Fundamentals of Control Systems

Elec 372

Lab Experiment #4

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Section UJ-X

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"I certify that this submission is my original work and meets the Faculty's Expectations of Originality."

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01/04/2024

1) Objectives

For the fourth experiment of the course Elec 372, students are tasked to investigate the transient and frequency response of control systems. For the transient response analysis, students aim to understand the behavior of open and closed loop systems under various conditions. For example, we will test with parameters such as rise time, peak time, overshoots and settling time. For the frequency response analysis, students will practice on observing response behavior under sinusoidal input signals of varying frequencies, observing changes in amplitude and phase. Overall, this experiment will provide practical insights to transient and frequency response.

2) Theory

Transient Response:

-Study the behavior of open-loop and closed-loop systems using performance criteria such as rise time, peak time, overshoot, and settling time.

-Investigate the effect of changing proportional gain factor (Kp) and introducing derivative feedback on system response.

-Analyze the impact of increasing Kp on the damping ratio (ζ) and natural frequency (ωn).

Frequency Response:

-Examine how systems respond to sinusoidal input signals of varying frequencies.

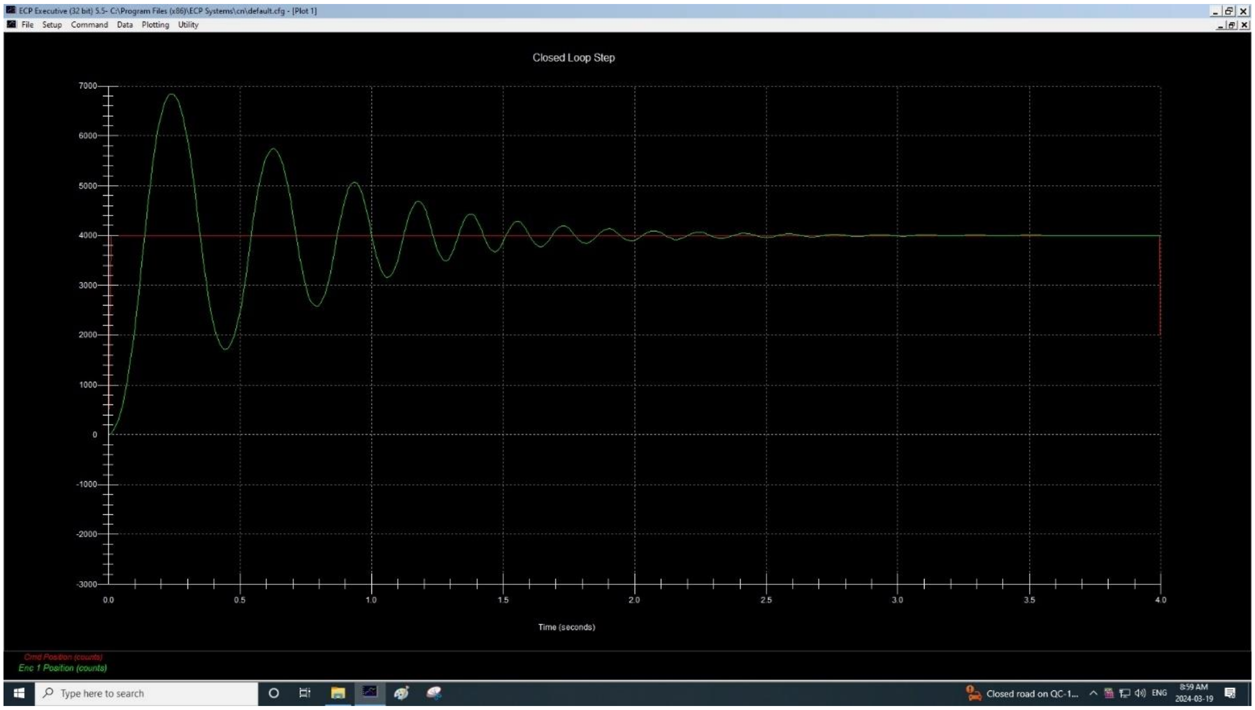
-Measure magnitude ratio and phase shift as functions of frequency.

-Use Bode plots and polar plots to visualize frequency response data.

-Conduct spot-frequency and sweep frequency measurements to assess system behavior across different frequency ranges.

3) Tasks / Results / Discussions

3.1 Closed-Loop Transient Response



Closed-Loop Step Response (K_p = 1)

Obtain* values for: the damped natural frequency πd and the overshoot (OS) and using a suitable axis scaling of the plot. (K_p = 1)

$$\omega_d = \frac{\pi}{T_p}$$

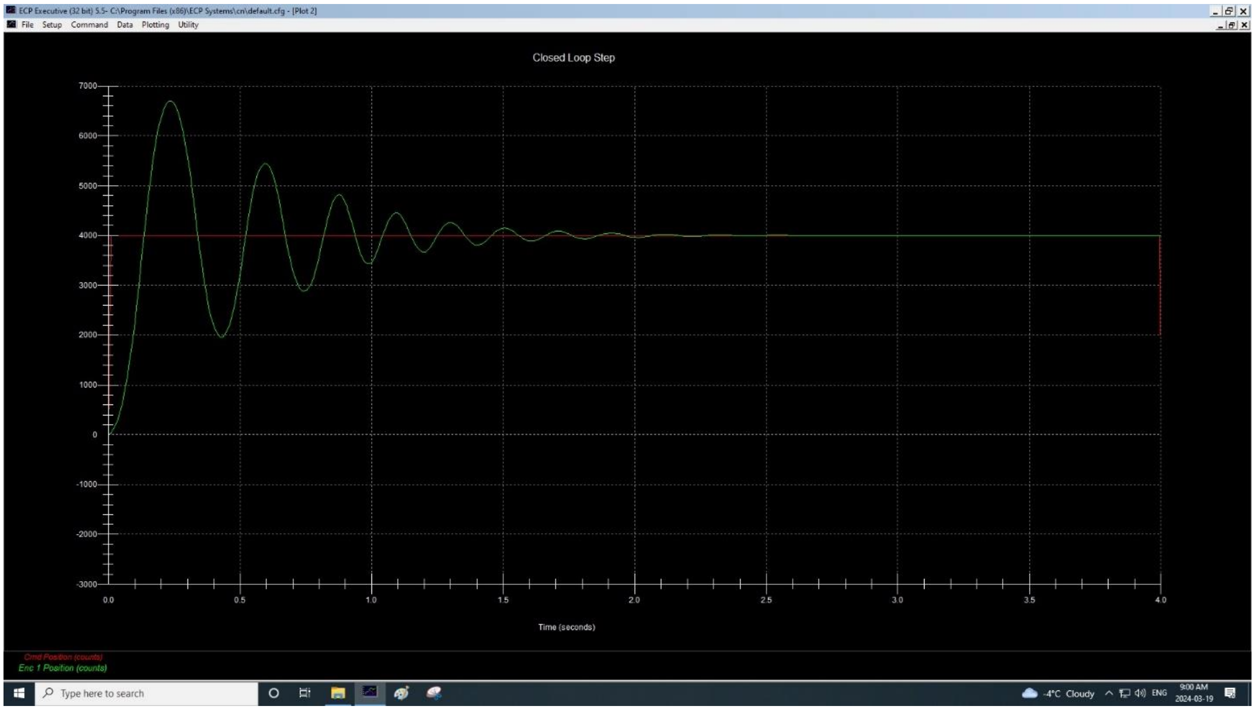
$$Peak\ Time\ is\ around\ 0.25sec$$

$$\omega_d = \frac{\pi}{T_p} = \frac{\pi}{0.25} = 4\pi$$

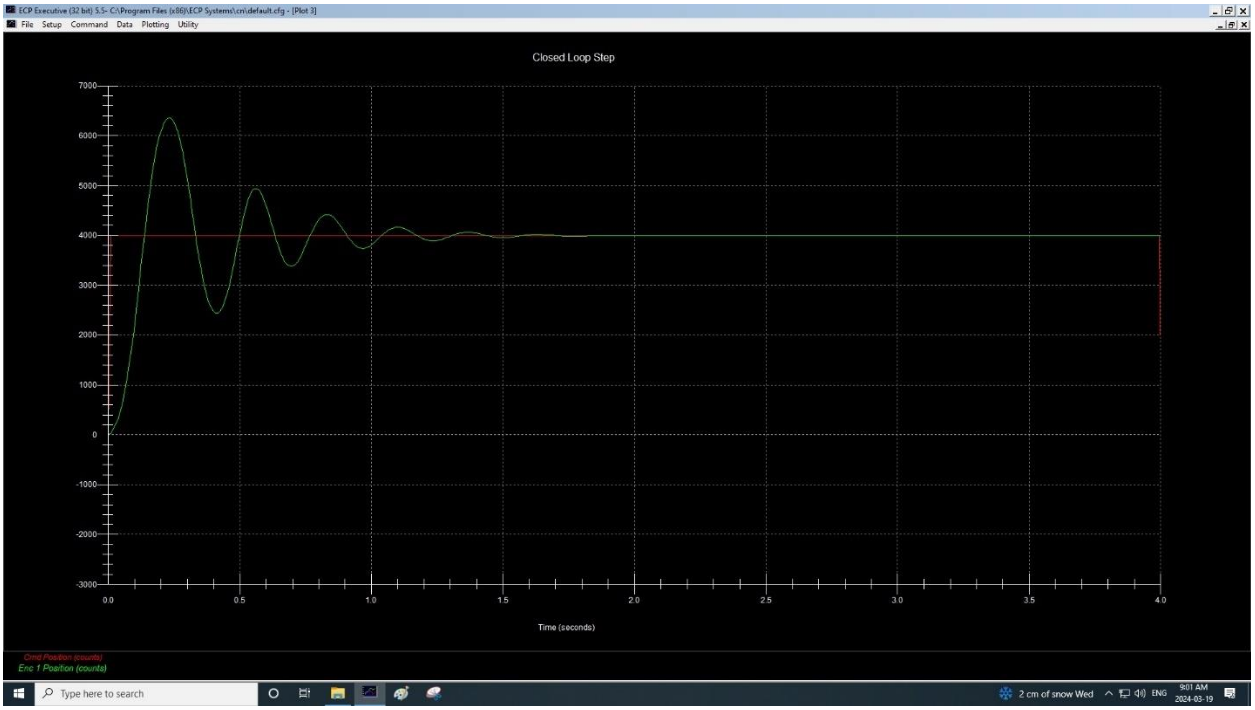
$$PO = 100\left[\frac{X_1 - 4000}{4000}\right]\%$$

$$X_1\ is\ around\ 6800$$

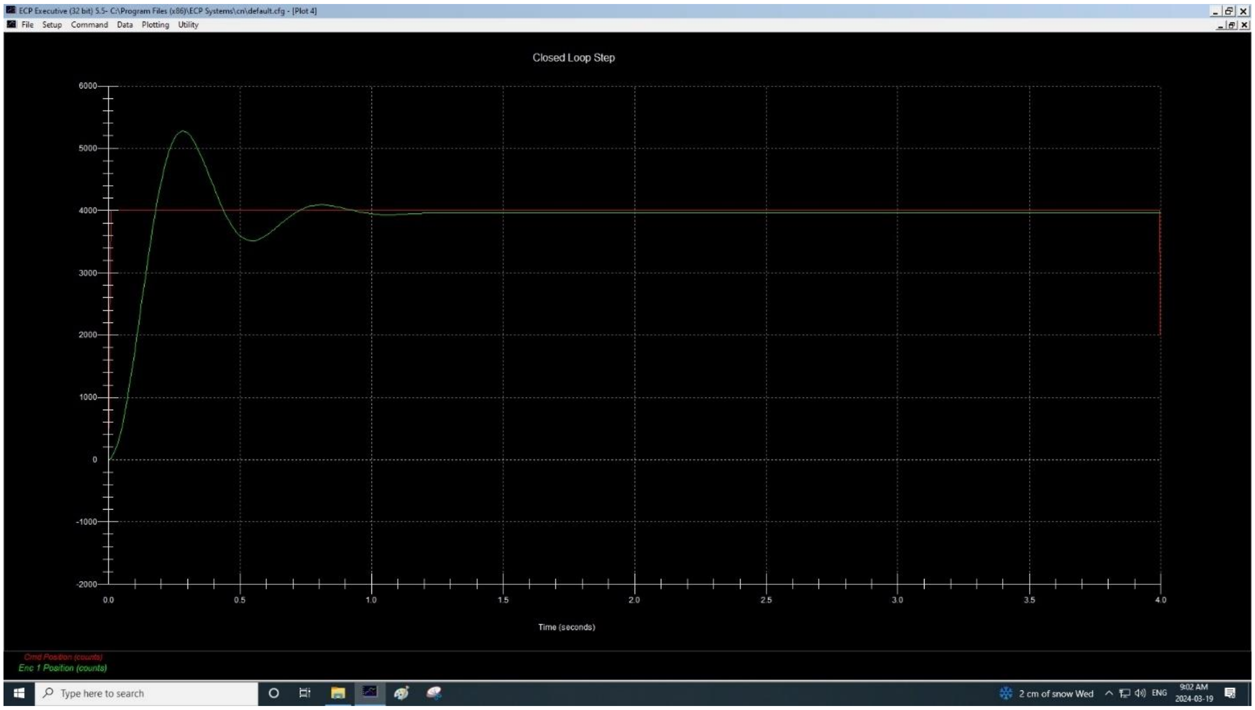
$$PO = 100\left[\frac{6800 - 4000}{4000}\right]\% = 70\%$$



