Lab Session 5
Frequency Domain Identification & PD Control

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Equipment

Agilent 54600B 100 MHz Ditizing Oscilloscope
Agilent 33120A Function/Arbitrary Waveform Generator
Agilent 6632A Power Supply
Agilent 34401A 6 1/2 Digit DMM
Agilent 35670A Dynamic Signal Analyzer
Agilent VEE 5.0 software
Matlab software (www.mathworks.com)
Amplifier/Motor/Potentiometer test set (hybrid, built in-house)
Analog computer: Comdyna GP6

Purpose

This experiment continues the study of the dc motor begun in Lab 4. The model that you obtained in the last set of experiments was found from transient response data. You will now obtain an input-output model directly by examining the frequency response of the motor. You will then implement a proportional-derivative controller, and record and analyze the step response of the closed-loop system for a range of feedback gains.

Preparation

Readings:

A portion of this experiment involves the use of frequency response techniques to determine selected system parameters. To prepare for this, you should review the information on Bode plots in Kuo, Appendix A.

Prelab:

(a) To obtain a frequency response for the open loop motor transfer function, you will apply a signal of the form $V_i(t) = A + B \sin(\omega t)$, where A and B are positive constants, with $A > B$. If the motor transfer function (from voltage input to shaft angular velocity) is $\Omega(s)/Vi(s) = K/(\tau s + 1)$, what is the resulting output (approximately) for large t (Final Value Theorem does not apply, why?)? Why do you think that the dc offset A is included in the excitation signal V_i?

(b) Using the results from your the last experiment, obtain the time constant τ and the gain K in the motor transfer function $\Omega(s)/V_i(s) = K/(\tau s + 1)$.

We next consider the design of a closed loop position control system using PD control. The structure is shown in Fig 5.1. For the sake of concreteness, assume now that the motor has the transfer function

$$\Omega(s)/V_i(s) = \frac{18}{1 + s/10}$$

In the lab, we will connect the system illustrated in Fig. 5.2 to the analog computer set up shown in Fig. 5.3, to form a closed loop system of the form Fig. 5.1. We are then interested in the voltage from the potentiometer, the output of the system, and how it behaves as the reference input voltage v_r is varied. This reference input will be supplied by the Agilent waveform generator.

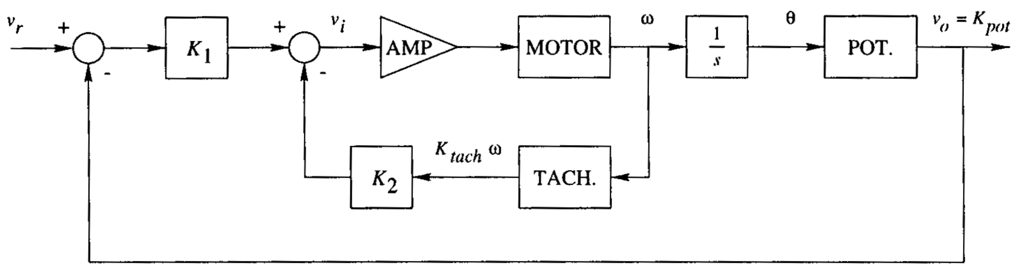

Figure 5. 1. A Feedback Control System for the DC Motor

Note: In practice, the reference input would typically be an angle, not a voltage. One then must construct a device (such as a potentiometer) to translate the desired angular position to an input voltage v_r.

(c) Suppose $K_{amp} = 2.4$, $K_{pot} = 10/2\pi \cong 1.6$ volt · s/rad, and $K_{tach} = 0.03$ volt · s/rad. Find the closed loop transfer function $V_o(s)/V_r(s)$ in terms of the potentiometer settings P_1 (= $K_1/10$) and P_2 (= $K_2/10$). Given this transfer function, compute the closed loop pole locations for the following settings:

P_1	0.15	0.25	0.1
P_2	0	0.35	0.5

(d) Using root locus methods, explain the effects of changing P_1 and P_2 on the closed loop step response. Obtain a root locus plot using MATLAB varying P_1 (overlay for each value of P_2), and then another plot varying P_2.

