**Khalifa University of Science and Technology (KUST)**
**Electrical Engineering Department**
**ELEN 323 – Feedback Lab**
**Fall 2024**

# *Design of Experiment*

| Name | ID number | Signature |
|---|---|---|
| Shayma Alteneiji | 100063072 | Shayma |
| Raneem Abdulla | 100061447 | Raneem |

**The KU Honor Pledge:**

*"We pledge that we have neither given nor received any unauthorized assistance on this laboratory report assignment"*

## *Objective*

- To design a lead compensator to control the speed of DC motor so as to satisfy given steady state and frequency domain characteristics.

# *Pre- Lab*

## ***Design of Lead Compensator for speed control of DC motor***

Draw a control scheme for speed control of DC motor using lead compensator so as to satisfy the following steady state and frequency domain characteristics:

- Steady State error $e_{ss}$=0
- Phase margin >=$60^0$
- Gain Crossover frequency =10 rad/sec

***Solution:***

We use the Bode diagram of the open-loop transfer function of the uncompensated system to design the phase- lead compensator. Given that the steady state error is zero, the open- loop transfer function then becomes that of the motor cascaded by an integrator. Figure 1 shows the Bode diagram of the OP T.F. The MATLAB code used to plot is shown below. The cursor is traced to the required crossover frequency ($\omega_{cn}$) on the magnitude and the phase response. The steps in designing the phase – lead compensator are listed below.

1) Calculate the compensator's gain Kc, using the equation given.

$$K_c = 10^{\frac{A_{dB}(\omega_{cn})}{-20}} = 10^{\frac{9.78}{20}} = 3.0832$$

1) Calculating the phase – compensator parameters ($\alpha$, and $\tau$):

$$\alpha = \frac{\phi_m - \phi_s(\omega_{cn}) - 180°}{90°} = \frac{60° - (-121°) - 180°}{90°} = \mathbf{0.0111}$$

$$\tau = \tan\left(\frac{\alpha\pi}{2}\right) + sec\left(\frac{\alpha\pi}{2}\right) = \mathbf{1.0176}$$

2) The transfer function of the phase – lead transfer function:

$$G_c(s) = 3.0832\frac{\left(\frac{1.0176s}{10} + 1\right)}{\left(\frac{s}{10} + 1.0176\right)}$$

The final control system design is shown in Figure 2.

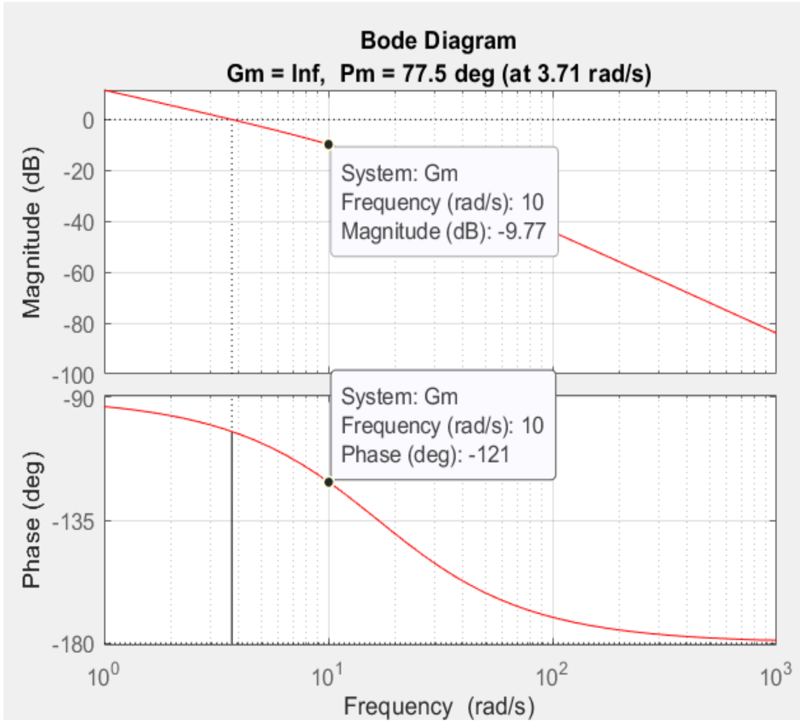


*Figure 1. The Bode diagram of open loop T.F. of the uncontrolled DC motor system.*