Closed-Loop Step Response (Kp = 0.7)



Closed-Loop Step Response (Kp = 0.4)



Closed-Loop Step Response (Kp = 0.1)

3.1.1 Results

<u>1) Tabulate ω_d and OS values for the above cases.</u>

K_p	T_p	X_1	ω_d	PO
1	0.25	6800	4π or 12.57	70%
0.7	0.265	6600	11.86	65%
0.4	0.28	6400	11.22	60%
0.1	0.295	5300	10.65	32.5%

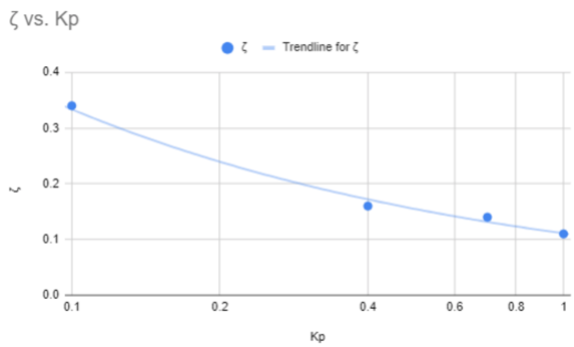
<u>2) Write a brief summary about the difference between open-loop and closed-loop system?</u>

An open-loop systems functions without any feedback from the output. For a closed-loop system, we have feedback which is used to adjust subsequent inputs. As such, closed-loop systems can monitor and adapt to changes or stabilise itself to a certain margin.

<u>3) From the OS values, use Equation (6.2) to calculate and tabulate the values of ζ, corresponding to the four Kp values used. Obtain a plot showing the effect of increasing Kp on the damping ratio ζ and comment on the result.</u>

$$\zeta = \sqrt{\frac{(ln\, p)^2}{\pi^2 (ln\, p)^2}}$$

K_p	p	ζ
1	70%	0.11
0.7	65%	0.14
0.4	60%	0.16
0.1	32.5%	0.34

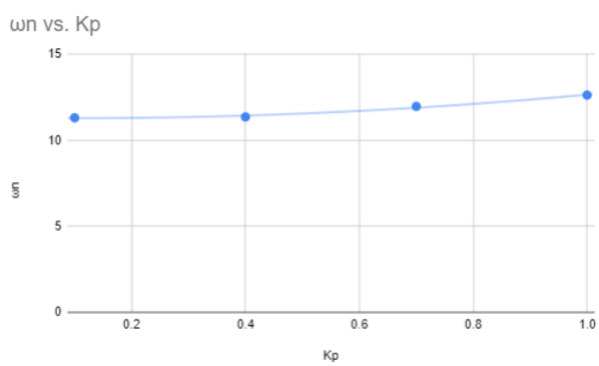


It can be noticed that by increasing K_p, the damping ratio decreases exponentially. For example, with an increase of K_p from 0.4, 0.7 and 1, the damping ratio decreases marginally from 0.16, 0.14 and 0.11 respectively. However, the jump from K_p of 0.1 to 0.4, notice that the damping ratio decrease largely from 0.34 to 0.16.

<u>4) From the tabulated values of ζ and ω_d, determine the corresponding ω_n values. Obtain a plot showing the effect of increasing Kp on the natural frequency ω_n and comment on the result.</u>

$$\omega_n = \frac{\omega_d}{\sqrt{1-\zeta^2}}$$

K_p	ω_d	ζ	ω_n
1	4π or 12.57	0.11	12.64
0.7	11.86	0.14	11.98
0.4	11.22	0.16	11.37
0.1	10.65	0.34	11.32



The natural frequency increases as K_p increases. The rate of increase in minimal as seen above.

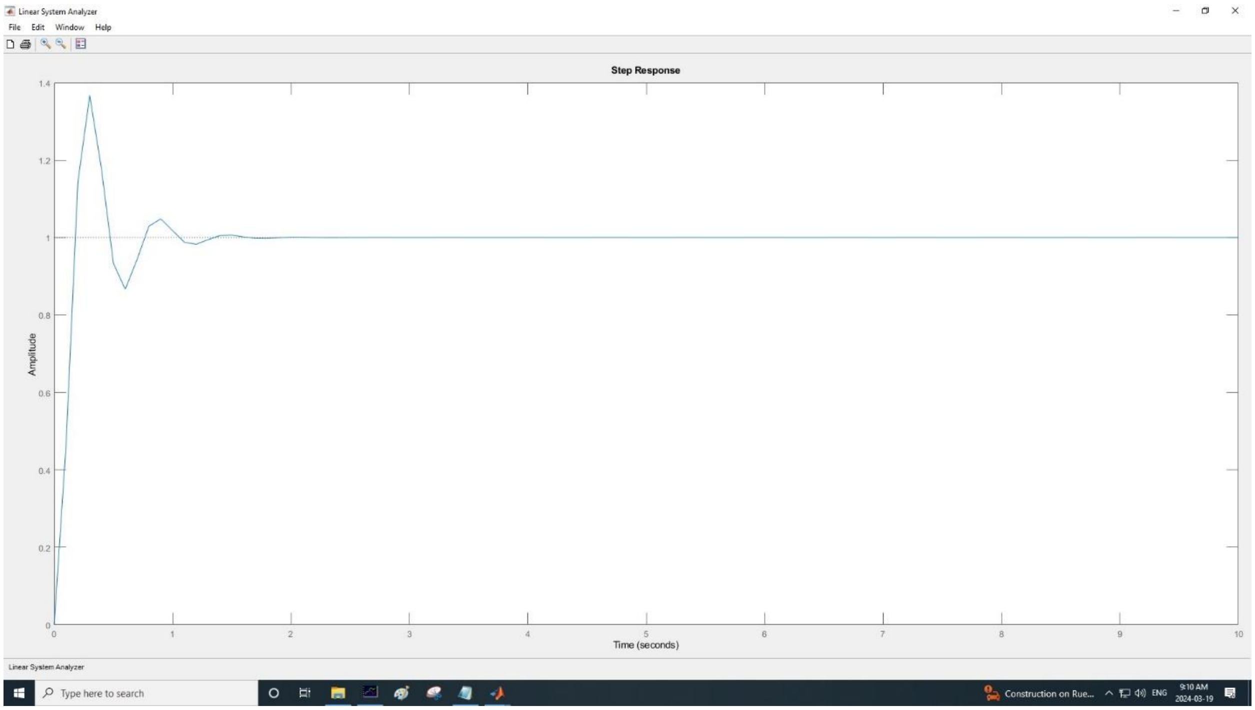
3.1.2 Analysis in MATLAB

1) Use the following settings: Ts = 0.00442 sec, Kp = 0.1 Ki = 0 and Kd = 0.005 and the obtained model in Experiment #2, write MATLAB code to calculate CLTF in the configuration of "PI + velocity feedback", see formula 6.3.

$$CLTF = \frac{0.512}{0.00481s^2 + 0.02749s + 0.512}$$

2) Refer to sample code in Experiment #1, using MATLAB LTI Viewer to analysis system step response.

(Raw MATLAB export found in the appendix)

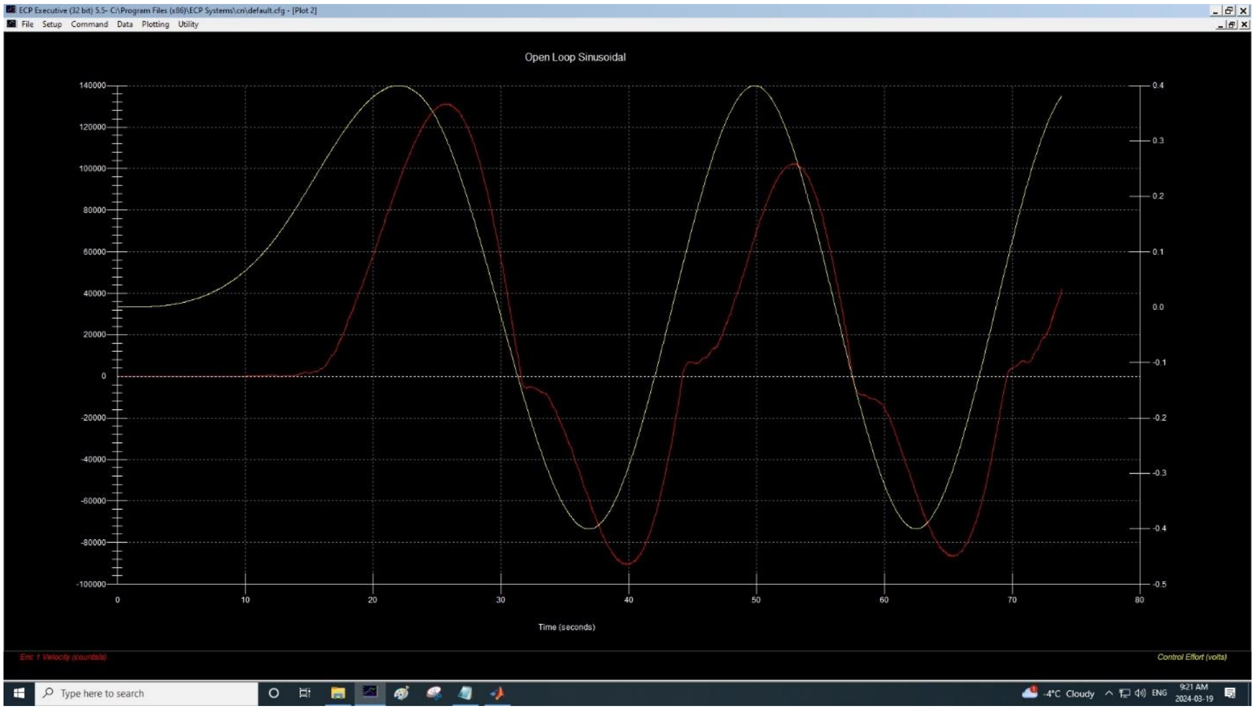


Closed-Loop Step Response ($K_p = 0.1$)

