EEE 342 Feedback and Control Systems Lab 2

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1. Introduction

The main purpose of this lab was to perform system identification studies on a physical DC motor in frequency domain [1]. This system identification was achieved by applying sinusoidal signals to a nonlinear model of DC motor kit. Lab consists of 4 stage. In the first part, estimated first order approximation transfer function is drawn. In the second part, by using GUI screen, DC motor nonlinear complex model is acquired. In the third part, bode plot is obtained by applying sinusoidal inputs with different frequencies given in a table and results are compared with theoretical calculations. Additionally, certain outputs with their sinusoidal values are plotted in given frequencies. In the last part, first order Pade approximation is done for 10ms time delay, which is generated due to the processing requirements of hardware system. Then, three different bode plots acquired in part 1, 3 and 4 are drawn to the same plot.

2. Laboratory Content

Question 1

In this part, the bode plot of estimated transfer function acquired in lab 1 is drawn. As a remainder, first order transfer function found in lab 1 was

$$G(s) = \frac{14.78}{0.191s + 1} \qquad (1)\ [2]$$

The code given in the lab manual was used to draw bode plot and K and tau variables were updated to 14.78 and 0.191 respectively. Bode plots are the following

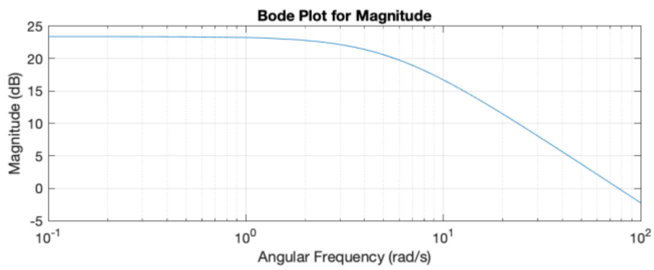

Figure 1: Bode Plot of G(jw) for Magnitude

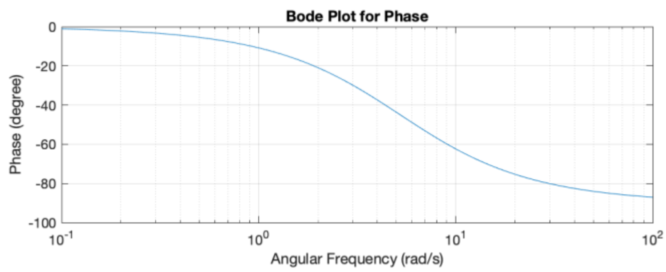

Figure 2: Bode plot of G(jw) for Phase

Question 2

In this part, 'prelab_App.mlapp' and 'prelab2_DCmotor.slx' files were downloaded from moodle [1]. By using the parameters of K and tau, which were mentioned in previous question, DC motor was built. GUI screen with step response of DC motor can be seen

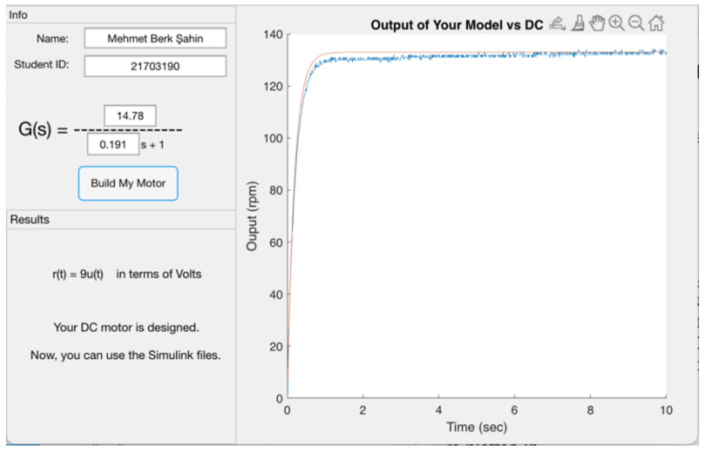

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Figure 3: GUI Screen with Step Response of DC Motor

Question 3

In this part, bode plot was obtained by applying sinusoidal inputs with various frequencies, and time domain and Fourier domain of inputs and outputs were plotted. To achieve these first, 'lab2_sinusoidal_input.slx' file was added to the main program's working directory. Then to change the angular frequency and simulation time through MATLAB code, variable names were written to necessary places in Simulink, which can be seen below

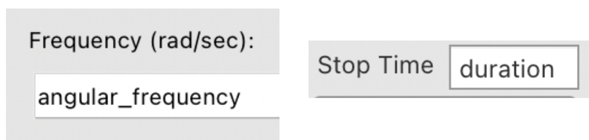

Figure 4: Updated Values in Simulink for MATLAB Code

In addition to these, step size was adjusted to fixed-step and to 0.01 to see better plots.