**MATLAB code** used to plot the Bode diagram uncompensated system

```
clear all; clc
Kall = 3.8; Tm = 0.06; %DC Motor T.F. parameters
Gm = Kall*tf([1],[Tm 1 0]);
margin(Gm, 'r')
grid on
```

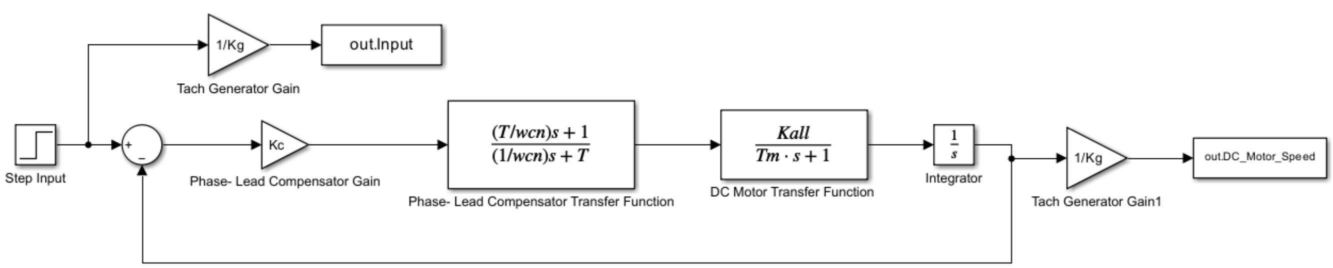


*Figure 2. Block diagram of a Lead Controlled system for speed control of DC motor in Simulink*

Use sisotool in MATLAB to design a lead compensator to satisfy the given steady state and frequency domain characteristics.

***Solution:***

The sisotool was used to obtain the T.F. of the phase – lead compensator. Figure 3 shows the parameters of the obtained phase – lead compensator. Figure 2 shows the results of the sisotool, showing the Bode diagram of the compensated system, step response the root locus. The phase margin at the given crossover frequency requirement is satisfied. The sisotool results in the T.F. obtained theoretically using El- Khazali method.

