College of Engineering
School of Aerospace Engineering

AE 6705: Introduction to Mechatronics

LAB9

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Table of Contents

Question 1

Generate a step input with 100% duty cycle and measure the open-loop motor response by capturing sampled motor speed values and storing it in an array. Print out this array to the CCS console after the motor reaches steady state. Repeat this experiment for different speed changes (i.e. 20%, 40%, 60%, and 80% duty cycles) so that the results can be compared.

Solution:

RPM Raw Data

```
,20%,40%,60%,80%,100%
RPM[0],163.24028,20.781232,45.546093,69.42585,126.74398
RPM[1],40.5289,36.906185,111.857941,235.407257,38.57468
RPM[2],72.675148,55.860237,236.520813,38.162495,43.653309
RPM[3],121.448868,130.994232,36.253265,41.428871,46.249653
RPM[4],37.338886,191.5728,38.379265,42.826981,55.35928
RPM[5],40.446934,233.429031,38.932102,50.541294,57.267784
RPM[6],40.913593,34.27039,45.434349,51.541592,57.241558
RPM[7],57.307163,34.880013,46.040974,51.266788,65.850777
RPM[8],58.28923,34.580883,45.55439,58.893406,66.658447
RPM[9],55.304173,39.704994,52.165363,59.018532,65.070923
RPM[10],80.193268,39.720764,52.132729,57.544594,74.162704
RPM[11],78.617134,38.730053,50.710445,65.206703,73.42218
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RPM[15],87.99807,47.121387,61.418129,69.348824,76.231895
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RPM[30],205.340866,58.221352,74.783875,84.67485,91.980316
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```
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RPM[150],35.132446,72.548607,92.507866,107.343277,116.850899
```

Question 2

Use a program such as MATLAB, Excel, etc. to plot the motor responses for each tested case versus time. Use the response corresponding to 100% duty cycle to measure the motor time constant and gain K. Write the open-loop transfer function for this case. This transfer function will describe the input-output relationship for each test case. What do you notice happening as the duty cycle increases? What is the reason for this?

Solution:
From the step response of 100% duty cycle in Figure 1, we can compute the parameters of the transfer function which are the time constant and gain where gain is the steady state RPM value and the time constant is the time that took for the response to reach approximately 63% of the steady state value.

Time Constant τ	Gain K
0.0753	123.3266

Table 1: Time constant and gain of first order system from data

Thus, the open loop transfer function for this system becomes

$$G(s) = \frac{123.3266}{0.0753s + 1}.$$

Furthermore, from Figure 1 we can see that as the duty cycle increases the fluctuations that occur at the beginning of the response becomes attenuated. This is due to a phenomenon called windup which causes the RPM to rise drastically and sporadically for when the duty cycle is low. This is due to saturation and not having an anti-windup scheme in our system.