To transfer sinusoidal input values to MATLAB workspace, one more box was added to Simulink model in 'lab2_sinusoidal_input.slx' file. It is as follows

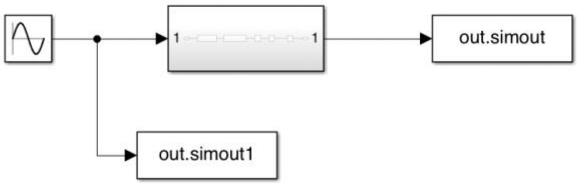

Figure 5: Model for Applying Sinusoidal Input to Transfer Function

10 sinusoidal inputs with different angular frequencies were applied, the table for the frequencies and their corresponding simulation times can be seen below

Angular Frequency (w – rad/s)	Simulation Time (sec)
0.1	180
0.3	120
0.7	120
1	60
3	60
7	30
10	10
30	10
70	5
100	5

Table 1: Angular Frequencies (rad/s) and Simulation Times (sec) [1]

After doing these, only thing that remained is finding magnitude and phase of the output signal.

If a sinusoidal input such as $A_m \cos(wt)$ enters a linear and time-invariant system, output will also be a sinusoidal such as $B_m \cos(wt + \emptyset)$. In Fourier domain, we get two crucial equations from this input-output relation. First one is

$$B_m = |G(j\omega)|A_m \qquad (2)\ [3]$$

and the other one is

$$\emptyset_{output} = \angle G(j\omega) + \emptyset_{input} \qquad (3)\ [3]$$

From these relations, bode plot for magnitude and phase can be drawn by applying sinusoidal inputs. MATLAB code for these formulas can be seen in the m-file of lab 2; codes are not provided in this paper.

Check-3.1 & -3.2

After writing the code, chosen angular frequencies, which are 0.1, 3 and 100, are plotted to MATLAB. Time domain and Fourier domain of sinusoidal inputs and outputs for the given frequencies are the following

For $\omega = 0.1\ rad/s$

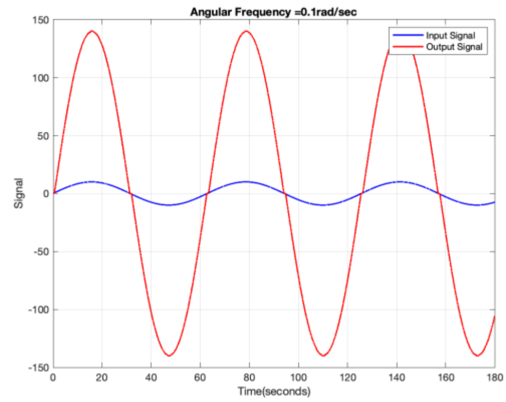

Figure 6: Output-Input Signal vs. Time (for 0.1 rad/s)

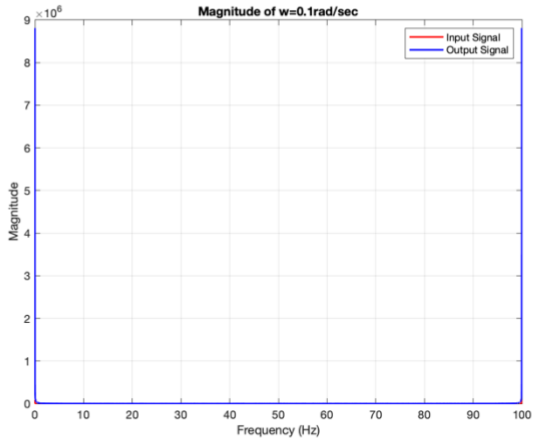

Figure 7: Output-Input Signal vs. Frequency (for 0.1 rad/s)

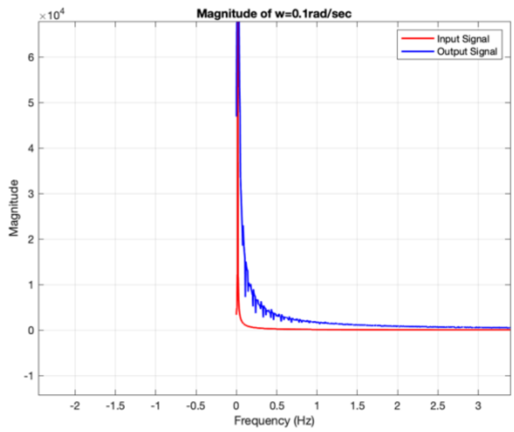

Figure 8: Output-Input Signal vs. Frequency (for 0.1 rad/s and zoomed to left side)