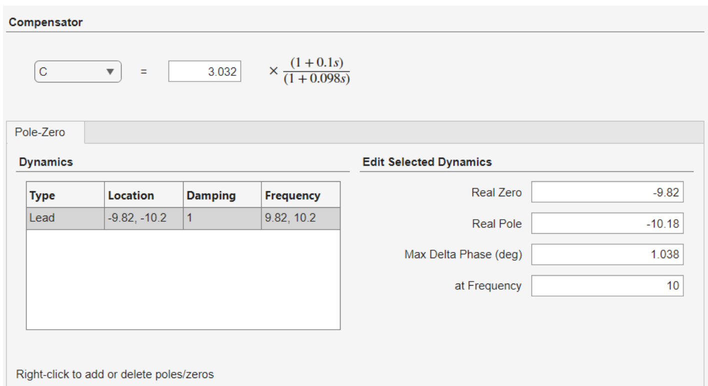


*Figure 3. sistool dialog page of the lead-compensator design*

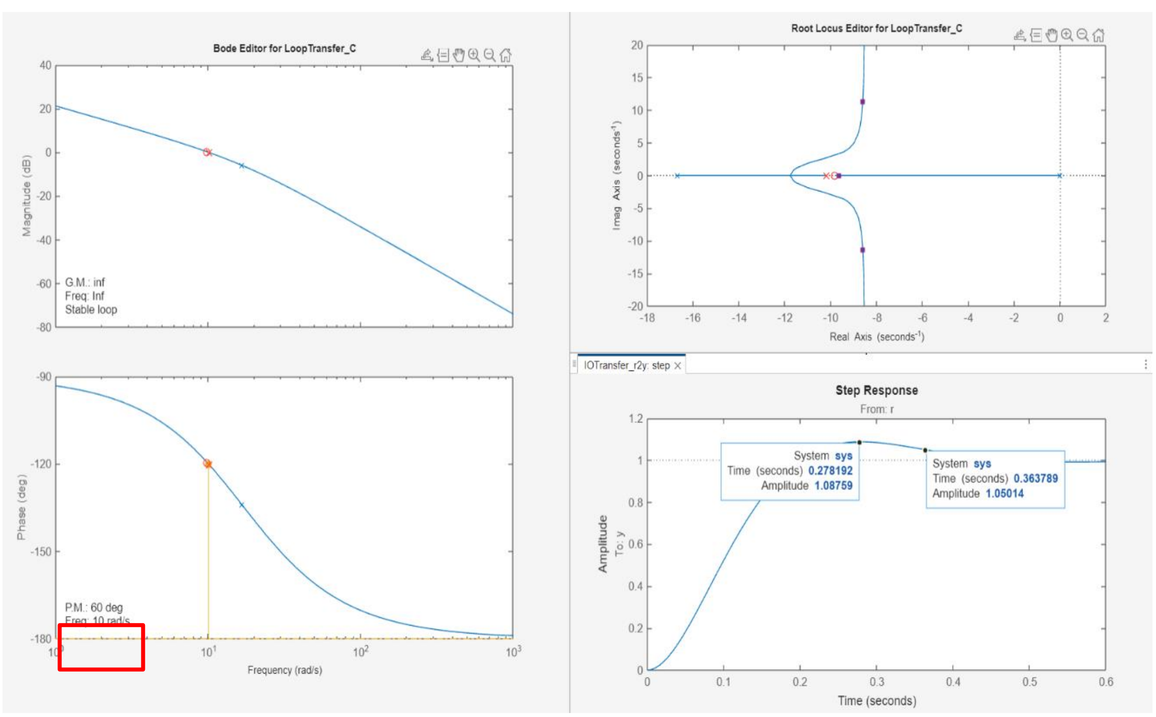


*Figure 4. sistool page showing the plots of the lead-compensator Bode diagram, step response and the root locus.*

Obtain the bode plot of the compensated system and verify whether the given criteria is satisfied or not.

***Solution:***

Figure 5 shows the Bode diagram of the compensated system, the phase margin and the crossover frequency are satisfied. The MATLAB code used to plot the Bode diagram is given below.

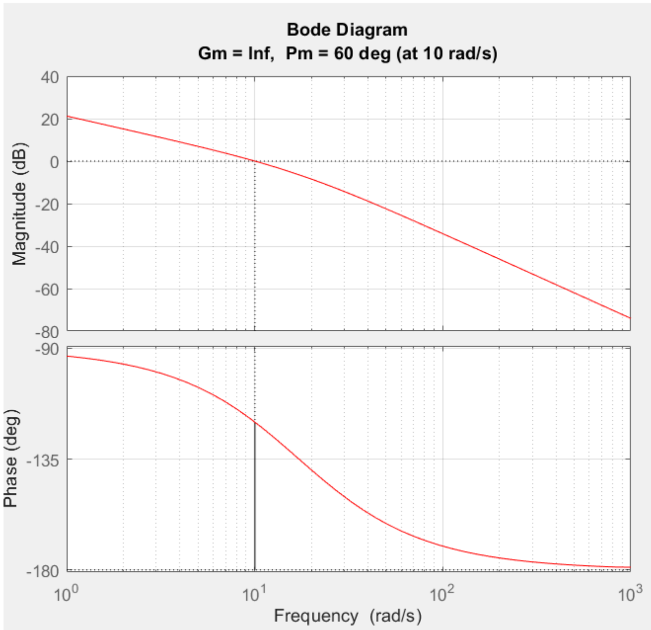


*Figure 5. The Bode diagram of open loop T.F. of the compensated DC motor system.*