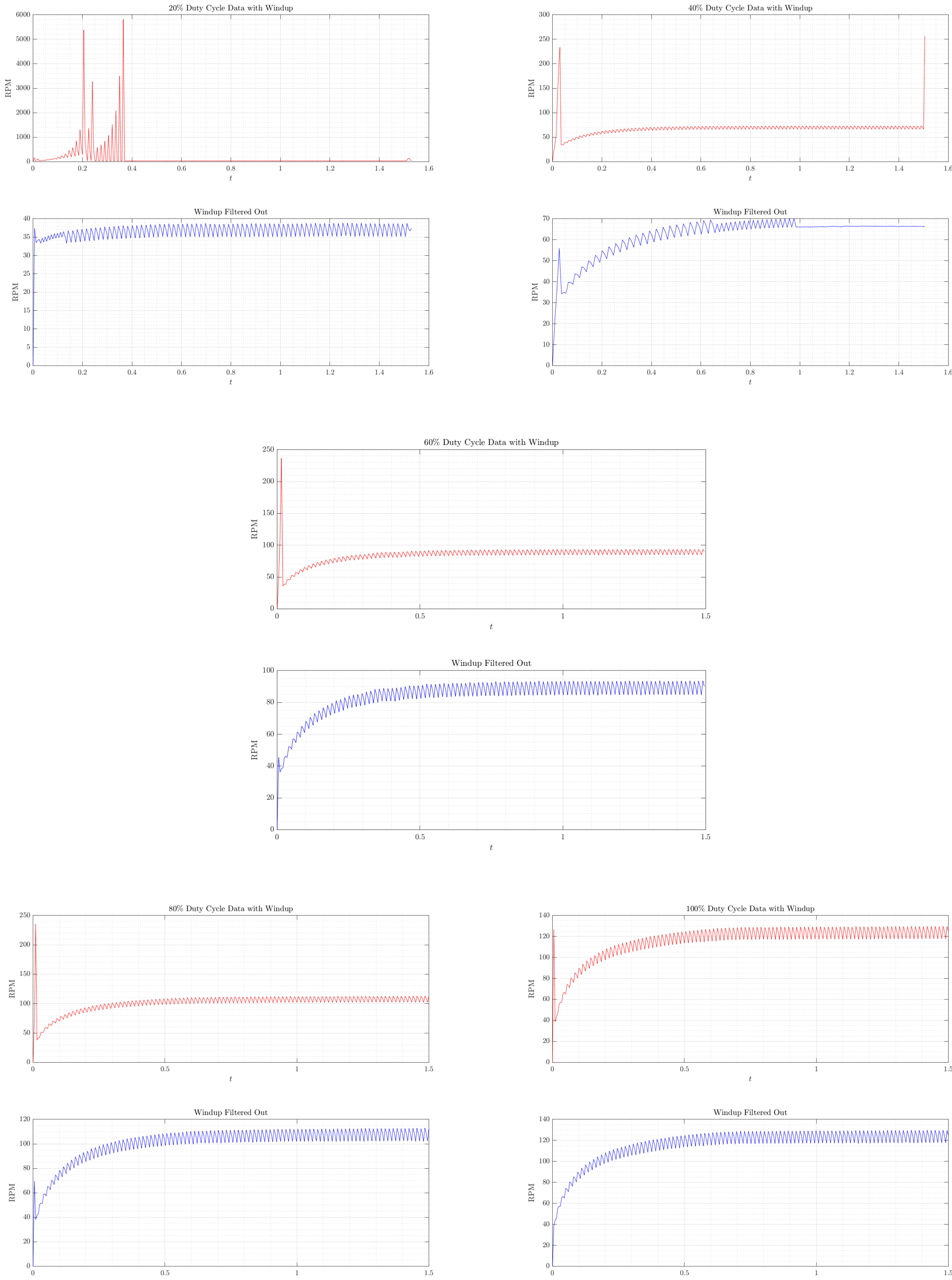

Figure 1: Step response for each corresponding duty cycles

Question 3

Verify the measured time constant and gain by creating and running a Simulink model for a first order system. Use this to simulate a step input. Your simulated response should be similar to your experimental results.