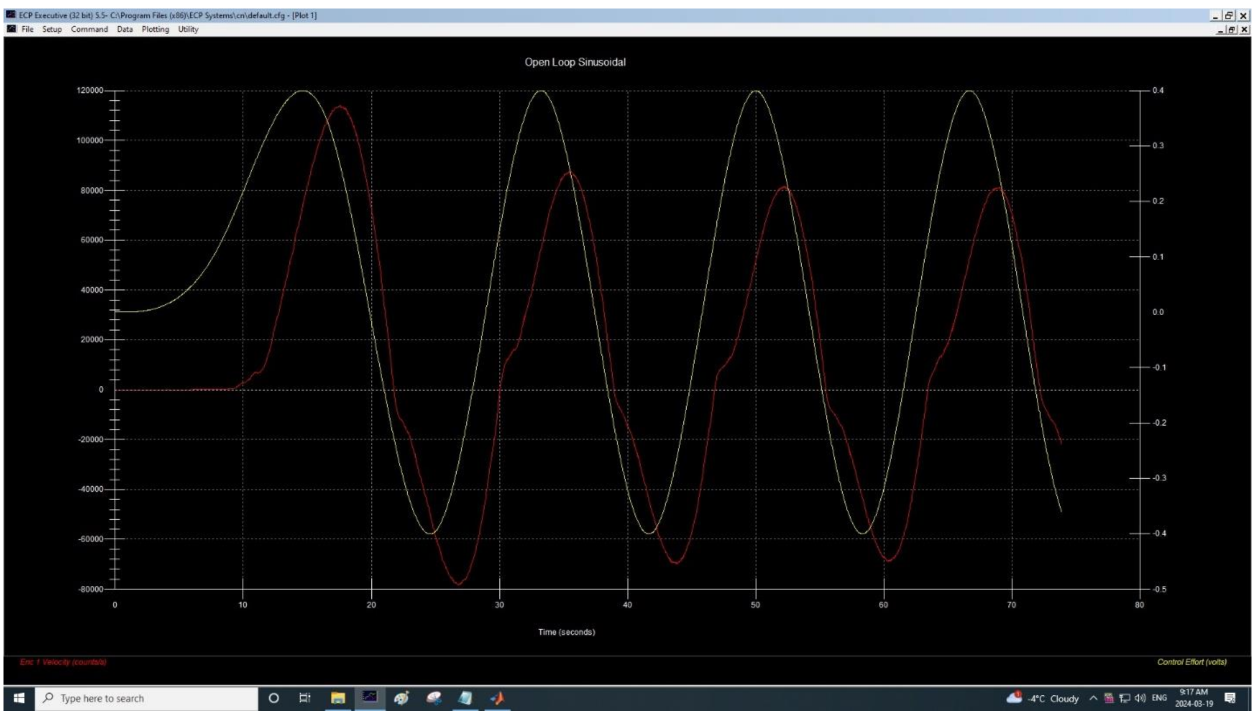
3) Compare the result with the exported raw data, for at least one Kp.

For $K_p = 0.1$, the above MATLAB figure has more peaks when compared to the one tested using ECP. Here, there are three peaks while the ECP only has two. In addition, MATLAB's curve is less smooth as seen from its pointy and sharp increases and decreases.

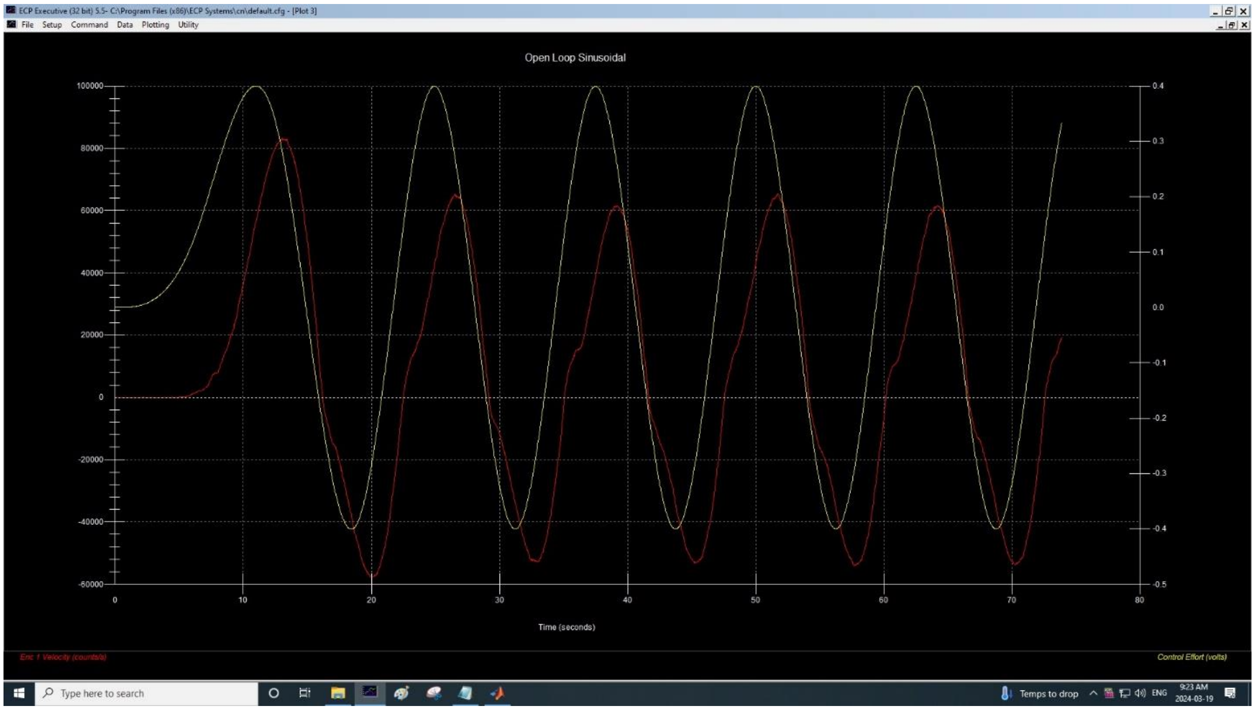
3.2 Open-Loop Frequency Response



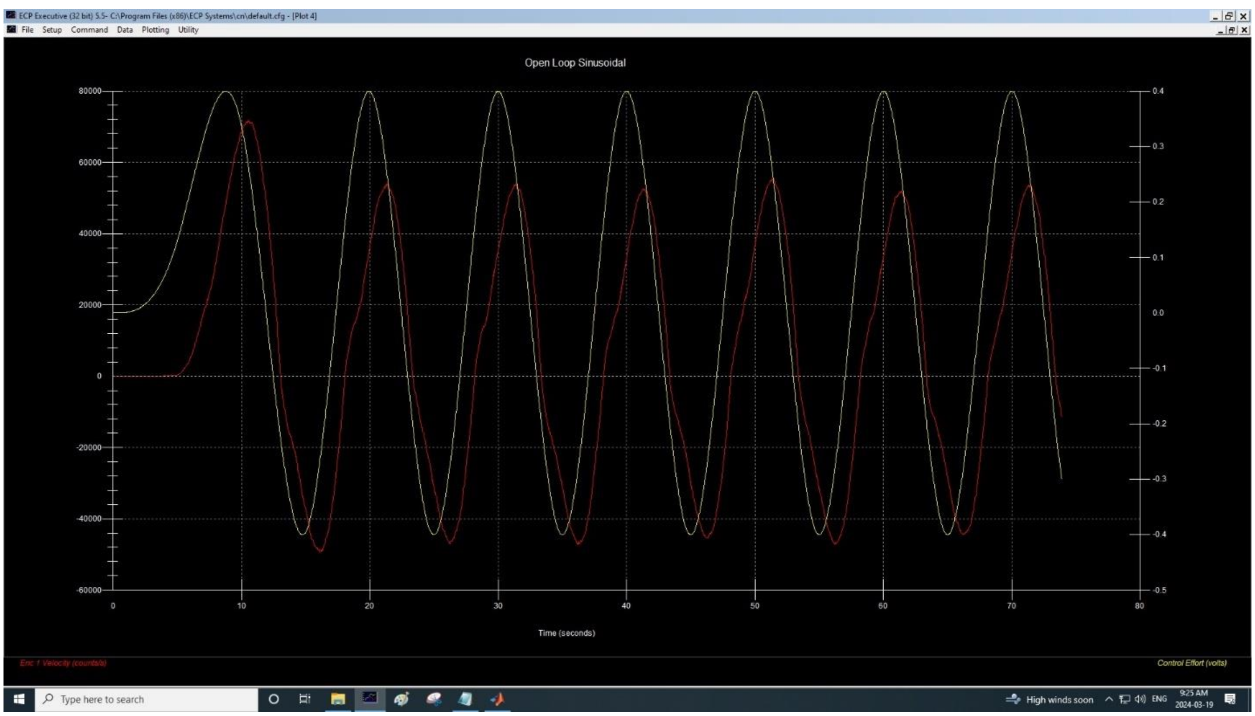
Open-Loop Sinusoidal (f=0.04)



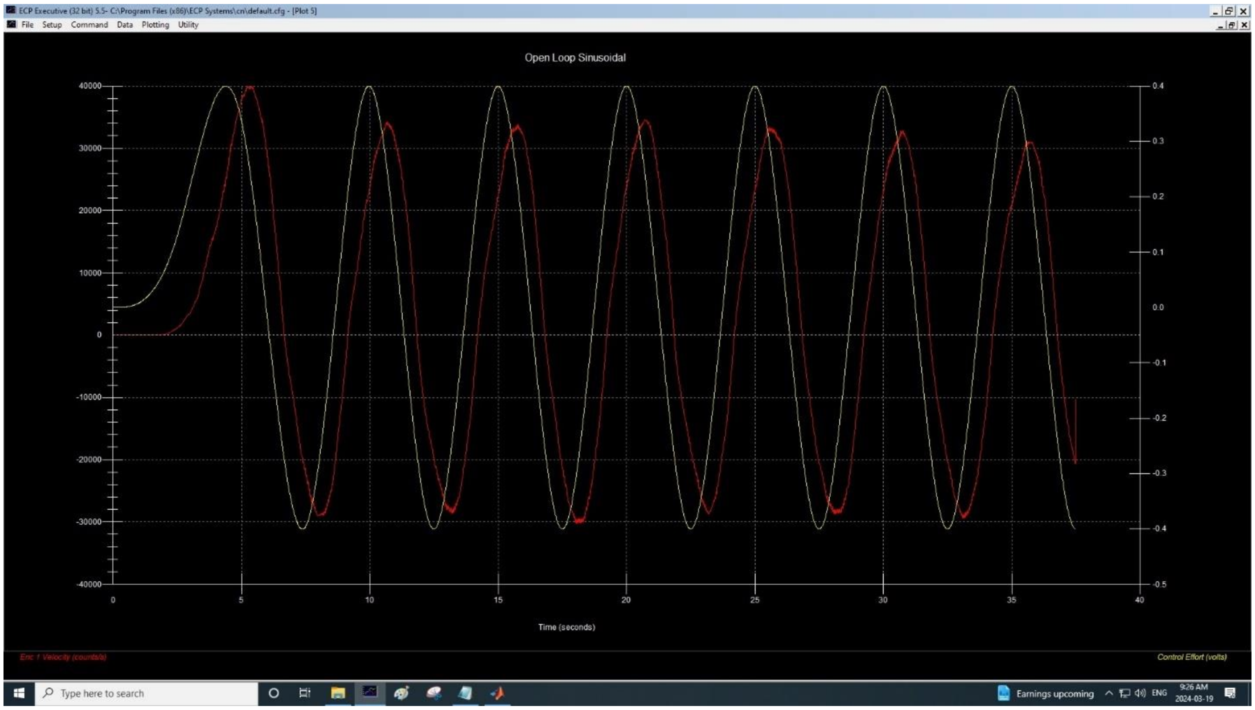
Open-Loop Sinusoidal (f=0.06)



Open-Loop Sinusoidal (f=0.08)