**MATLAB code** used to plot the Bode diagram compensated system

```
clear all; clc
Kall = 3.8; Tm = 0.06; %DC Motor T.F. parameters
T = 1.0176; wcn = 10;Kc = 3.0832;   %Phase compensator parameters
Gm = Kall*tf(1,[Tm 1 0]);
Gc = (10^(9.77/20))*tf([T/wcn 1],[1/wcn T]);
margin(Gc*Gm, 'r')
grid on
```

Simulate the designed controller as shown in Figure 2 in Simulink for a step response and obtain the percent overshoot and settling time.

***Solution:***

The resulting step response is shown in figure 6. The recorded percent overshoot is $\frac{1631.96-1500}{1500} \times 100 = \mathbf{8.797\%}$**,** and the settling time is **0.615** seconds.

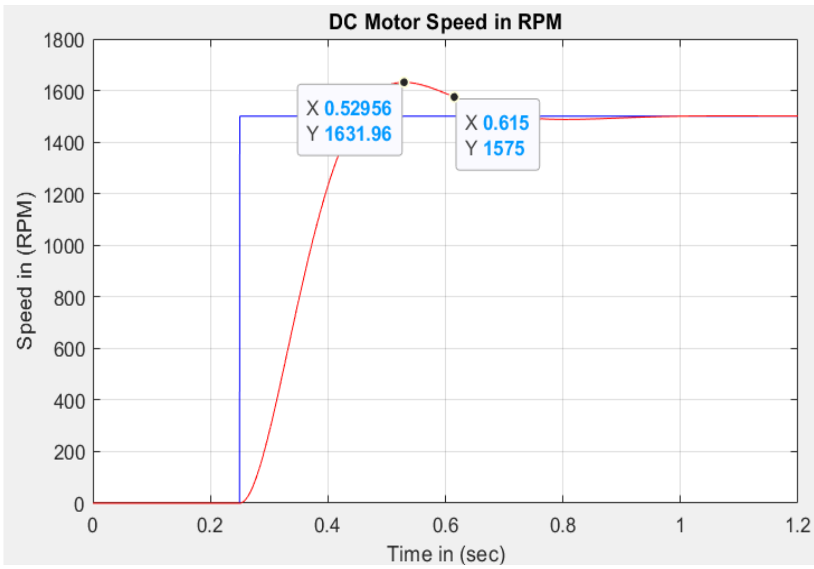

*Figure 6. Step response of the compensated DC motor system.*

**MATLAB code** used to simulate the step response

```
T  = 1.0176;Tm = 0.06; wcn = 10; Kc = 3.0832;
Kall = 3.8;Vref = 4.201;Kg = 28e-4;
out = sim('feed_project_sim',1.2)
plot(out.tout,out.Input, 'b',out.tout,out.DC_Motor_Speed ,'r')
grid on
title("DC Motor Speed in RPM")
ylabel('Speed in (RPM)')
xlabel("Time in (sec)")
xlim([0 1.2])
```

# *Introduction/Theoretical Background:*

DC motors are widely used in industrial, automotive, and robotics applications due to their simplicity, reliability, and ease of control. The speed control of a DC motor is important in these systems, and it usually uses a closed-loop feedback mechanism to meet the requirements.

The goal of this experiment is to design a lead compensator for speed control of a DC motor to achieve the desired steady state and frequency characteristics. The lead compensator improves system stability and transient performance by increasing the phase margin and shifting the gain crossover frequency to a specified value. Also, the addition of the integrator ensures zero steady state error for step inputs.

The compensator needs to meet the following requirements: (1) Steady State error ess=0, (2) Phase margin >=600, and (3) Gain Crossover frequency =10 rad/sec.