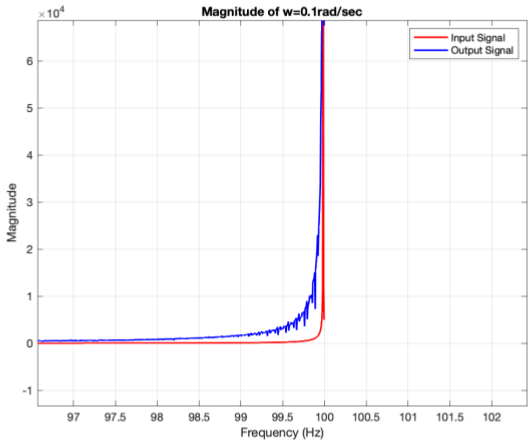

Figure 9: Output-Input Signal vs. Frequency (for 0.1 rad/s and zoomed to right side)

For ω = $3\ rad/s$

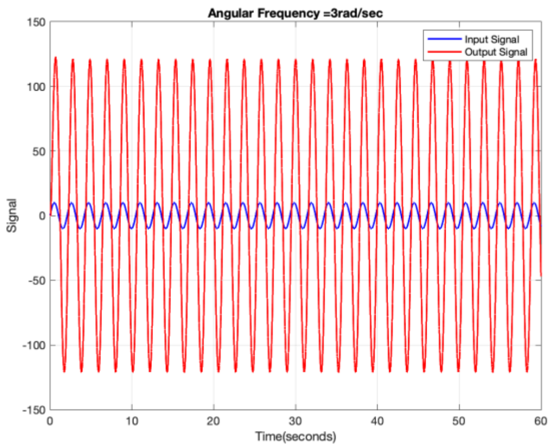

Figure 10: Output-Input Signal vs. Time (for 3 rad/s)

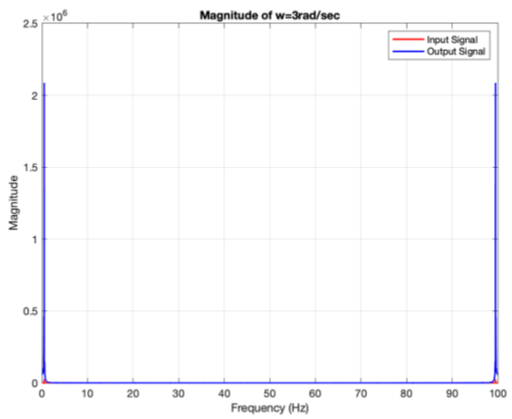

Figure 11: Output-Input Signal vs. Frequency (for 3 rad/s)

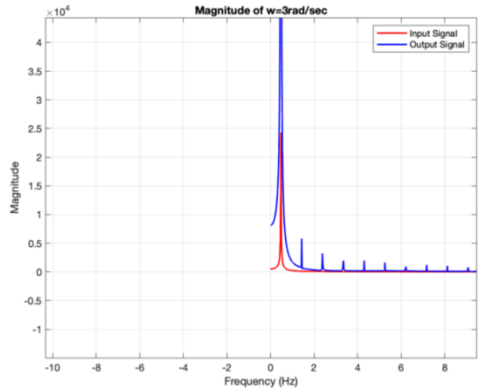

Figure 12: Output-Input Signal vs. Frequency (for 3 rad/s and zoomed to left side)

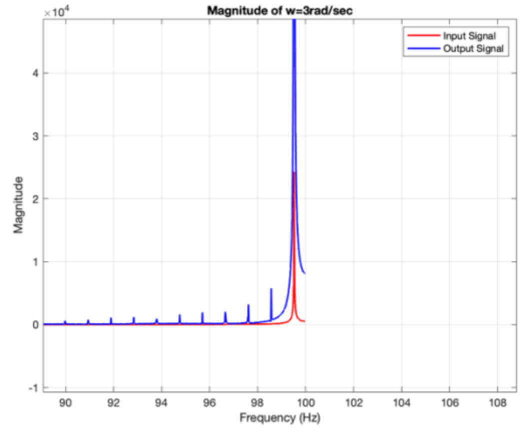

Figure 13: Output-Input Signal vs. Frequency (for 3 rad/s and zoomed to right side)