Solution:
Using the Simulink model below

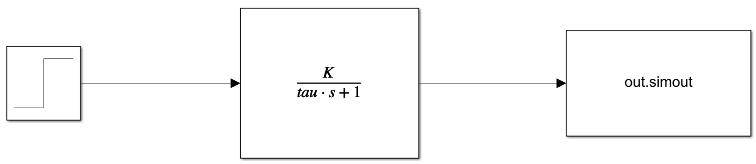

Figure 2: Simulink model of first order system

we obtain the following result

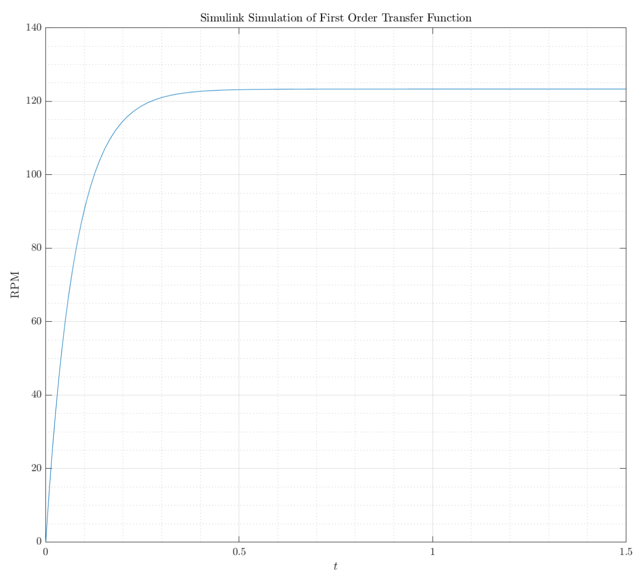

Figure 3: Simulink model of first order system

Question 4

Calculate the transfer function using step responses resulted from other duty cycles. Is the resulting transfer function the same for all the experiments? If not, discuss why.

Solution:
Using MATLAB we compute the other transfer functions with their gains and time constants. The result is tabulated as follows.

Time Constant τ	Gain K	Transfer Function
≈ 0 (ϵ)	37.0432/0.2	$\frac{185.216}{\epsilon s+1}$
0.0821	66.5705/0.4	$\frac{166.4263}{0.0821s+1}$
0.0654	89.0193/0.6	$\frac{148.3655}{0.0654s+1}$
0.0953	107.0021/0.8	$\frac{133.7526}{0.0953s+1}$
0.0753	123.3266	$\frac{123.3266}{0.0753s+1}$

Table 2: Time constant and gain of first order system for all cases

We can observe from this table that the transfer functions each have a different gain value as well as a time constant. For each duty cycle there is a slight error or deviation between the theoretical value and the actual value that is output from the system due to factors such as disturbances and errors. For the case of 20% duty cycle there was a lot of errors due to winding and it even had a rapid rise that made it difficult to measure the time constant value. These limitations due to the digital system along with the disturbances and errors caused this deviation of transfer functions for each duty cycle case.

