Nathan Isaman ME 477: Lab 8 14 Mar 17

Description

The purpose of this lab was to include data output to the code developed in Lab 7 in order to analyze the DC motor's step response and response to disturbances. The block diagram for the complete system under test can be seen in Figure 1 below.

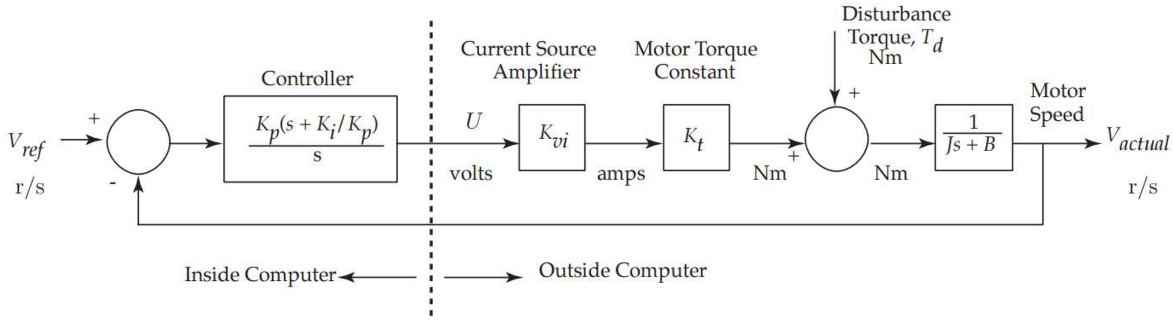

Figure 1: DC Motor/Controller Block Diagram

The code was largely unchanged, other than the inclusion of MATLAB file creation functions seen in the *main()* function as well as an if() statement added to the *Timer_Irq_Thead()* function to capture and store the actual velocity and torque values in a globally defined double array.

```
Hierarchy:
main()
|_MyRio_Open()                                   // Opens a session with the MyRio
|_AIO_initialize()                               // Initializing Analog Input/Output
|_Aio_Write()                                    // Further initialization
|_EncoderC_initialize()                          // Initializes the encoder interface
|_Irq_RegisterTimerIrq()                         // Register the timer interrupt
|_pthread_create()                               // Create a new thread for the interrupt
|       |_Timer_Irq_Thread()    (argument)       // Interrupt service function
|_pthead_create()                                // Register the update thread
|       |_Table_Update_Thread() (argument)       // IRQ that updates the control table
|_ctable()                                       // Displays the control Table on the LCD
|_openmatfile()                                  // Creates a .mat file to output data to
|_matfile_addstring()                            // Adds a string to the .mat file
|_matfile_addmatrix() x7                         // Creates a data matrix in the .mat file
|_matfile_close()                                // Finishes creating the .mat file
|_pthread_join()                                 // Terminates the timer IRQ
|_pthread_join()                                 // Terminates the update IRQ
|_Irq_UnregisterDiIrq()                          // Unregister the timer IRQ
|_printf_lcd()                                   // Confirmation message on LCD
|_MyRio_Close()                                  // Closes the session with the MyRio

Timer_Irq_Thread()                               // Timer interrupt service function
|_while()                                        // Interrupt until thread stopped by main
|       |_Irq_Wait()                             // wait for IRQ to assert or time out
|       |_NiFpga_WriteU32()                      // Scheduling next interrupt
|       |_NiFpga_WriteBool()                     // More timer interrupt parameter setting
```

```
|          |_if()                                    // if the IRQ is asserted
|                   |_vel()                          // calculates the BDI
|                   |_cascade()                      // call cascade and process input/output
|                   |_Aio_Write()                    // transmit y0 to analog output
|                   |_Irq_Acknowledge()              // Interrupt acknowledged to the scheduler
|_pthread_exit()                                     // Terminate the new thread

Table_Update_Thread()                                // Update interrupt service function
|_while()
|          |_nanosleep()                             // sleeps for a designated # of nanosec
|          |_update()                                // updates the control table
|_pthread_exit()                                     // Terminate the thread

cascade()                                            // Uses a biquad cascade
|_for()                                              // difference eq to calculate y0

vel()                                                // Function calculates the BDI
|_Encoder_Counter()                                  // gets the current count from the encoder
```

Testing

The code was tested and debugged using the following system parameters:

Parameter	Value	Units
Vref	+- 200	rpm
BTI Length	5	ms
Kp	0.1	V-s/r
Ki	2.0	V/r

Table 1: Standard System Parameters Used

Additional tests and analysis are done in the results section below.

Results

The responses to the posed question (2-9) can be found below and represent the bulk of the testing performed on the DC motor/Controller system. Initial tests performed with the values seen in Table 1 occurred without incident and the data collected from that test were used for the response to question 9 below.