## *Equipment required:*

The equipment required for the design experiment are listed below:

- USB Data Acquisition board Quanser Q2-USB.
- MATLAB/Simulink.
- Quanser-Quarc.
- Real Time windows Target  library in MATLAB.
- Microsoft Visual Studio 2010.
- Power Supply: PS150E.
- Attenuator Unit: AU150B.
- Servo Amplifier: SA150D.
- DC Servo Motor: DC150F.
- Reduction Gear Tacho Unit: GT150X.

## *Circuit diagram:*

Figure 7 shows the circuit diagram of the real time implementation of the control system for speed control of DC motor.

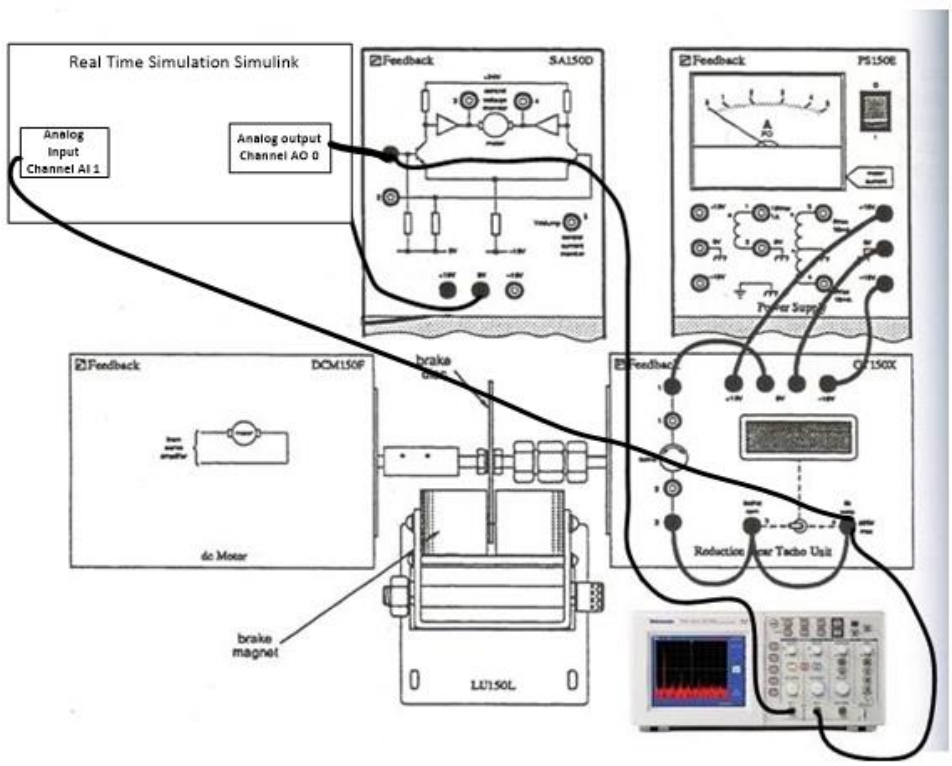


*Figure 7. Circuit connection for lead speed controller for Real Time implementation*

## *Procedure:*

This section lists the procedures followed in this design experiment.

1. Connect the circuit as shown in figure 8.

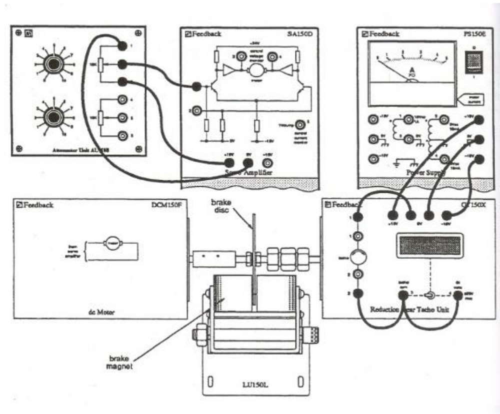

*Figure 8. Open Loop Speed Control of DC Servo Motor*

2. Set the brake to unloaded position.
3. Adjust the DC motor input voltage such that the speed of the DC motor is 1500 rpm.
4. Toggle the switch on reduction gear tacho unit (GT150X) to read tacho voltage. Record this voltage as reference voltage Vref.