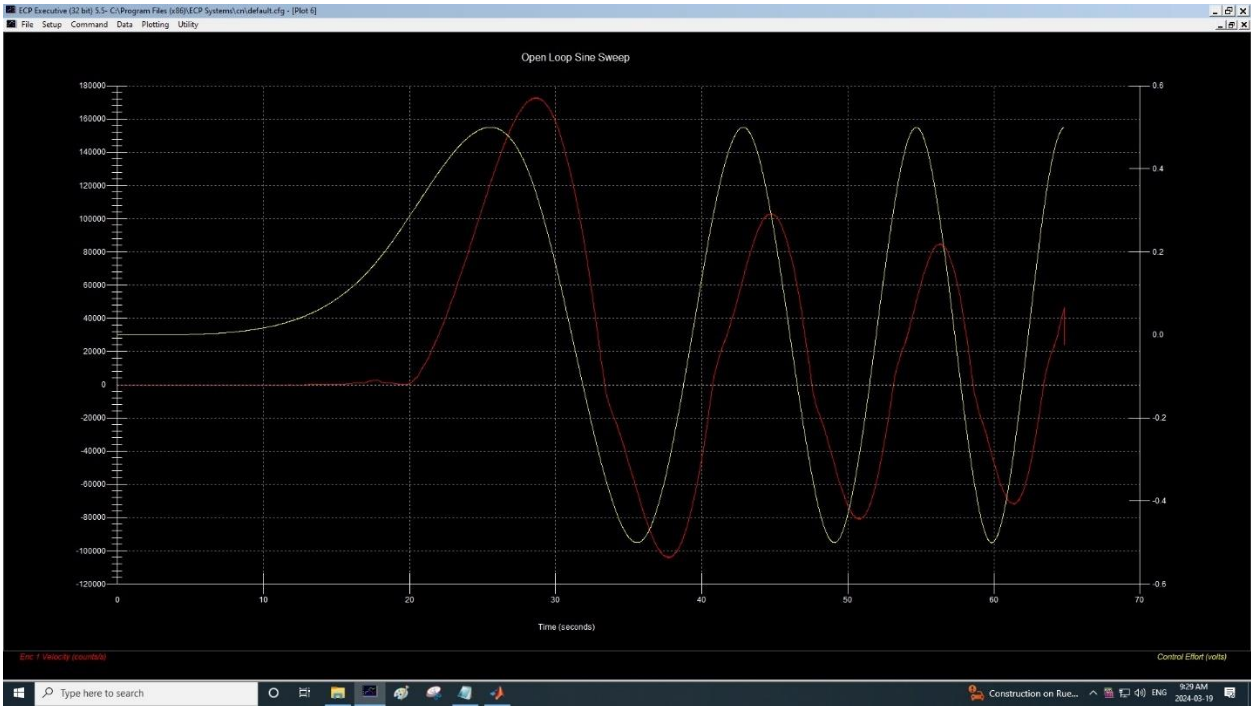
Open-Loop Sinusoidal (f=0.1)



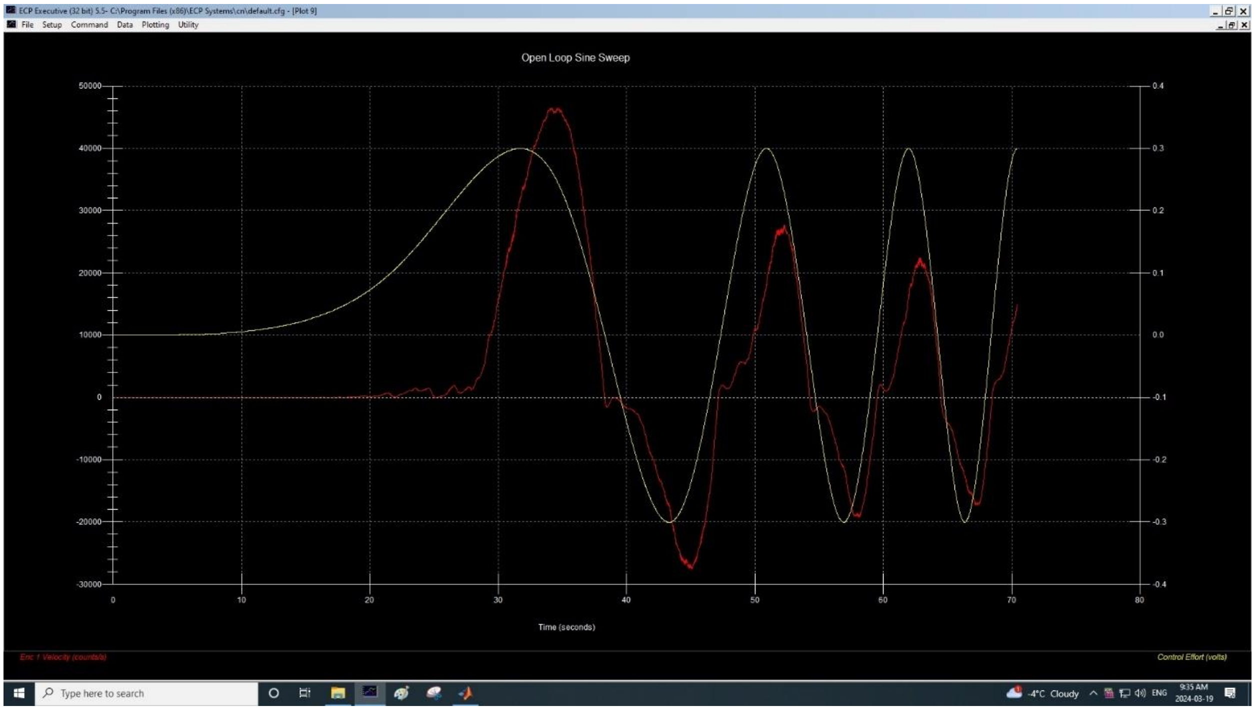
Open-Loop Sinusoidal (f=0.2)

$$Phase\ Shift = -360 * f * Tphase$$
$$w = 2 * pi * f$$

Frequency	w(rad/sec)	Ω_{pp}	Tphase (sec)	Phase Shift
0.04	0.25	190000	3.5	-50.4
0.06	0.38	160000	2	-43.2
0.08	0.50	145000	1.6	-46.08
0.1	0.63	98000	1.2	-43.2
0.2	1.26	70000	0.8	-57.6



Open-Loop Linear Sweep



Open-Loop Log Sweep

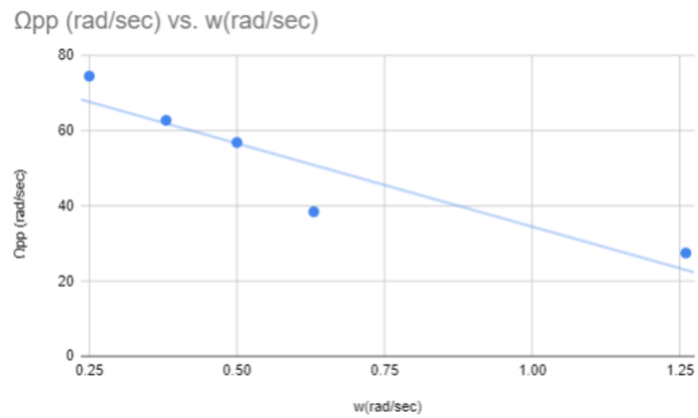
3.2.1 Results

1) Using the data tabulated in Step 4 above, use the conversion factor Ke to convert the values of Ωpp (counts/sec.) to Ωpp (radians/sec.). Plot Ωpp (radians/sec.) against the radian frequency ω using a linear scale.

$K_p = 2546.5$

Ωpp (rad/sec) = Ωpp (counts/sec)/K_p

w(rad/sec)	Ωpp (counts/sec)	Ωpp (rad/sec)
0.25	190000	74.61
0.38	160000	62.83
0.50	145000	56.94
0.63	98000	38.48
1.26	70000	27.49



Ωpp (rad/sec) over w(rad/sec) with Linear Scale

2) Assuming that the input remained constant, the output magnitude should also be a constant (say, Y) at low frequencies approaching 0 Hz. Using the magnitude equation, it can be shown that the output magnitude will drop to $(1/2)^{0.5}$Y or 0.707Y when $\omega_c = 1/\tau$, where ω_c is called the 'cut-off frequency' or 'break frequency'. Assuming Y is the magnitude corresponding to the frequency of 0.04 Hz, determine ω_c and hence find τ. How does this value compare with the value found in EXPR#2(Sect4.3.2)? Comment on any difference observed. (The value of $\tau = 1/\omega_c$ can also be estimated by finding fc =1/2piω_c where the phase shift is – 45°.)