2. Measure the steady-state speed of the motor with the tachometer. Compare this value to the reference speed that you specified in the table. How close is it?

Vref (rpm)	200
Vact (rpm)	198-204
Vtac (rpm)	198.6
Error (%)	0.7

Table 2: Steady-State Velocity Values and Error

The steady-state value for the motor speed was very close to the reference value and was found to be within 0.7% of the value read by the tachometer and approximately 1-2% from the Vactual values reported by the encoder.

3. While the motor is at steady-state speed, gently apply a steady load torque to the motor shaft. What are the responses of the actual speed and control voltage? Explain.

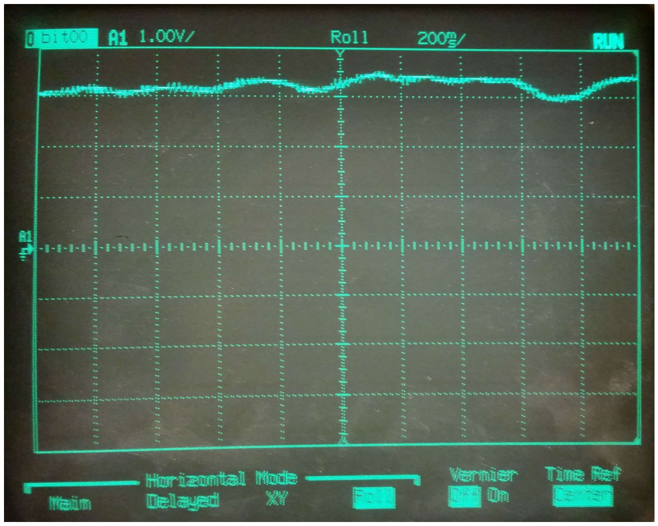

Figure 2: Problem 3, Voltage Response to Applied Torque

The controller output a higher voltage as seen in Figure 2 in order to drive a larger current from the amplifier and therefore create a larger torque on the motor to counteract the external torque. The speed initially slowed, but then began to rise as the motor controller adjusted the output voltage. Eventually the steady-state voltage returned to the desired level. Care was taken to ensure the external torque was constant and not adjusted to maintain a certain motor speed.

4. Beginning with the base set of parameters, explore the effect of varying the Proportional Gain Kp on the transient response. Try small (0.05) and large (0.2) values of Kp. What are the effects on the oscillation frequency and on the damping? Explain in terms of the transfer function parameters.

Kp	**Effect on Oscillation Frequency and Damping**
0.1	--
0.05	Lower damping, reached steady-state faster
0.2	Higher damping, reached stead-state almost immediately. Some overshoot
0.4	Higher damping, almost no overshoot seen in response

Table 3: Varying Kp

The above observations make sense given the equation for zeta. The gain value Kp scales the overall damping in the system response so larger values of Kp will lead to larger damping values and the commensurate system response. Overshoot and settling time also depend heavily on the damping factor and it would be expected to see very little overshoot and a faster settling time when the damping factor is high.

$$\zeta = \frac{K_p}{2}\sqrt{\frac{K}{JK_i}}$$

$$\omega_n = \sqrt{\frac{K_i K}{J}}$$

$$T_s = \frac{4}{\zeta \omega_n}$$

5. Beginning with the base set of parameters, explore the effect of varying the Integral Gain on the transient responses. Try small (1) and large (10) values of Ki . What are the effects on the oscillation frequency and on the damping? Explain in terms of the transfer function parameters.

Ki	Effect on Transient Response
2	--
1	Some overshoot, faster settling time
10	More overshoot, longer settling time
15	Much longer settling time

Table 4: Varying Ki

Changing Ki should not affect the settling time based on the equations for ζ and ω_n since when they are multiplied together $\zeta\omega_n$ becomes Kp*K/2*J; Ki cancels out. The equation above for the settling time is an approximation however and might not accurately represent the real system response seen. Taking the equations for ζ and ω_n separately we see that increasing Ki will decrease ζ and increase ω_n. A lower damping ratio leads to a larger overshoot and a larger natural frequency results in faster oscillations; both of these results were seen in the oscilloscope response as Ki was increased from 2 to 15.

6. Beginning with the base set of parameters, try setting the Integral Gain to zero. Does the system still act to overcome an error in speed if you apply a steady load torque? Again, measure the steady-state speed of the motor and compare to the reference speed.

No, the system did not attempt to overcome the external load torque. The motor kept running at whatever speed the torque reduced the speed to. No increase in voltage was seen on the oscilloscope.

Vref (rpm)	200
Vtac (rpm)	74
Error (%)	63%

Table 5: Vref with zero Ki

7. Beginning with the base set of parameters, try setting the Proportional Gain (only) to zero. Vary the Integral Gain. What is the nature of the transient response?

