s+1)}, \qquad \text{and}$$

$$G(s) = \frac{V_{pot}(s)}{V_{in}(s)} = \frac{K_m K_{pot}}{s(T_m s+1)}$$

Where $K_{pot} = 0.09$ V/rad.

Assume the compensator transfer function to be of the form,

$$G_c(s) = K_a \frac{\tau_1 s+1}{\tau_2 s+1}$$

(a) Find the requirement on the gain K_a to satisfy the steady state error specification.

(b) Determine the location of the dominant complex poles of the closed loop system to satisfy the overshoot and settling time specifications.

(c) Check to see whether the uncompensated system (with $G_c(s) = K_a$) will satisfy the specifications by choosing a suitable value of K_a. If not, continue.

(d) Using the root locus method, design a lead compensator that will satisfy all the given specifications and have a **pole-zero cancellation**. Specifically, place the compensator zero to cancel the motor pole. This implies the determination of τ_1, τ_2, and K_a.

Normally, there is not one specific solution to meet the specifications. You would have freedom in choosing one of these parameters. Once it was chosen, the other two parameters would be determined to satisfy the desired closed loop pole locations. Fortunately, we helped you choose one of the parameters!

IV. Design Evaluation

(a) Draw the root locus.
(b) Determine the closed loop poles and zeros of the compensated system.
(c) Simulated the step response and ramp response of the compensated system and verify the specifications.
(d) Test the system for robustness to variations in the motor's mechanical time constant. In a real application, different motors may have different time constants, and we must ensure that your compensator design provides reasonable performance despite such differences.

In order to estimate robustness, draw the root locus of the compensated system as the parameter T_m is varied. This can be done by rewriting the characteristic equation in the form,

$1+\frac{1}{T_m}F(s)=0$, where F(s) is a rational function of s.

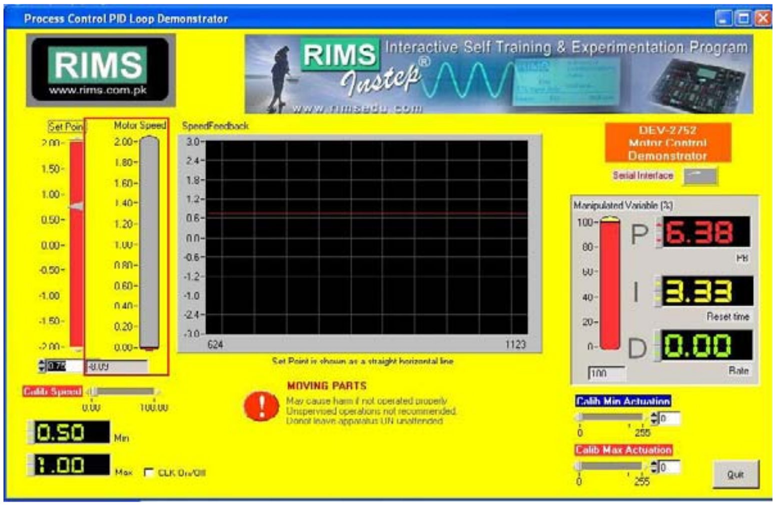
Note, F(s) is not a function of T_m.

In MATLAB, the *rlocus* command uses the characteristic equation form, 1+K*F(s). The *rlocus* command will vary the parameter K, which in our case will be $1/T_m$. Therefore, we can evaluate the sensitivity of our system to changes in the motor time constant.
Using *rlocus*, draw the root locus and also determine the closed loop poles and zeros for several different values of T_m in the range of +/- 50% of its nominal value. From these pole and zero locations, you will be able to estimate, qualitatively, the sensitivity of the closed loop response to variations in T_m . You may verify your analysis by simulating the system for various T_m values within the +/- 50% range.

V. Report

Include the following in your report:

- Show all design steps, details, and evaluation of your work.
- Discuss the robustness of your compensator, illustrate by showing and comparing variations in the specs.



Process Control PID Loop Demonstrator

MOVING PARTS
May cause harm if not operated properly
Unsupervised operations not recommended.
Donot leave apparatus UN unattended

Set Point is shown as a straight horizontal line

P 6.38 PB
I 3.33 Reset time
D 0.00 Rate

0.50 Min
1.00 Max
☐ CLK On/Off

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