(e) For the same control system considered above, find values of P_1 and P_2 such that overshoot is approximately 15% ($M_p \approx 0.15$) and the rise time is approximately 20 ms ($t_r \approx$ 20ms). Use the formulas from Kuo as referenced in Session 1.

(f) Draw a patch panel wiring diagram for the analog computer setup shown in Fig. 5.3 (P_1 and P_2 are variable)

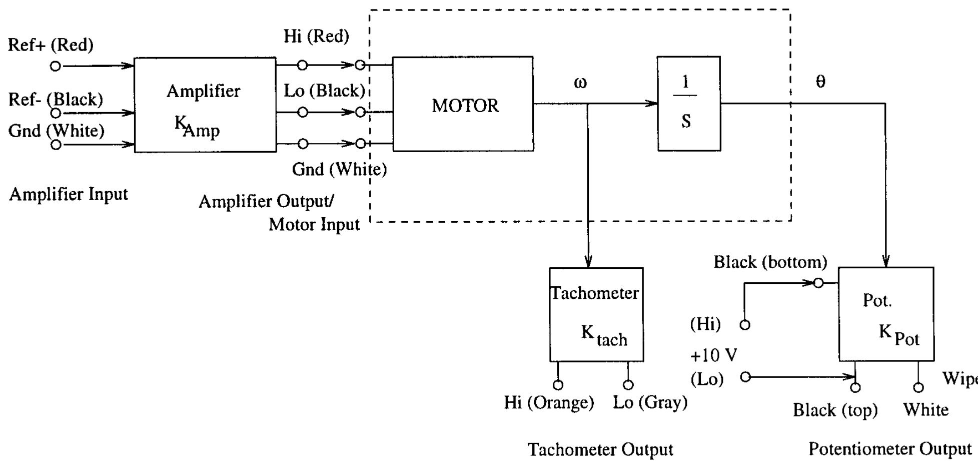

Figure 5.2. Motor Block Diagram.

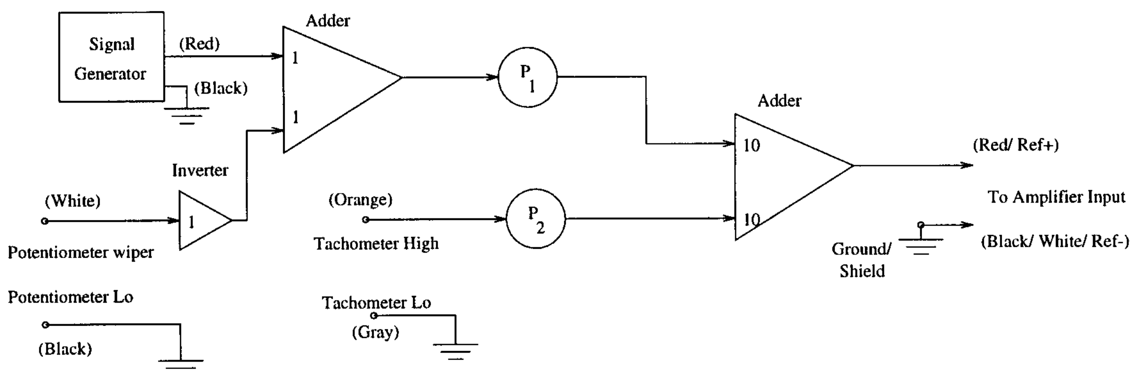

Figure 5.3. Analog Computer Wiring Diagram.