Kp	Ki	Transient Response
0	1	The system response (when starting from 0 and 200rpm Vref) was a constant amplitude sinusoid. When starting from a non-zero Vref, the amplitude grew until it reached saturation.
0	10	The system response amplitude quickly grew to saturation and oscillated with a higher frequency than the previous test with Ki=1.

Table 6: Effect on Transient Response by Varying Ki with Kp Set to Zero

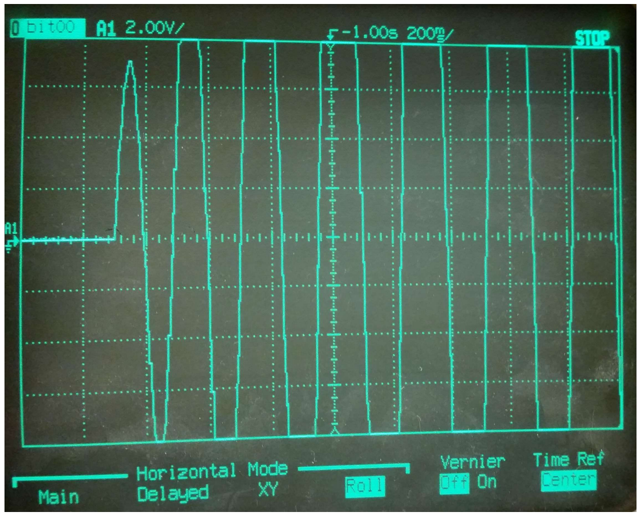

Figure 3: Voltage Response with Saturation with Ki=10

8. Beginning with the base set of parameters, explore the effect of varying the length of a BTI, on the transient and steady-state responses. ...on the speed of response? ...on the damping? ...on the velocity resolution?

BTI	Transient	Steady-State	Misc
4	Same as 5	Same	Less accurate Vact (195-202)
10	Similar to 5	Same	More accurate Vac (198-201)
20	Longer Tsettle	Same	Vact more accurate
30	Longer Tsettle	Same	Vact changes in 2rpm increments

Table 7: Effect on System Response by Varying BTI

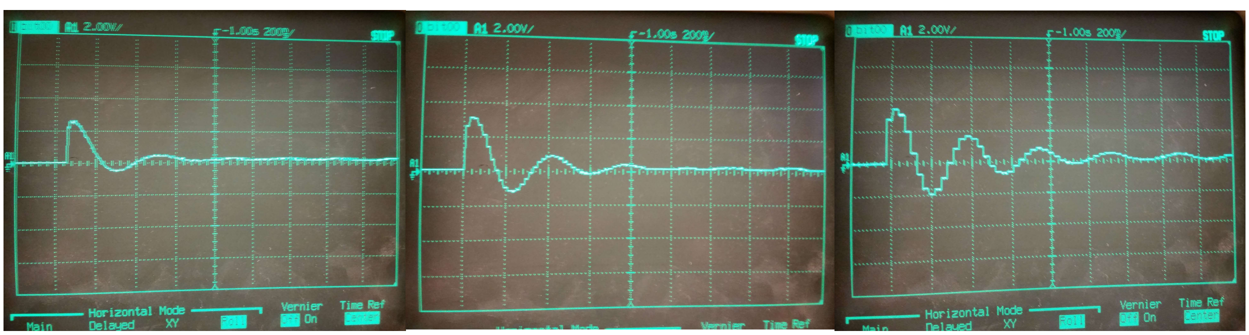

Figure 4: (Left to Right) 5, 20, and 30 BTI Voltage Response

Increasing the BTI changed the transient response and the shape of the voltage response curve as seen in Figure 4 above. The settling time and overshoot increased and the voltage response curve became more discretized. The resolution for the velocity improved, however, and the changes in the motor speed reduced from 6rpm increments to 2rpm increments around a BTI of 30. The steady-state response was roughly the same for each of these tests.

9. Finally, using the base set of parameters, record the control torque and actual velocity responses for a step change in the reference velocity that starts from −200 rpm and goes to +200 rpm. In

MATLAB, compare these experimental responses with the analytical responses for the continuous system approximation. What do you conclude?