For ω = $100\ rad/s$

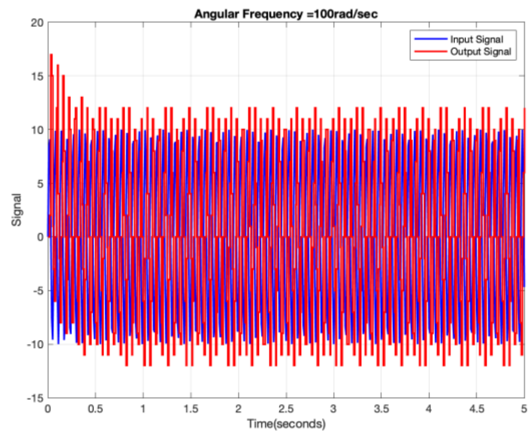

Figure 14: Output-Input Signal vs. Time (for 100 rad/s)

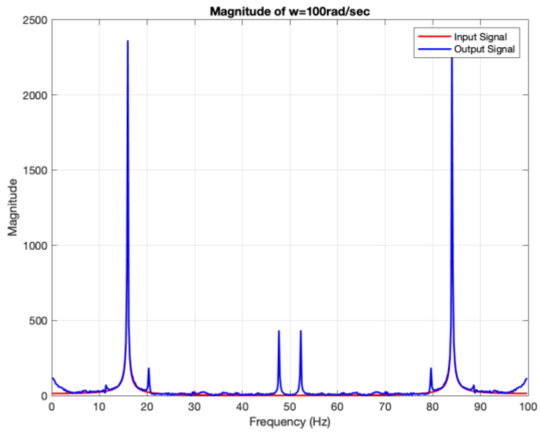

Figure 15: Output-Input Signal vs. Frequency (for 100 rad/s)

As it can be seen in Fourier Transform plots input and output frequencies are equal, which is expected due to the sinusoidal input, so plots are correct.

Check-3.3

In this part, bode plot acquired from question 1 is plotted with 10 sample points which were obtained from Table 1. These sample points consist of 10 different frequency value. Plot can be seen below

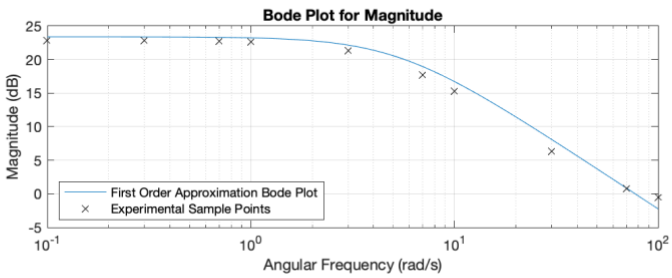

Figure 16: Bode Plot For Magnitude with Comparison of 10 Sample Points and Bode Plot in Q1

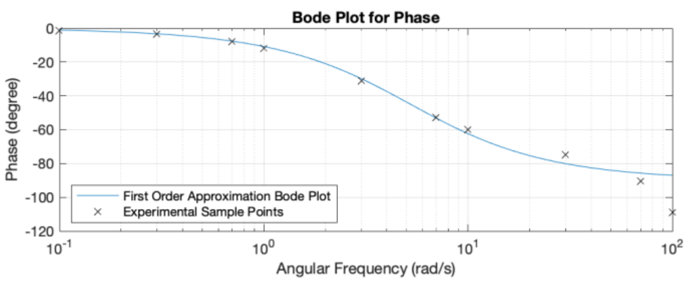

Figure 17: Bode Plot For Phase with Comparison of 10 Sample Points and Bode Plot in Q1

As it can be seen in Figure 16 and 17, transfer function approximation by applying sinusoidal inputs with different frequencies are pretty good. In fact, the transfer function acquired in question is almost constructed by applying sinusoidal inputs. However, note that there is an error at the last sample point on the phase plot. This error is large compared to other sample points, why does that happen? It happens due to the 10ms time delay which is generated due to the hardware system (simulation for this lab).

Question 4

Hardware system's 10ms time delay was generated due to the processing requirements and it produced phase difference in high frequencies [1]. The purpose of this part is to take this 10ms time delay into consideration and create estimated transfer function accordingly.

Step 1

To achieve the estimated transfer function, Pade approximation was used as given in lab manual [1] so old transfer function created in question 1 was updated as

$$G_{delayed}(s) = G(s)\frac{1 - 0.005s}{1 + 0.005s} \qquad (4)\ [1]$$

This was implemented in MATLAB code.