Appendix

5.1 MATLAB Code

```
% AE6705 MATLAB code
% Tomoki Koike
clear all; close all; clc;  % housekeeping commands
set(groot, 'defaulttextinterpreter','latex');
set(groot, 'defaultAxesTickLabelInterpreter','latex');
set(groot, 'defaultLegendInterpreter','latex');
%%
% Time
t_interr = 15000 / 3e+6;
%%
% DC 20%
data = csvread("dc20.csv");
T = t_interr * length(data);
data = [0; data];
fdata1 = data(data < 40);
t = linspace(0,T,length(data));
ft1 = linspace(0,T,length(fdata1));
fig = figure("Renderer","painters","Position",[60 60 950 800]);
    subplot(2,1,1)
    plot(t,data,'--r')
    title('20\% Duty Cycle Data with Winding')
    xlabel('$t$')
    ylabel('RPM')
    grid on; grid minor; box on;
    subplot(2,1,2)
    plot(ft1,fdata1,'--b')
    title('Winding Filtered Out')
    xlabel('$t$')
    ylabel('RPM')
    grid on; grid minor; box on;
saveas(fig,'outputs/dc20_plot.png')
%%
% DC 40%
data = csvread("dc40.csv");
T = t_interr * length(data);
data = [0; data];
fdata2 = data(data < 70);
t = linspace(0,T,length(data));
ft2 = linspace(0,T,length(fdata2));
fig = figure("Renderer","painters","Position",[60 60 950 800]);
```

```
    subplot(2,1,1)
    plot(t,data,'-r')
    title('40\% Duty Cycle Data with Winding')
    xlabel('$t$')
    ylabel('RPM')
    grid on; grid minor; box on;
    subplot(2,1,2)
    plot(ft2,fdata2,'-b')
    title('Winding Filtered Out')
    xlabel('$t$')
    ylabel('RPM')
    grid on; grid minor; box on;
saveas(fig,'outputs/dc40_plot.png')
%%
% DC 60%
data = csvread("dc60.csv");
T = t_interr * length(data);
data = [0; data];
fdata3 = data(data < 100);
t = linspace(0,T,length(data));
ft3 = linspace(0,T,length(fdata3));
fig = figure("Renderer","painters","Position",[60 60 950 800]);
    subplot(2,1,1)
    plot(t,data,'-r')
    title('60\% Duty Cycle Data with Winding')
    xlabel('$t$')
    ylabel('RPM')
    grid on; grid minor; box on;
    subplot(2,1,2)
    plot(ft3,fdata3,'-b')
    title('Winding Filtered Out')
    xlabel('$t$')
    ylabel('RPM')
    grid on; grid minor; box on;
saveas(fig,'outputs/dc60_plot.png')
%%
% DC 80%
data = csvread("dc80.csv");
T = t_interr * length(data);
data = [0; data];
fdata4 = data(data < 120);
t = linspace(0,T,length(data));
ft4 = linspace(0,T,length(fdata4));
fig = figure("Renderer","painters","Position",[60 60 950 800]);
    subplot(2,1,1)
```

```
    plot(t,data,'-r')
    title('80\% Duty Cycle Data with Winding')
    xlabel('$t$')
    ylabel('RPM')
    grid on; grid minor; box on;
    subplot(2,1,2)
    plot(ft4,fdata4,'-b')
    title('Winding Filtered Out')
    xlabel('$t$')
    ylabel('RPM')
    grid on; grid minor; box on;
saveas(fig,'outputs/dc80_plot.png')
%%
% DC 100%
data = csvread("dc100.csv");
T = t_interr * length(data);
data = [0; data];
fdata5 = data;
fdata5(2) = [];
t = linspace(0,T,length(data));
ft5 = linspace(0,T,length(fdata5));
fig = figure("Renderer","painters","Position",[60 60 950 800]);
    subplot(2,1,1)
    plot(t,data,'-r')
    title('100\% Duty Cycle Data with Winding')
    xlabel('$t$')
    ylabel('RPM')
    grid on; grid minor; box on;
    subplot(2,1,2)
    plot(ft5,fdata5,'-b')
    title('Winding Filtered Out')
    xlabel('$t$')
    ylabel('RPM')
    grid on; grid minor; box on;
saveas(fig,'outputs/dc100_plot.png')
%%
% Computing the time constant and the gain
K = mean(fdata5(100:end));
fval = fdata5(end);
idx = max(find(abs(fdata5-fval)>=0.37*fval));
tau = ft5(idx);
%%
% Verify with simulink model
res = sim("motor_model.slx");
%%
```

```
fig = figure("Renderer","painters","Position",[60 60 950 800]);
    plot(res.tout, res.simout.signals.values);
    grid on; grid minor; box on;
    title("Simulink Simulation of First Order Transfer Function")
    xlabel('$t$')
    ylabel('RPM')
saveas(fig,"outputs/model_resp.png")
%%
% Computing the time constant and gains for the other duty cycles
Ks = [0 0 0 0 0];
taus = [0 0 0 0 0];
fts = {ft1 ft2 ft3 ft4 ft5};
ct = 1;
for fd = {fdata1 fdata2 fdata3 fdata4 fdata5}
    k = mean(fd{1,1}(100:end));
    fv = fd{1,1}(end);
    i = max(find(abs(cell2mat(fd)-fv)>=0.37*fv));
    ftemp = fts{1,ct};
    toe = ftemp(i);
    Ks(ct) = k ;
    taus(ct) = toe;
    ct = ct + 1;
end
```