   Vref = **4.29 V, 1520 rpm**

5. Use a voltmeter to adjust the voltage between 0V and slider of potentiometer 1 (terminal 2 on AU150B) to be equal to Vref as found in step 4.
6. Connect the circuit as shown in figure 7.
7. Build the Simulink block diagram shown in figure 9. (Follow the steps given in lab 5 to use the Quarc target library).
8. Set the stop time of simulation to 0.7 sec and use fixed step ode solver with a step size of 0.001.
9. Use analog output channel 'AO 0' and set its sampling time as 0.001 to feed the controller output to DC motor servo amplifier.
10. Use analog input channel 'AI 1' and set its sampling time as 0.001 to acquire the feedback signal in Simulink from tacho-generator.
11. Connect the real time simulation to target and run the simulation.
12. Use MATLAB to plot the system response, and find the maximum overshoot and settling time to verify whether the designed criteria are met or not.

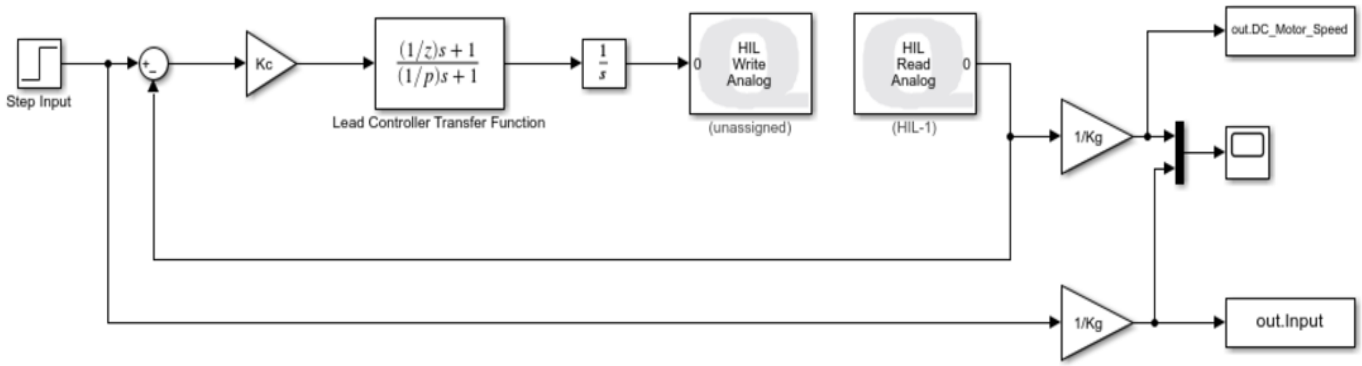


*Figure 9. Block diagram of the lead speed controller system for Real Time implementation*

**MATLAB** code used to obtain the step response

```
z = 9.82; p = 10.18; Kc = 3.0939;
Vref = 4.201;Kg = 28e-4;
plot(out.tout,out.Input, 'b',out.tout,out.DC_Motor_Speed ,'r')
grid on
title("DC Motor Speed in RPM")
ylabel('Speed (rpm)')
xlabel("Time (sec)")
xlim([0 2])
```

# *Results*

Figure 10 shows the step response obtained experimentally. The recorded OS% is $\frac{1651.49-1500}{1500} \times 100 = 10.10\%$, The recorded settling time is 0.684 seconds. The percentage of error between the simulation and experimental results are calculated below.

$$\%\, Percentage\ of\ errer = \frac{|Theoratical - Experimental\,|}{Theoratical} \times 100$$

**Ts:** $\%\, Percentage\ of\ errer = \frac{|0.615\ -0.684\,|}{0.615} \times 100 = \mathbf{11.22}\%$

**%OS:** $\%\, Percentage\ of\ errer = \frac{|8.797-10.10\,|}{8.797} \times 100 = \mathbf{14.81}\%$

The percentage of error is moderately high, one reason could be due to the simplification and assumptions made when obtaining the transfer function of the motor. Moreover, losses and nonidealities of real components would also introduce errors and deviation from the ideal simulation results.