Laboratory Exercise

Open Loop Frequency Response Measurements:

In the previous lab you obtained a transfer function based on transient response data. It is also possible to obtain a frequency response directly by exciting the system with sinusoids of varying frequency. For each frequency, it is possible to measure the gain and phase directly from the waveform on an oscilloscope. To obtain a rational transfer function, one can simply fit a curve to the data.

We will obtain a model for the transfer function $\frac{\Omega(s)}{V_i(s)}$. The transfer function $\frac{\Theta(s)}{V_i(s)}$ is then obtained immediately since $s\Theta(s) = \Omega(s)$.

- Remember: Do not turn on power on the patch panel until instructed to do so. Never “hot wire” the system.
- Turn on the oscilloscope and the function generator.
- The function generator should have the following settings.

1. Output: Hi Z. To set the expected load impedance, follow these steps: Press the **Shift** key and the **Enter** key (the one with **Menu** written in black above it). Press the > key 3 times until the menu item displayed on the screen is *Sys Menu.*

   Press the V key twice until the display reads *Parameter/ 50 ohms*. Now press the > key until you see *High Z* displayed on the screen. At this point press the **Enter** key.

2. Frequency = 0.2 Hz

3. Amplitude = 2 V p-p

4. Waveform = sine

5. DC offset = 4 V

- Connect the function generator to the **Amplifier Input** on the patch panel, as follows. Using the coaxial cable (BNC to banana), connect the red banana jack to “Ref+”, and the black to “Ref-”. The “Sig. Gnd” must also be connected to ”Ref-“.

- The scope settings are:
  1. Channel 1 and Channel 2: Both should be On, and should be set on DC Coupling, 1 V/div. Offset should be set to -4 V for each.
  2. **Timebase** = 1 s
  3. **Trig. Mode** = Normal, DC coupling, Noise Reject ON, Reject HF
  4. **Trig. Source** = Ch 2, 4 V
  5. Measure **Time** (Next), (Next), Phase
  6. Measure **Voltage** Ch 1, (Next), (Next), V_{amp}; Ch 2, (Next), (Next), V_{amp}

- Disconnect the potentiometer from the motor assembly,

- Make sure that the motor and flywheel are secured firmly to the bench.

- Connect **Amplifier Input** “Ref-“ and “Ref+”, respectively, to the black and red coaxial cable banana plugs to the Channel 2 input on the scope. Follow Fig. 5.2 to make the connections.

- Connect the motor to the **Amplifier Output** on the patch panel using the special grey twisted lead cable (with three banana plugs), following the red/white/black color code.

- Connect the Tachometer output to Channel 1 of the oscilloscope using the coaxial cable (BNC to banana) and the noise filter. The grey jack on the motor should be connected to the black lead of the cable, and the orange jack to the red lead.

- Connect the pushbutton to **Amp Inhibit** on the patch panel.

Have the TA check your wiring before you power the amplifier.

- Turn on both power switches on the patch panel. You should observe the reference waveform on the actual scope. Depress the pushbutton, and keep it depressed. Press **STOP** on the oscilloscope to stop data collection. Adjust **Timebase** to make sure that you see approximately two complete periods on the scope. Collect V_in, V_out, and phase and record in the table at the end of this session. Note: you need to Press **RUN** on the oscilloscope to collect more data.

- Repeat the entire experiment using the frequencies: 0.4, 0.8, 1.6, 2, 2.5, 3, 3.5, 4.5,6, 12, and 20 Hz. You will need to make adjustments to the time-base and voltage sensitivity. Add any other points you think are necessary to determine the pole with reasonable accuracy.

Closed Loop Step Response Measurements:

To begin, wire up the analog computer in accord with your patch panel diagram from part (6) of the prelab. You should then follow these detailed instructions.