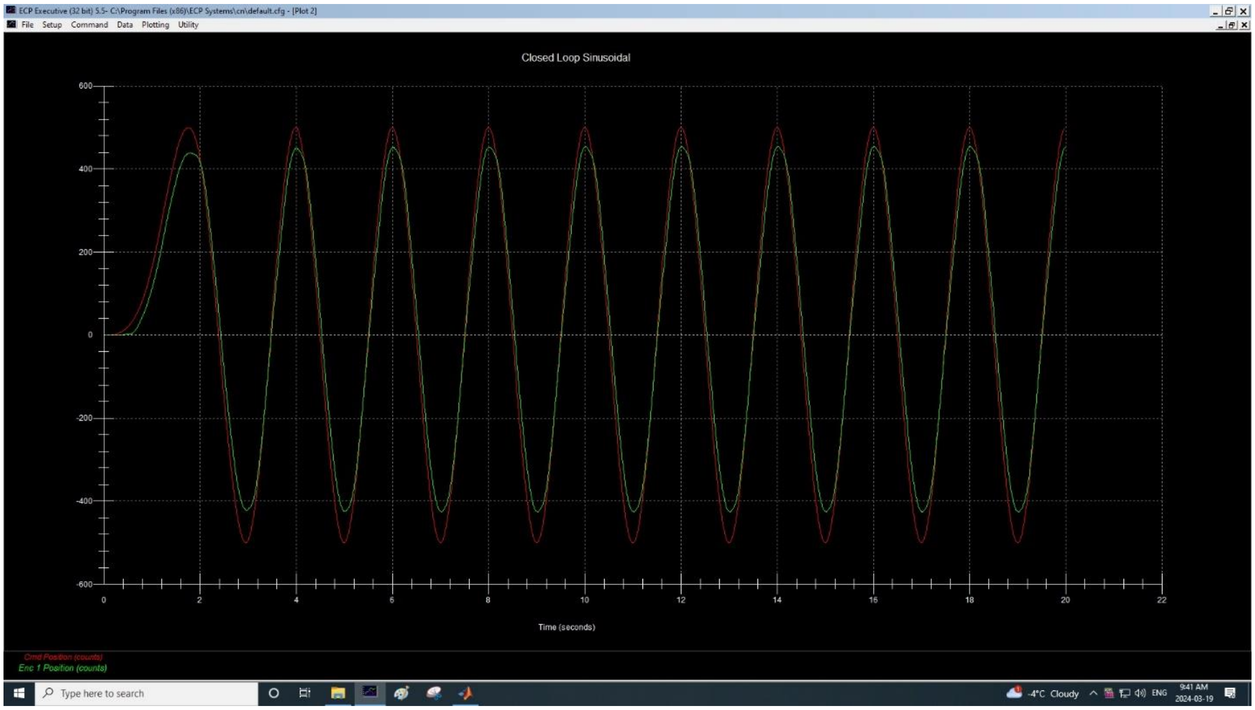
$$Phase\ Shift = -360 * f * Tphase$$

$$Tphase = \frac{Phase\ Shift}{-360 * f} = \frac{-45}{-360 * 0.04} = 3.125$$

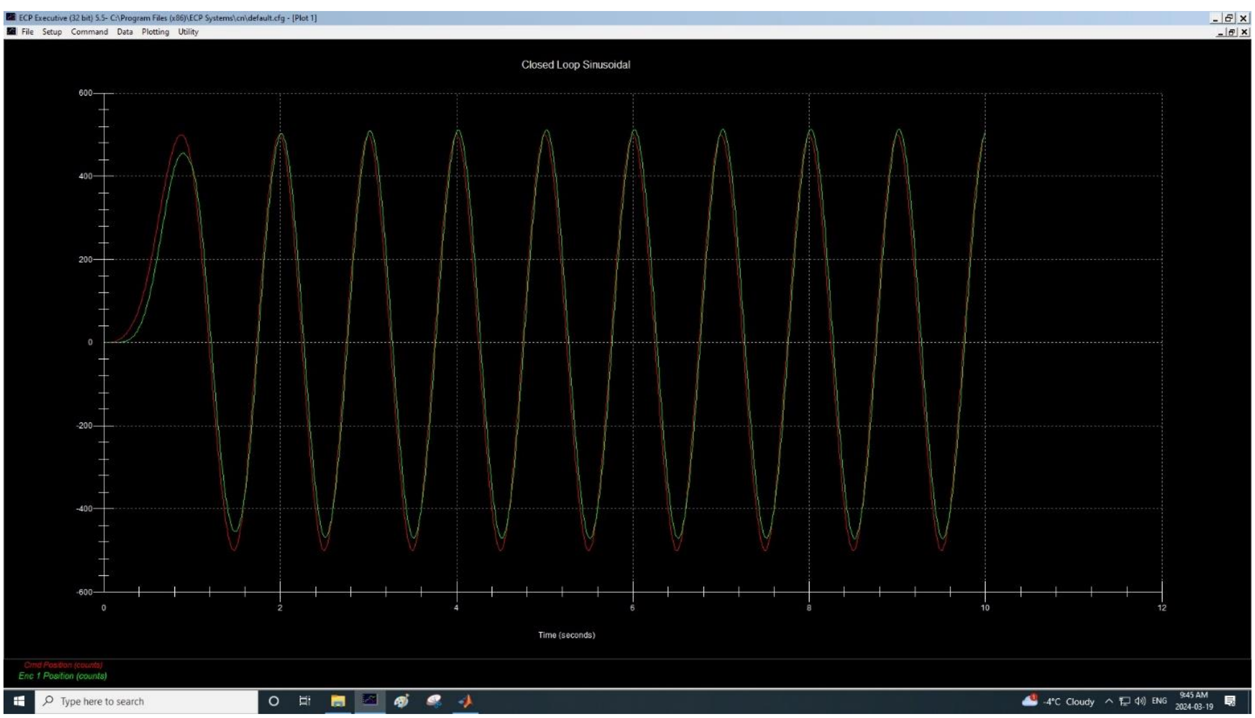
$$\omega_c = \frac{1}{\tau} = \frac{1}{3.125} = 0.32$$

Yes, these values are similar to the value found in experiment #2 section 4.3.2.

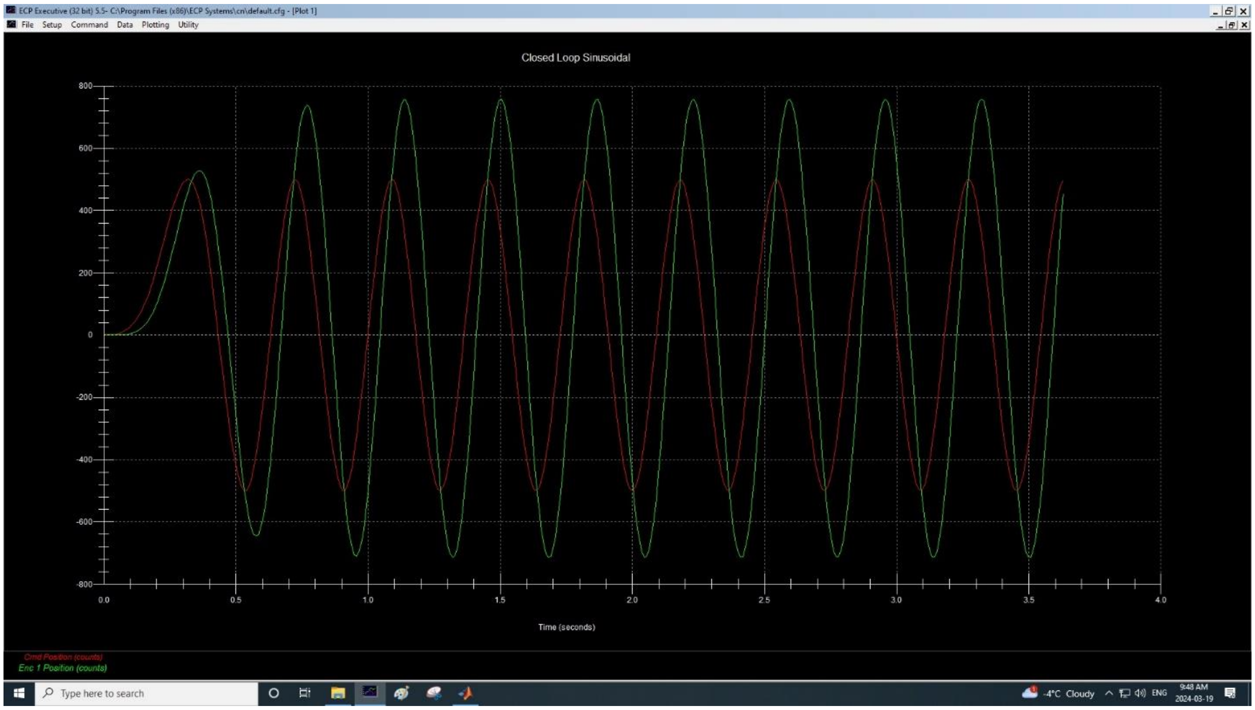
3.3 Closed-Loop Frequency Response



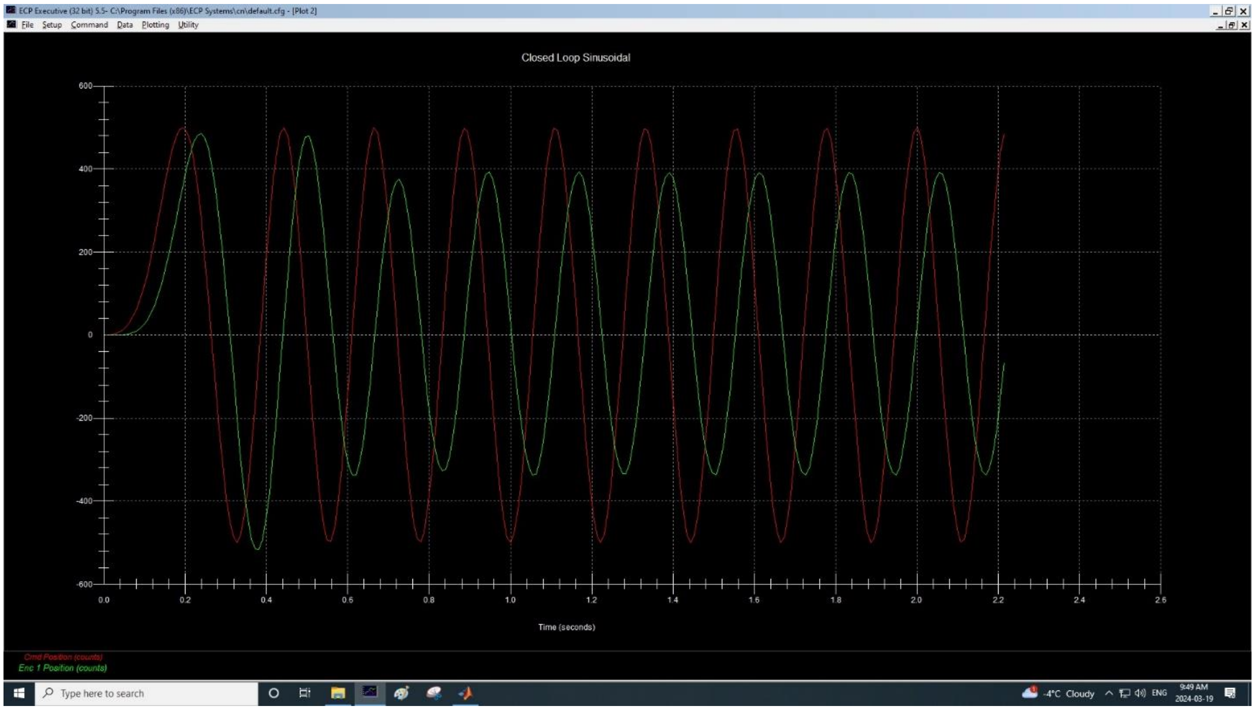
Closed Loop Sinusoidal (f=0.5)



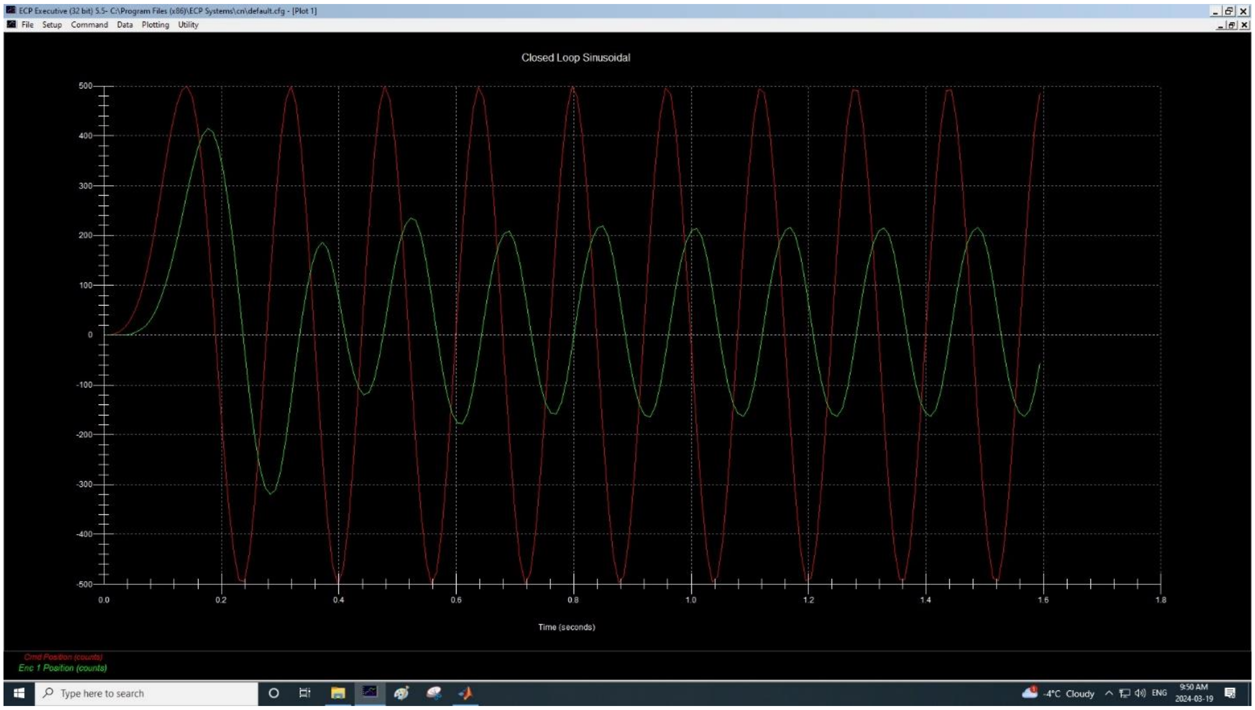
Closed Loop Sinusoidal (f=1)