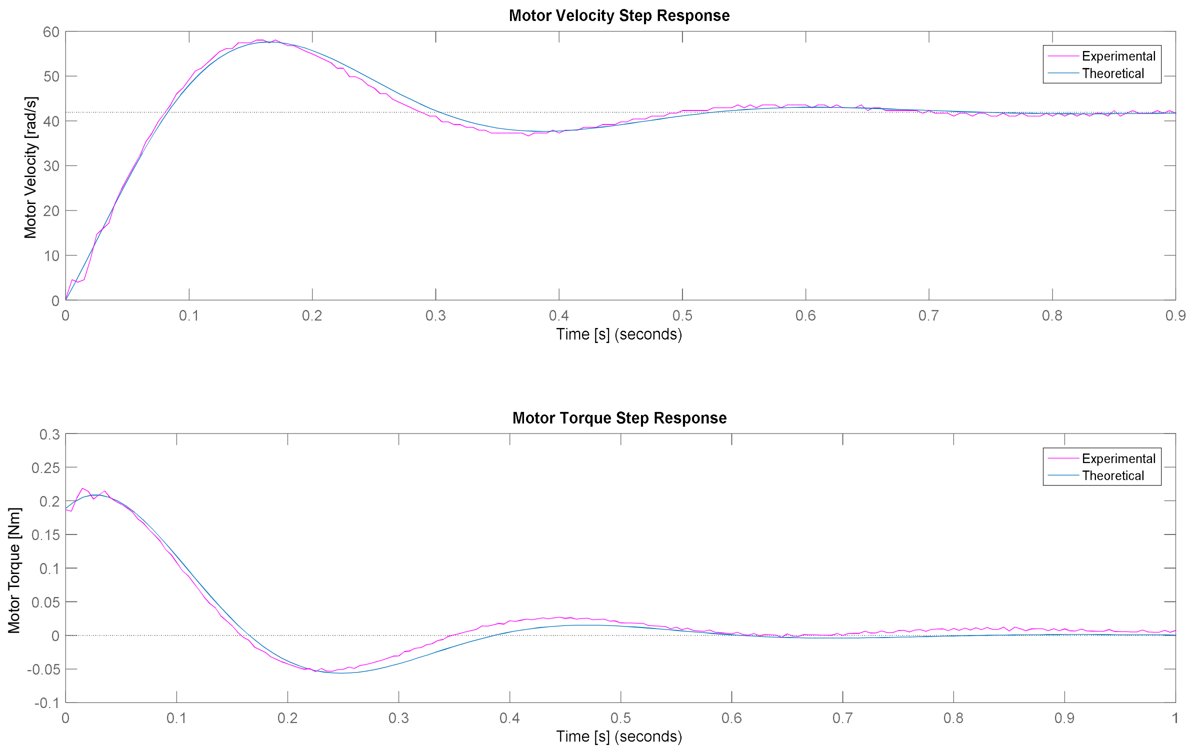

Figure 5: Experimental and Theoretical Motor Velocity and Torque Response

The experimental and theoretical responses were analyzed in MATLAB using the code attached to this report. The experimental data was shifted upward by 200 rpm and then converted into radians per second for comparison against the step response for the motor velocity and the torque. The theoretical step responses were amplified by the appropriate magnitude (400 rpm * 2pi / 60). Figure 5 shows that the experimental response closely matches the theoretical response. This suggests that the theoretical model and the system parameters used represent the experimental system well and could be used for theoretical tests.

MATLAB Code:

```
%Nathan Isaman
%ME477 - Lab 8
clear all; close all; clc

load('Lab8_NPI_3.mat');

BTIreal=BTI/1000;   %seconds
timevec=0:BTIreal:(length(V_act)-1)*BTIreal;

%System Parameters
Kvi=0.41;
Kt=0.11;
Kir=Ki;
Kpr=Kp;
J=3.8*10^-4;
Kd=1/(Kir*Kvi*Kt);
Ku=J/(Kvi*Kt);
tau=Kpr/Kir;
zeta=(0.5*Kpr)*sqrt((Kvi*Kt)/(J*Kir));
Wn=sqrt((Kir*Kvi*Kt)/J);

%Transfer Functions
T1=tf([tau,1],[(1/Wn^2), (2*zeta/Wn),1]);
T2=tf([Kd],[(1/Wn^2), (2*zeta/Wn),1]);
T3=tf([tau*Ku,Ku,0],[(1/Wn^2), (2*zeta/Wn),1]);

%Plots
subplot(2,1,1)
plot(timevec,(V_act+200)*(pi/30),'m-'), hold on
step(400*(pi/30)*T1)
xlabel('Time [s]')
ylabel('Motor Velocity [rad/s]')
title('Motor Velocity Step Response')
legend('Experimental','Theoretical','Location','NE')

subplot(2,1,2)
plot(timevec,Torque/1000,'m-'), hold on    %I goofed and got mV not V
step((400*(pi/30))*T3*Kvi*Kt)
xlabel('Time [s]')
ylabel('Motor Torque [Nm]')
title('Motor Torque Step Response')
legend('Experimental','Theoretical','Location','NE')
```