- Make sure power to the patch panel is off.
- Connect the potentiometer to the motor assembly.
- Connect the outputs of tachometer and the potentiometer attached to the motor, as illustrated in Fig. 5.2, to the inputs of the analog computer as shown in Fig. 5.3. Connect the output of the analog computer in Fig. 5.3 to the amplifier input in Fig. 5.2, using the color codes indicated in these figures. Your lab bench should be equipped with two of the red/black/white three-lead cables to make connections to the amplifier. Remember to short the black and white leads to the ground of the analog computer when connecting the amplifier input to the analog computer output.
- Connect the power to the potentiometer. Connect **Hi +10V** to the bottom black socket on the potentiometer, and **Lo +10V** to the top black socket.
- Connect Channel 1 of the oscilloscope to the potentiometer by connecting the red jack to the wiper (white) and black jack to the top black socket (Lo). Connect Channel 2 to the output of the signal generator/input of analog computer, using corresponding colors (red to red and black to black). The noise filter will not be used here.
- In order to save the data for analysis in MATLAB, start Agilent Vee and open **`f:\labs\Ee386\3861ab5.VEE.`** Be sure to adjust the file name you wish the data saved to, and the data name in the **Formula** box.
- In Agilent Vee, click on the scope icon and the main panel of the signal generator icon in order to set the desired parameters on the scope and function generator.

Note: the function generator should be sending a 0.1 Hz square wave, amplitude 2V peak-to-peak with 4V dc offset. Adjust scope settings until the system triggers off the input as you desire (it may be necessary to adjust the **TRIGLevel** to 4.2V instead of 4.5V).

Remember that the scope is triggering on a 0.1 Hz signal. This means that the screen will not update for ten seconds, so be patient. If the scope does not trigger, push the Main/delayed button on the scope and switch to **ROLL** mode. For best results, remember to switch back to **Main** mode before collecting your data in AgilentVee.

Have your TA check your wiring and scope settings before you proceed.

- Connect the push button to the **Amp Inhibit** on the amplifier. Turn on both power switches on the patch panel.
- Turn on the analog computer. In **Pot Set** mode, set the potentiometer levels P_1 and P_2**.** The values of P_1 and P_2 for which the experiment should be repeated are:

P_1	0.15	0.25	0.1
P_2	0	0.35	0.5

In addition, apply the values that you designed to meet the specifications in the prelab.

- Switch to **OPR** mode on the analog computer. Depress pushbutton, and wait. Soon you should see a step response on the scope (it may take two changes of the input, based on the triggering settings). Press **Start** in AgilentVee to display the waveform on the computer. Compute the overshoot, rise time, settling time, and steady-state error of the step response. Repeat these steps for each value of P_1 and P_2.

Report:

1. Using MATLAB, plot the open loop frequency domain data obtained, both magnitude and phase, using symbols. Your two plots should span 3 decades in frequency (Hz or rad/s), and 20 dB or 100 degrees in phase, and they should be in landscape mode. This will allow you to get a best-fit estimate of the pole and gain from these plots by overlaying the transparencies provided by your TA. Determine from the graph a first order transfer function for the motor of the form

$$\Omega(s)/V_i(s) = \frac{K}{(\tau s + 1)}$$

   Be sure to use both magnitude and phase information. Also remember to remove the gain of the amplifier and the tachometer. Does the transfer function obtained in this way approximate the linearized transfer function constructed in Lab Session 4?

2. Using K and τ from the frequency response identification, compute theoretical values of ζ, ω_n, M_p, t_r, and t_s for each value of P_1 and P_2, for the system in Fig. 5.2. Use the formulas from Kuo as referenced in Session 1. Now compute the experimental values of M_p, t_r and t_s from the step response data obtained in lab. Discuss your findings, including an explanation of the contribution of Coulomb friction.

3. How well did your design perform in the lab? Did you meet the specifications laid out in the prelab? If not, suggest improvements to do so. Was the steady state error as expected in all cases? Explain why or why not. What adjustments of the gains help to improve the steady-state error?

Save your results to compare with the next experiment.

Open Loop Frequency Response Data:

Freq. (Hz)	Phase (deg)	V_i	V_o	Gain