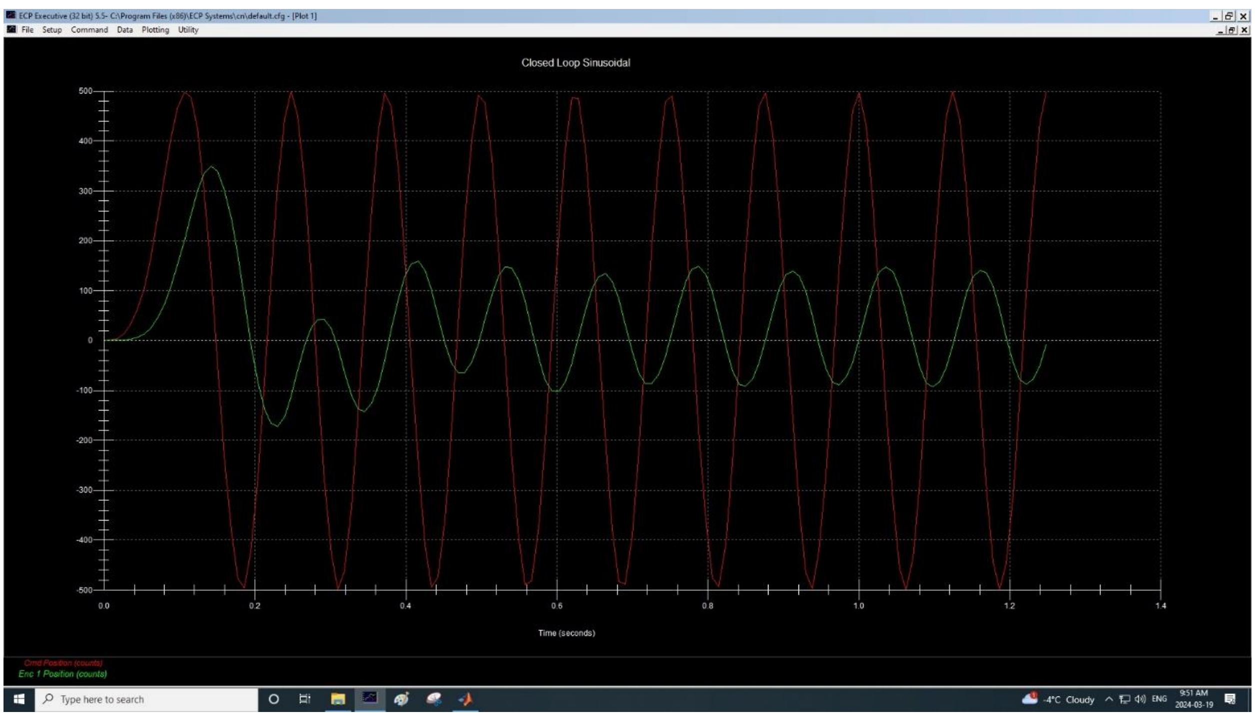
Closed Loop Sinusoidal (f=2.75)



Closed Loop Sinusoidal (f=4.5)



Closed Loop Sinusoidal (f=6.25)



Closed Loop Sinusoidal (f=8)

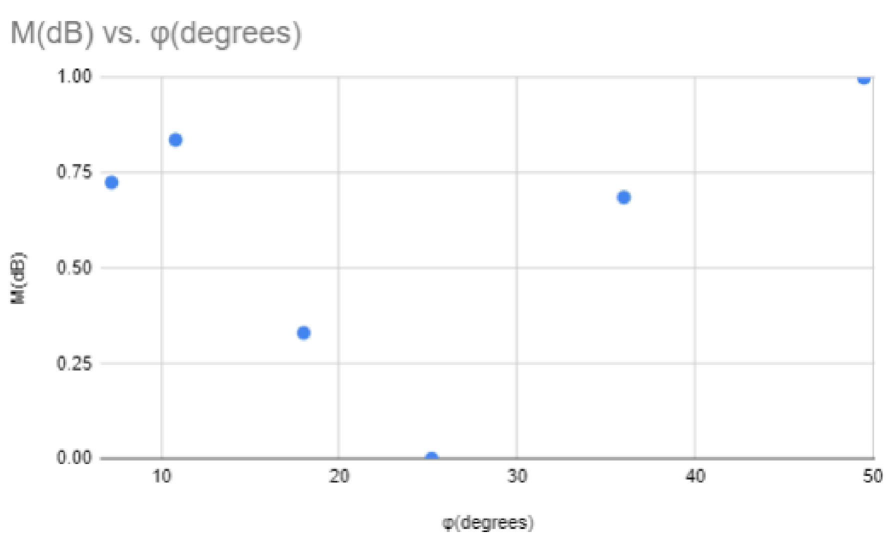
Frequency (Hz)	Peak-Peak Output (Counts)	Tphase(sec)
0.5	410	0.04
1	510	0.03
2.75	700	0.05
4.5	380	0.3
6.25	190	0.048
8	100	0.04

3.3.1 Results: Spot-Frequency Measurement

1) Use the data table obtained in Step 3 to calculate and tabulate M(dB) and φ(degrees) against ω=2πf (radians/sec). Obtain Bode magnitude and phase plots for the frequency range 0.05 to 8 Hz (~0.3 to 50.3 radians/sec). Use 3-cycle semi-logarithmic graph paper. Also draw the corresponding polar plot for your data range.

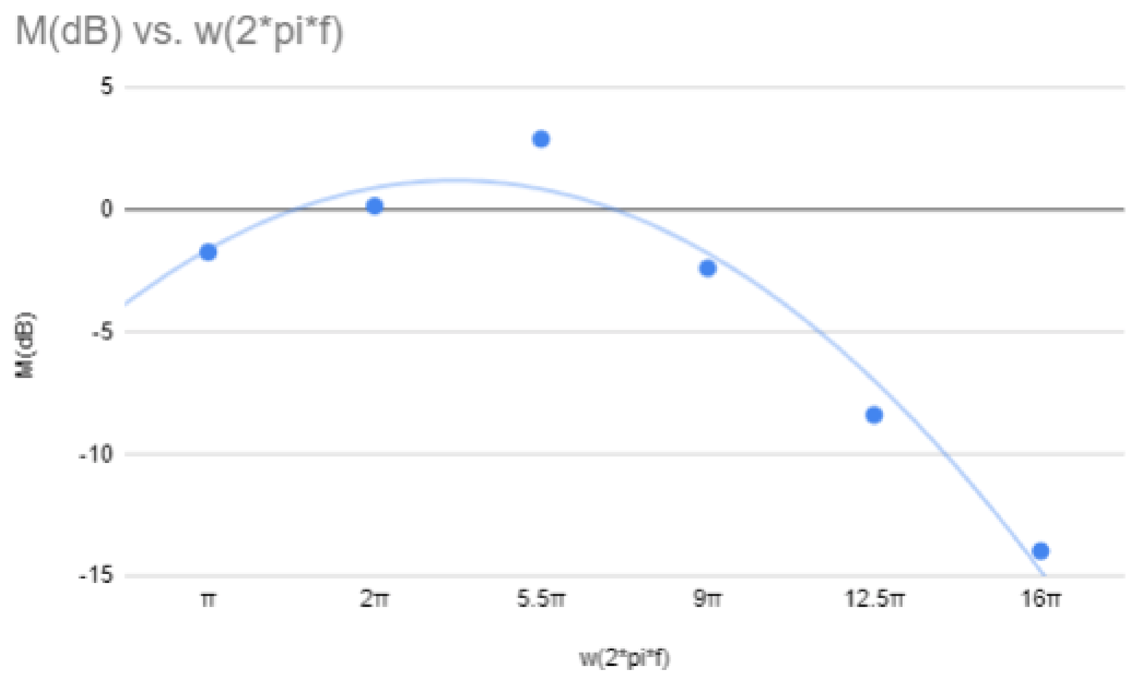
$$M(dB) = 20log_{10}(M)$$
$$where\ M = Output/Input\ Amplitude$$
$$Imput\ Amplitude = 500$$

Frequency (Hz)	w(2*pi*f)	M(dB)	φ(degrees)
0.5	π	-1.72	7.2
1	2π	0.17	10.8
2.75	5.5π	2.92	49.5
4.5	9π	-2.38	486
6.25	12.5π	-8.4	108
8	16π	-13.98	115.2

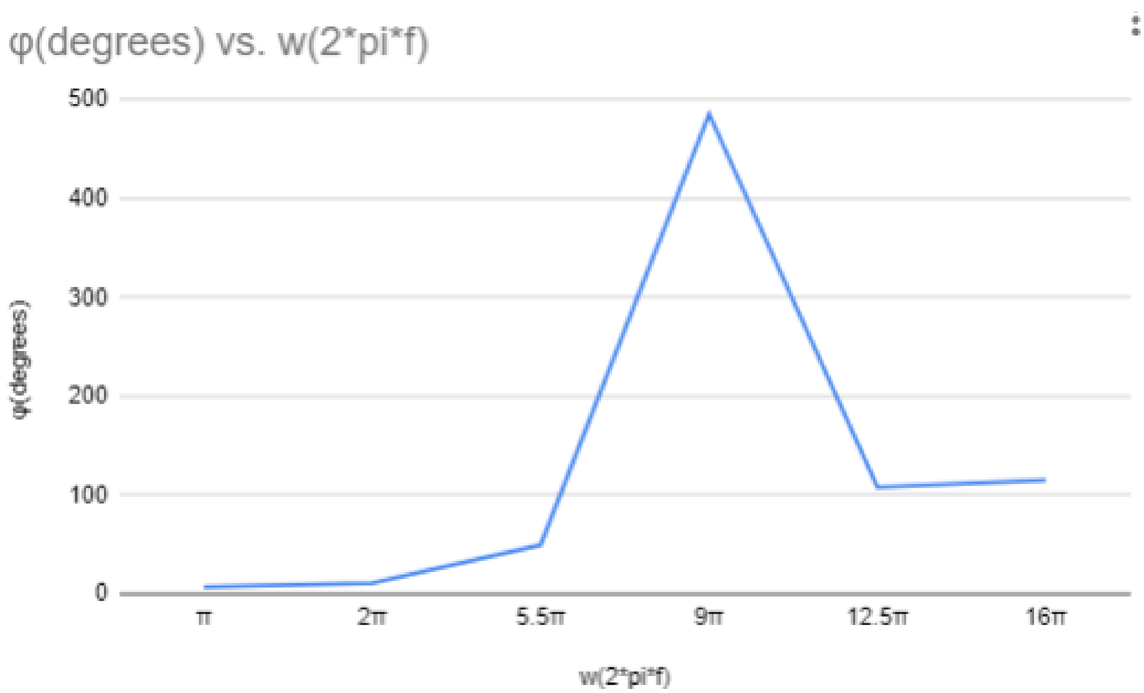


M(dB) vs Phase Shift (scaled)