Step 2 & Check-4

For the comparison of Bode plots and sample points obtained in question 1, 3 and 4, following plots were created in MATLAB

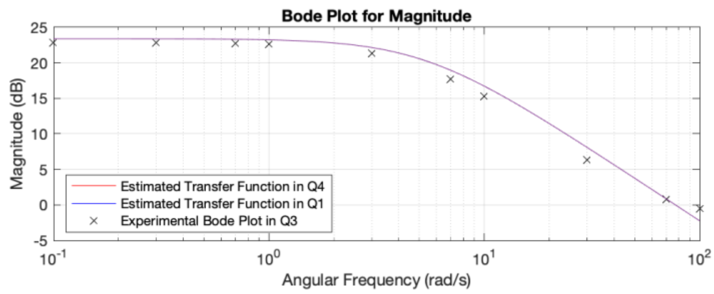

Figure 18: Comparison of Bode Plots Obtained in Q1, Q3 and Q4

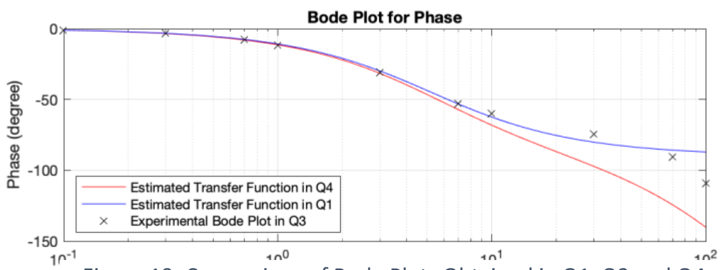

Figure 19: Comparison of Bode Plots Obtained in Q1, Q3 and Q4

As it can be seen in Figure 18, magnitude of estimated transfer functions obtained in question 1 and 4 are the same. This is expectable because the magnitude of Pade transfer function is 1. This can be seen below

$$G_{Parade}(s) = \frac{1 - 0.005s}{1 + 0.005s} \quad (5)$$

By putting $s = j\omega$, we get

$$G_{Parade}(j\omega) = \frac{1 - 0.005j\omega}{1 + 0.005j\omega} \quad (6)$$

Then, by taking the absolute value, we get

$$|G_{Parade}(j\omega)| = \sqrt{\frac{1 + (0.005\omega)^2}{1 + (0.005\omega)^2}} = 1 \quad (7)$$

Therefore, in terms of magnitudes, Pade approximation does not any make changes on the transfer function. However, it makes changes on phase of the estimated transfer function obtained in question 1. By considering the equation 4 and 6, following phase equation can be written

$$\angle H(j\omega) = \angle \mathrm{G}(j\omega) - 2tan^{-1}(0.005\omega) \quad (8)$$

MATLAB code is implemented according to this equation and plot is drawn. This relation changes the phase of the transfer function obtained in question 1. Note that for high frequencies, $tan^{-1}(0.005\omega)$ is large, but for low frequencies, it is very small and negligible. This is exactly what we want because 10ms time delay of hardware system creates phase difference in high frequencies but in low frequencies there is no problem. To estimate the phase difference in high frequencies, we simply put a variable which is $tan^{-1}(0.005\omega)$ and it decreases the phase of the transfer function as frequency becomes higher.

3. Conclusion

The purpose of this lab was to perform a system identification studies on DC motor simulation in frequency domain [1]. This system identification was achieved by applying various sinusoidal inputs to the approximated transfer function of nonlinear DC motor. To observe the characteristics of the transfer function, bode plots were used because they are the most comprehensive method for our purposes. Sinusoidal inputs were taken from Table 1 and three of them were plotted in MATLAB with corresponding outputs. Additionally, Fourier transform of the outputs and inputs were plotted. After plotting 10 sample points which are obtained by applying sinusoidal inputs, it was seen that there is an error at the high frequency last sample point. To take this error into consideration, Pade approximation was done to adjust the phase accordingly in high frequencies. In this lab, I have learnt how to identify a system by applying sinusoidal inputs with different frequencies and I have learnt how to do Pade approximation by using MATLAB and bode plots.

REFERENCES

[1] Bilkent University, “eee342_lab2_manual.pdf,” 8 April 2021. [Online]. Available: moodle.bilkent.edu.tr. [Accessed 8 April 2021].

[2] M. B. Şahin, “MehmetBerkŞahin_EEE342_LAB01Report,” 2021.

[3] Dorf, R. C., & Bishop, R. H. (2022). *Modern control systems*. Hoboken, NJ: Pearson Education.