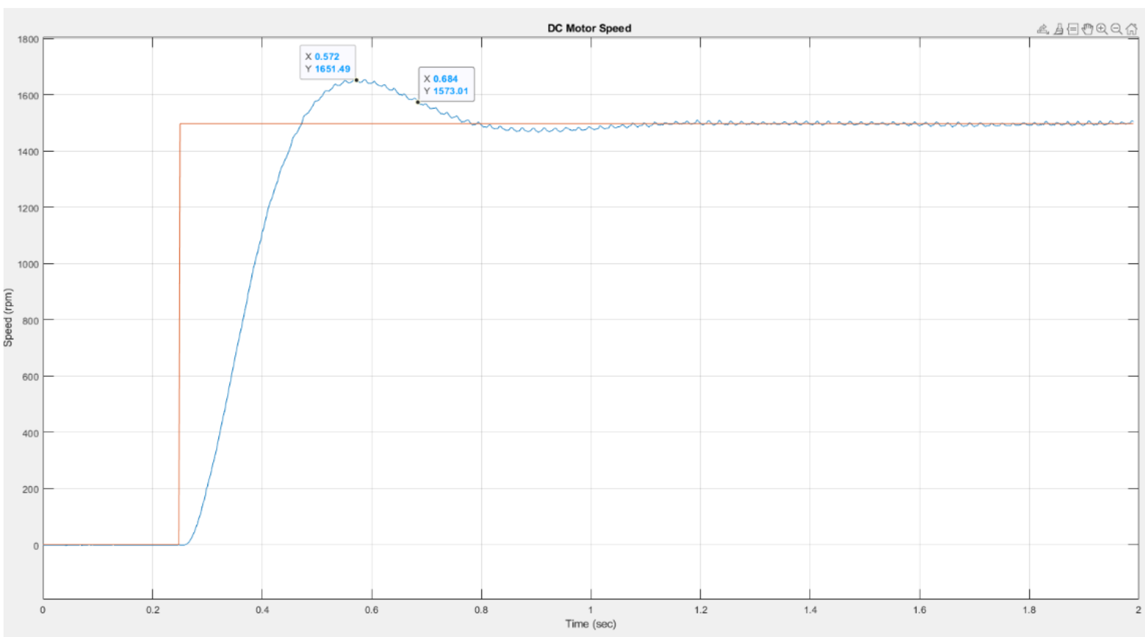


*Figure 10. Step response of the compensated DC motor system obtained from the experimental implementation.*

## *Post Lab Discussion:*

1. **What is the role of a lead compensator in a control system?**

   A lead controller improves the transient response and the stability of the system. It increases the phase margin by shifting the gain crossover frequency to the desired value.

2. **How does the choice of zero and pole locations in a lead compensator affect the system's frequency response?**

   Zero location: if the zero is closer to the origin the phase lead is increased at lower frequencies.

   Pole location: if the pole is further from the origin, the phase lead decreases at higher frequencies.

3. **Why is it important to verify both the frequency domain and time domain characteristics of the compensated system?**

   Bode plots provide insight into the stability of the system. (gain margin, phase margin, and gain crossover frequency)

   Step response evaluates the system's transient performance. (rise time, settling time, overshoot)

4. **Why is the gain crossover frequency chosen as 10 rad/sec?**

   The gain crossover frequency is chosen at a value that balances between fast response and stability. The higher the crossover frequency the faster the response, but this can reduce the phase margin. Meanwhile, a lower crossover frequency increases stability but will have a slow response.

5. **What are the performance metrics in the step response of the compensated system?**

   Percent Overshoot: indicates how much the system exceeds the desired steady state value during transients.

   Settling Time: the time it takes for the system to settle within a range of the steady state value.