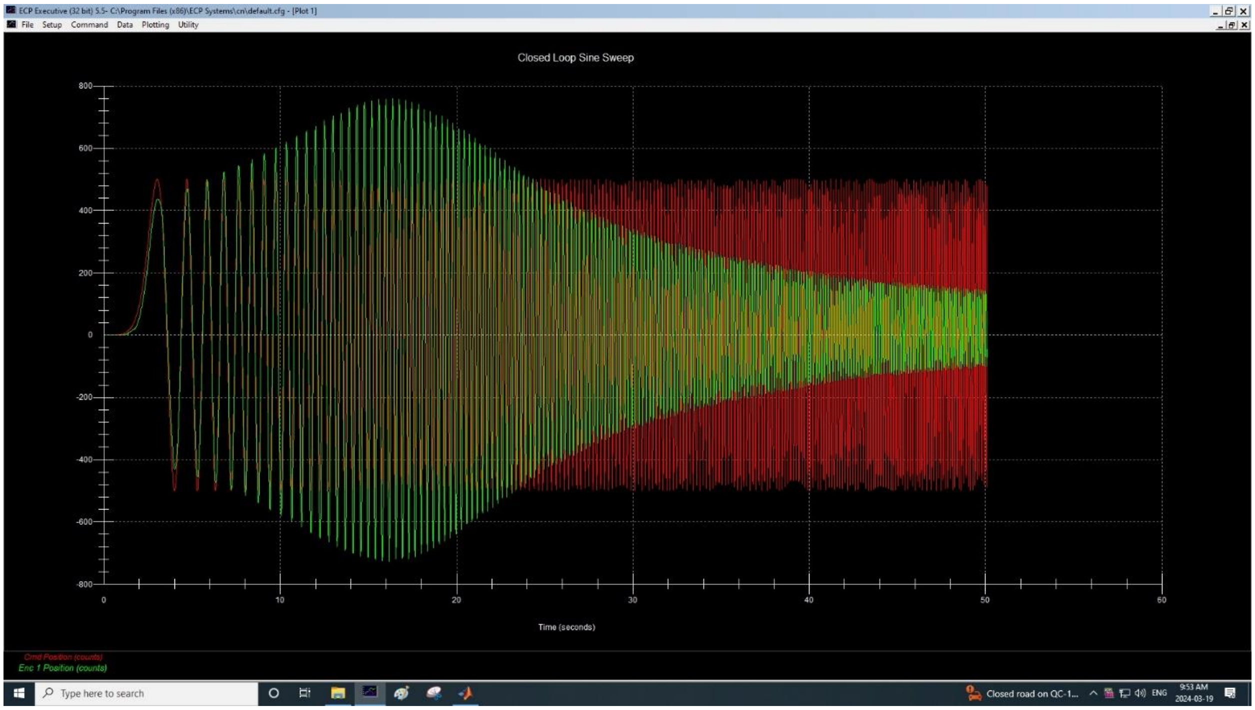
<u>2) Attempt to fit the Bode magnitude data to an asymptotic plot and hence obtain an approximate transfer function.</u>



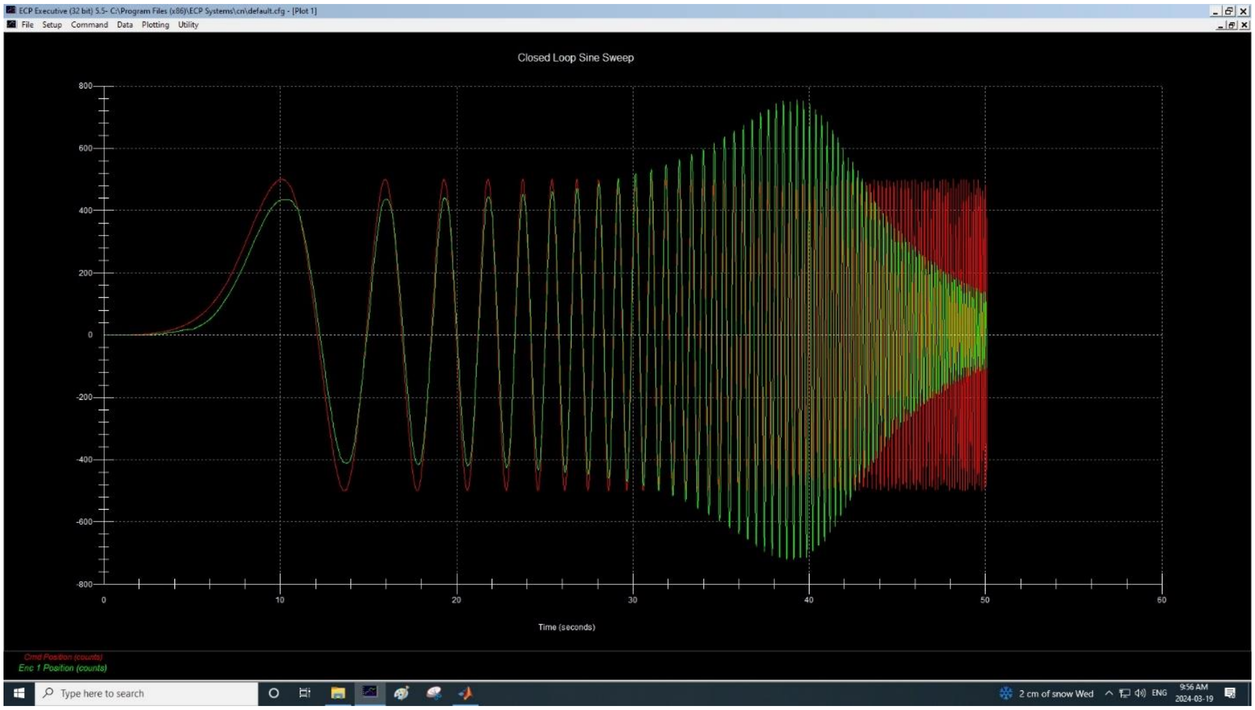
M(dB) vs Radian Frequency



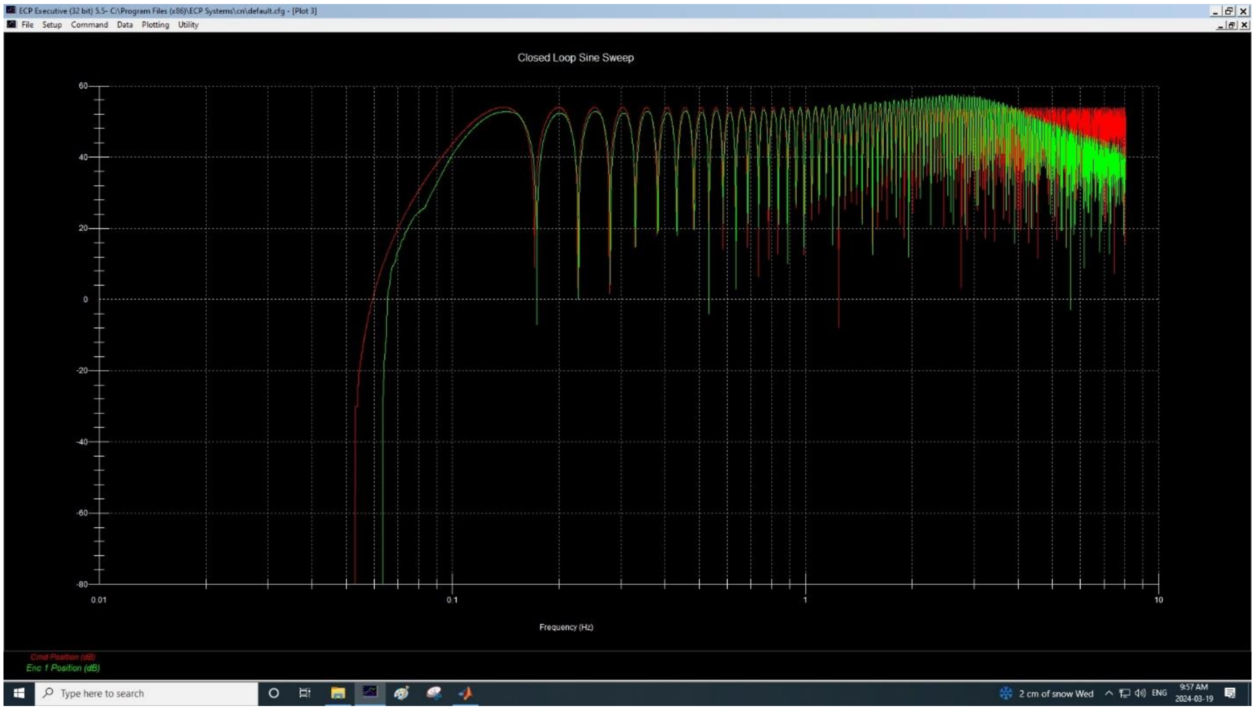
Phase Shift vs Radian Frequency



Closed Loop Linear Sine Sweep



Closed Loop Log Sine Sweep



Closed Loop Log Sine Sweep with M in DB

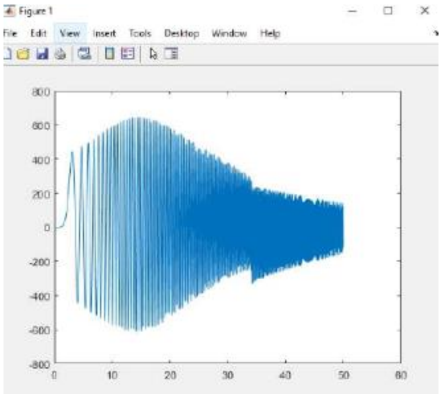
3.3.2 Results: Sweep Frequency Measurement

<u>1) Evaluate the amplitude and frequency and at a few points on the curve and compare the results with the spot-frequency data obtained earlier. Comment on the results.</u>

Frequency (Hz)	Amplitude (Counts), Spot	Amplitude (Counts), Sweep
0.5	410	420
1	510	500
2.75	700	720
4.5	380	370
6.25	190	220
8	100	130

While each individual amplitude values of the spot frequency data and the sweep frequency data are different, notice that the general trend remains the same. As we increase the frequency from 0.5Hz to 8Hz, notice how the amplitude increase until it peaks at frequency 2.75, then it reduces back down.

2) *Use MATLAB LTI viewer to do system frequency-domain analysis. Refer to the code in the section 6.3 CLOSED-LOOP TRANSIENT RESPONSE.



Closed Loop Transient Response MATLAB

3) Summarize the roles of engineering tool MATLAB/Simulink when you design a control system.

The role of the engineering tool MATLAB and Simulink when designing a control system is to provide a simulation environment to test and validate results. Given a correct set of instruction, it is able to predict theoretical values which is useful when trying to analyse the results. In our case, students used MATLAB to validate their experiments by exporting the raw data from the ECP 220. Overall, it is a very practical tool that can be used to facilitate control, system design as well as a simulation platform to verify experimental results.

4) Questions

(answered throughout the whole report)

5) Conclusions

In conclusion, the fourth experiment of Elec 372 provided practical insights into transient and frequency responses of control systems. By testing various input parameters such as rise time, overshoot and phase shift, students were able to analyse the behavior and stability of open and closed loop systems. For the second part, students practiced on frequency response on systems with different input frequencies such as magnitude and phase. Overall, this lab experiment contributed to the student's knowledge on control systems and their transient and frequency response.

6) Appendix

MATLAB file for 3.2.2 (Closed-Loop Step Response K_p = 0.1)

```
% Sample    Time      Commanded Pos    Encoder 1 Pos    Encoder 2 Pos

data = [    0    0.000            4000              0
0;
      1    0.009            4000              18              0;
      2    0.018            4000              80              3;
      3    0.027            4000             170             18;
      4    0.035            4000             276             45;
      5    0.044            4000             402             84;
      6    0.053            4000             557            128;
      7    0.062            4000             747            175;
      8    0.071            4000             961            226;
      9    0.080            4000            1189            285;
     10    0.089            4000            1428            348;
     11    0.097            4000            1678            414;
     12    0.106            4000            1937            481;
     13    0.115            4000            2202            548;
     14    0.124            4000            2468            616;
     15    0.133            4000            2733            684;
     16    0.142            4000            2994            750;
     17    0.151            4000            3250            815;
     18    0.159            4000            3495            879;
     19    0.168            4000            3728            940;
     20    0.177            4000            3951            996;
     21    0.186            4000            4162           1048;
     22    0.195            4000            4360           1096;
     23    0.204            4000            4538           1141;
     24    0.213            4000            4696           1183;
     25    0.221            4000            4835           1219;
     26    0.230            4000            4957           1251;
     27    0.239            4000            5060           1276;
     28    0.248            4000            5143           1296;
     29    0.257            4000            5204           1311;
     30    0.266            4000            5247           1322;
     31    0.274            4000            5270           1327;
     32    0.283            4000            5277           1328;
     33    0.292            4000            5267           1327;
     34    0.301            4000            5241           1320;
     35    0.310            4000            5201           1310;
     36    0.319            4000            5149           1296;
     37    0.328            4000            5086           1280;
     38    0.336            4000            5015           1262;
     39    0.345            4000            4936           1241;
```

```
    40    0.354              4000               4851               1220;
    41    0.363              4000               4761               1197;
    42    0.372              4000               4669               1173;
    43    0.381              4000               4575               1149;
    44    0.390              4000               4480               1125;
    45    0.398              4000               4386               1100;
    46    0.407              4000               4293               1077;
    47    0.416              4000               4202               1053;
    48    0.425              4000               4115               1031;
    49    0.434              4000               4031               1009;
    50    0.443              4000               3953                989;
    51    0.452              4000               3879                971;
    52    0.460              4000               3812                953;
    53    0.469              4000               3750                938;
    54    0.478              4000               3696                924;
    55    0.487              4000               3649                912;
    56    0.496              4000               3609                902;
    57    0.505              4000               3576                894;
    58    0.514              4000               3550                887;
    59    0.522              4000               3531                882;
    60    0.531              4000               3519                879;
    61    0.540              4000               3513                878;
    62    0.549              4000               3511                877;
    63    0.558              4000               3516                877;
    64    0.567              4000               3527                880;
    65    0.576              4000               3542                884;
    66    0.584              4000               3561                889;
    67    0.593              4000               3583                895;
    68    0.602              4000               3608                901;
    69    0.611              4000               3636                908;
    70    0.620              4000               3665                915;
    71    0.629              4000               3695                923;
    72    0.638              4000               3726                931;
    73    0.646              4000               3758                939;
    74    0.655              4000               3789                947;
    75    0.664              4000               3820                955;
    76    0.673              4000               3850                963;
    77    0.682              4000               3879                970;
    78    0.691              4000               3907                977;
    79    0.699              4000               3934                984;
    80    0.708              4000               3958                990;
    81    0.717              4000               3981                996;
    82    0.726              4000               4002               1001;
    83    0.735              4000               4021               1006;
    84    0.744              4000               4038               1010;
    85    0.753              4000               4052               1014;
    86    0.761              4000               4064               1017;
    87    0.770              4000               4074               1019;
```

88	0.779	4000	4082	1021;
89	0.788	4000	4087	1023;
90	0.797	4000	4091	1024;
91	0.806	4000	4092	1024;
92	0.815	4000	4092	1024;
93	0.823	4000	4091	1024;
94	0.832	4000	4087	1024;
95	0.841	4000	4082	1023;
96	0.850	4000	4076	1021;
97	0.859	4000	4069	1020;
98	0.868	4000	4061	1017;
99	0.877	4000	4053	1015;
100	0.885	4000	4044	1013;
101	0.894	4000	4036	1011;
102	0.903	4000	4027	1009;
103	0.912	4000	4018	1006;
104	0.921	4000	4009	1004;
105	0.930	4000	4000	1002;
106	0.939	4000	3992	1000;
107	0.947	4000	3984	998;
108	0.956	4000	3976	996;
109	0.965	4000	3969	994;
110	0.974	4000	3963	992;
111	0.983	4000	3957	991;
112	0.992	4000	3951	989;
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123	1.089	4000	3935	985;
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131	1.160	4000	3951	988;
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476	4.215	0	-817	-216;
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496	4.392	0	-560	-145;
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    644    5.702                0                16                4;
    645    5.711                0                16                4;
    646    5.720                0                16                4;
    647    5.729                0                16                4;
    648    5.738                0                16                4;
    649    5.746                0                16                4;
    650    5.755                0                16                4;
    651    5.764                0                16                4;
    652    5.773                0                16                4;
    653    5.782                0                16                4;
    654    5.791                0                16                4;
    655    5.799                0                16                4;
    656    5.808                0                16                4;
    657    5.817                0                16                4;
```

658	5.826	0	16	4;
659	5.835	0	16	4;
660	5.844	0	16	4;
661	5.853	0	16	4;
662	5.861	0	16	4;
663	5.870	0	16	4;
664	5.879	0	16	4;
665	5.888	0	16	4;
666	5.897	0	16	4;
667	5.906	0	16	4;
668	5.915	0	16	4;
669	5.923	0	16	4;
670	5.932	0	16	4;
671	5.941	0	16	4;
672	5.950	0	16	4;
673	5.959	0	16	4;
674	5.968	0	16	4;
675	5.977	0	16	4;
676	5.985	0	16	4;
677	5.994	0	16	4;
678	6.003	0	16	4;
679	6.012	0	16	4;
680	6.021	0	16	4;
681	6.030	0	16	4;
682	6.039	0	16	4;
683	6.047	0	16	4;
684	6.056	0	16	4;
685	6.065	0	16	4;
686	6.074	0	16	4;
687	6.083	0	16	4;
688	6.092	0	16	4;
689	6.101	0	16	4;
690	6.109	0	16	4;
691	6.118	0	16	4;
692	6.127	0	16	4;
693	6.136	0	16	4;
694	6.145	0	16	4;
695	6.154	0	16	4;
696	6.163	0	16	4;
697	6.171	0	16	4;
698	6.180	0	16	4;
699	6.189	0	16	4;
700	6.198	0	16	4;
701	6.207	0	16	4;
702	6.216	0	16	4;
703	6.224	0	16	4;
704	6.233	0	16	4;
705	6.242	0	16	4;

```
  706   6.251             0            16             4;
  707   6.260             0            16             4;
  708   6.269             0            16             4;
  709   6.278             0            16             4;
  710   6.286             0            16             4;
  711   6.295             0            16             4;
  712   6.304             0            16             4;
  713   6.313             0            16             4;
  714   6.322             0            16             4;
  715   6.331             0            16             4;
  716   6.340             0            16             4;
  717   6.348             0            16             4;
  718   6.357             0            16             4;
  719   6.366             0            16             4;
  720   6.375             0            16             4;
  721   6.384             0            16             4;
  722   6.393             0            16             4;
  723   6.402             0            16             4;
  724   6.410             0            16             4;
  725   6.419             0            16             4;
  726   6.428             0            16             4;
  727   6.437             0            16             4;
  728   6.446             0            16             4;
  729   6.455             0            16             4;
  730   6.464             0            16             4;
  731   6.472             0            16             4;
  732   6.481             0            16             4;
  733   6.490             0            16             4;
  734   6.499             0            16             4;
  735   6.508             0            16             4;
  736   6.517             0            16             4;
  737   6.526             0            16             4;
  738   6.534             0            16             4;
  739   6.543             0            16             4;
  740   6.552             0            16             4;
  741   6.561             0            16             4;
  742   6.570             0            16             4;
  743   6.579             0            16             4;
  744   6.588             0            16             4;
  745   6.596             0            16             4;
  746   6.605             0            16             4;
  747   6.614             0            16             4;
  748   6.623             0            16             4;
  749   6.632             0            16             4;
  750   6.641             0            16             4;
  751   6.649             0            16             4;
  752   6.658             0            16             4;
  753   6.667             0            16             4;
```

```
   754    6.676              0              16               4;
   755    6.685              0              16               4;
   756    6.694              0              16               4;
   757    6.703              0              16               4;
   758    6.711              0              16               4;
   759    6.720              0              16               4;
   760    6.729              0              16               4;
   761    6.738              0              16               4;
   762    6.747              0              16               4;
   763    6.756              0              16               4;
   764    6.765              0              16               4;
   765    6.773              0              16               4;
   766    6.782              0              16               4;
   767    6.791              0              16               4;
   768    6.800              0              16               4;
   769    6.809              0              16               4;
   770    6.818              0              16               4;
   771    6.827              0              16               4;
   772    6.835              0              16               4;
   773    6.844              0              16               4;
   774    6.853              0              16               4;
   775    6.862              0              16               4;
   776    6.871              0              16               4;
   777    6.880              0              16               4;
   778    6.889              0              16               4;
   779    6.897              0              16               4;
   780    6.906              0              16               4;
   781    6.915              0              16               4;
   782    6.924              0              16               4;
   783    6.933              0              16               4;
   784    6.942              0              16               4;
   785    6.951              0              16               4;
   786    6.959              0              16               4;
   787    6.968              0              16               4;
   788    6.977              0              16               4;
   789    6.986              0              16               4;
   790    6.995              0              16               4;
   791    7.004              0              16               4;
   792    7.013              0              16               4;
   793    7.021              0              16               4;
   794    7.030              0              16               4;
   795    7.039              0              16               4;
   796    7.048              0              16               4;
   797    7.057              0              16               4;
   798    7.066              0              16               4;
   799    7.074              0              16               4;
   800    7.083              0              16               4;
   801    7.092              0              16               4;
```

```
802    7.101               0               16                4;
803    7.110               0               16                4;
804    7.119               0               16                4;
805    7.128               0               16                4;
806    7.136               0               16                4;
807    7.145               0               16                4;
808    7.154               0               16                4;
809    7.163               0               16                4;
810    7.172               0               16                4;
811    7.181               0               16                4;
812    7.190               0               16                4;
813    7.198               0               16                4;
814    7.207               0               16                4;
815    7.216               0               16                4;
816    7.225               0               16                4;
817    7.234               0               16                4;
818    7.243               0               16                4;
819    7.252               0               16                4;
820    7.260               0               16                4;
821    7.269               0               16                4;
822    7.278               0               16                4;
823    7.287               0               16                4;
824    7.296               0               16                4;
825    7.305               0               16                4;
826    7.314               0               16                4;
827    7.322               0               16                4;
828    7.331               0               16                4;
829    7.340               0               16                4;
830    7.349               0               16                4;
831    7.358               0               16                4;
832    7.367               0               16                4;
833    7.376               0               16                4;
834    7.384               0               16                4;
835    7.393               0               16                4;
836    7.402               0               16                4;
837    7.411               0               16                4;
838    7.420               0               16                4;
839    7.429               0               16                4;
840    7.438               0               16                4;
841    7.446               0               16                4;
842    7.455               0               16                4;
843    7.464               0               16                4;
844    7.473               0               16                4;
845    7.482               0               16                4;
846    7.491               0               16                4;
847    7.499               0               16                4;
848    7.508               0               16                4;
849    7.517               0               16                4;
```

```
850    7.526             0             16              4;
851    7.535             0             16              4;
852    7.544             0             16              4;
853    7.553             0             16              4;
854    7.561             0             16              4;
855    7.570             0             16              4;
856    7.579             0             16              4;
857    7.588             0             16              4;
858    7.597             0             16              4;
859    7.606             0             16              4;
860    7.615             0             16              4;
861    7.623             0             16              4;
862    7.632             0             16              4;
863    7.641             0             16              4;
864    7.650             0             16              4;
865    7.659             0             16              4;
866    7.668             0             16              4;
867    7.677             0             16              4;
868    7.685             0             16              4;
869    7.694             0             16              4;
870    7.703             0             16              4;
871    7.712             0             16              4;
872    7.721             0             16              4;
873    7.730             0             16              4;
874    7.739             0             16              4;
875    7.747             0             16              4;
876    7.756             0             16              4;
877    7.765             0             16              4;
878    7.774             0             16              4;
879    7.783             0             16              4;
880    7.792             0             16              4;
881    7.801             0             16              4;
882    7.809             0             16              4;
883    7.818             0             16              4;
884    7.827             0             16              4;
885    7.836             0             16              4;
886    7.845             0             16              4;
887    7.854             0             16              4;
888    7.863             0             16              4;
889    7.871             0             16              4;
890    7.880             0             16              4;
891    7.889             0             16              4;
892    7.898             0             16              4;
893    7.907             0             16              4;
894    7.916             0             16              4;
895    7.924             0             16              4;
896    7.933             0             16              4;
897    7.942             0             16              4;
```

```
   898    7.951                 0                 16                  4;
   899    7.960                 0                 16                  4;
   900    7.969                 0                 16                  4;
   901    7.978                 0                 16                  4;
   902    7.986                 0                 16                  4];

K=4.92, B=0.0018, J=0.00386;
Kp=0.1, Kd=0.005;
s=tf('s');
cltf=(K*Kp)/(J*s^2+(B+K*Kd)*s+K*Kp);
ltiview('step',cltf,0:0.1:10);

time = data(:,1);
y=data(:,3);
u=data(:,4);
plot(time,y);
hold on;
plot(time,u);
```