APPENDIX A

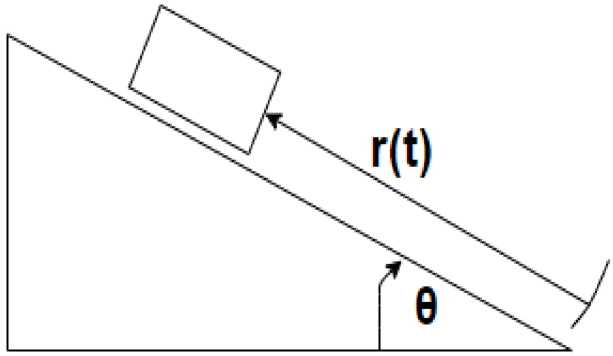

Figure 1: linear DC motor mechanical side diagram.

The bar slips on the rail with an incline under the influence of the frictional force. Due to the incline, the potential energy is present in the system and the magnetic force act as the applied force to control the movement of the bar.

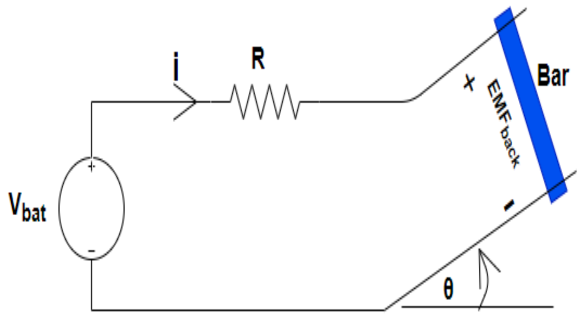

Figure 2: linear DC motor electrical side diagram.

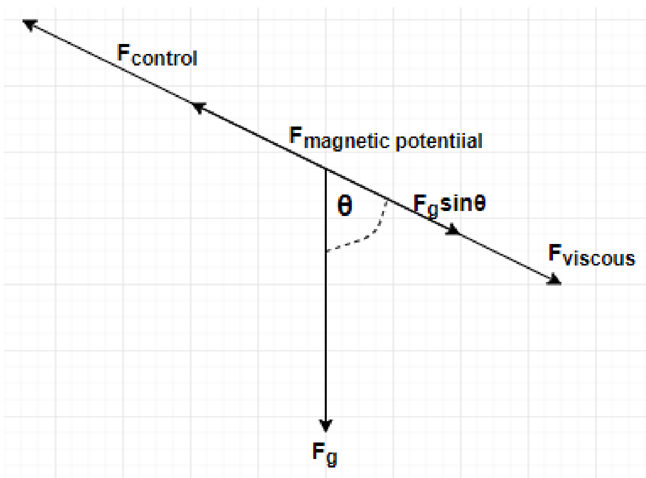

Figure 3: linear DC motor free body diagram.

APPENDIX B

Table 1: Parameters for the linear DC motor.

PARAMETERS	VALUE
Mass (m)	0.280kg
Length (l)	0.9m
Resistor (R)	1.2Ω
Voltage (V_{motion})	5V
Viscous coeffcient (b)	0.08

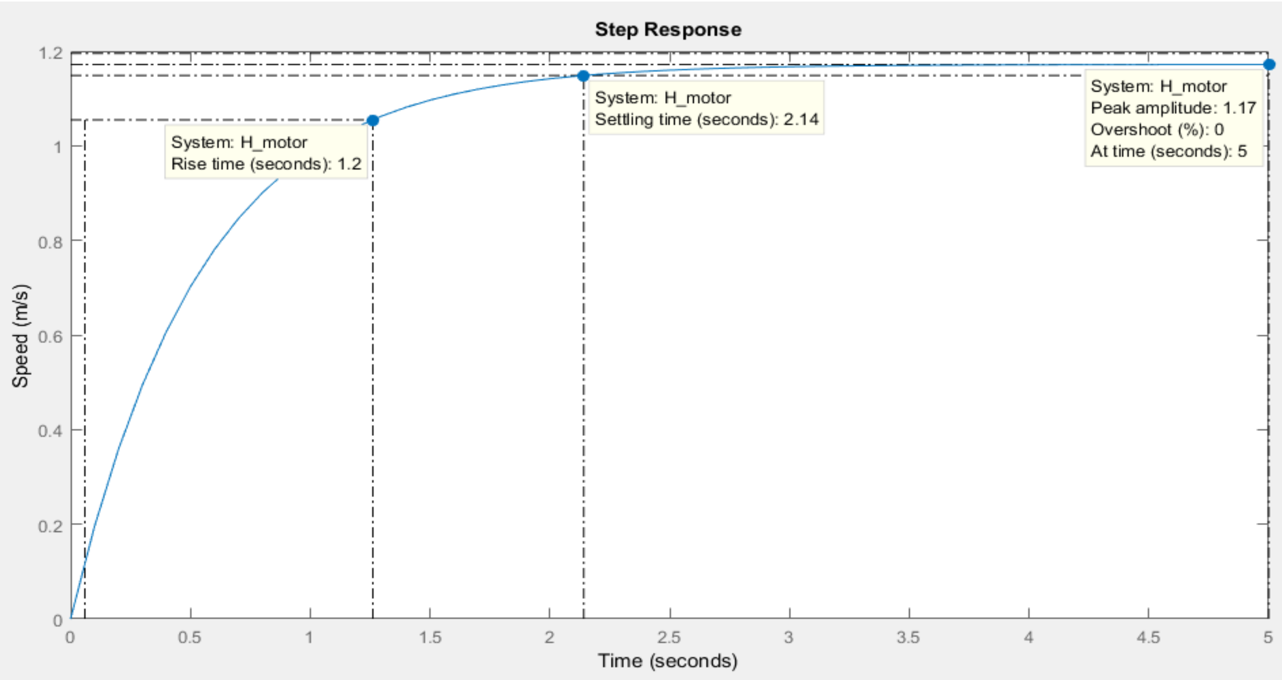

Figure 4: Uncompensated system velocity step response.

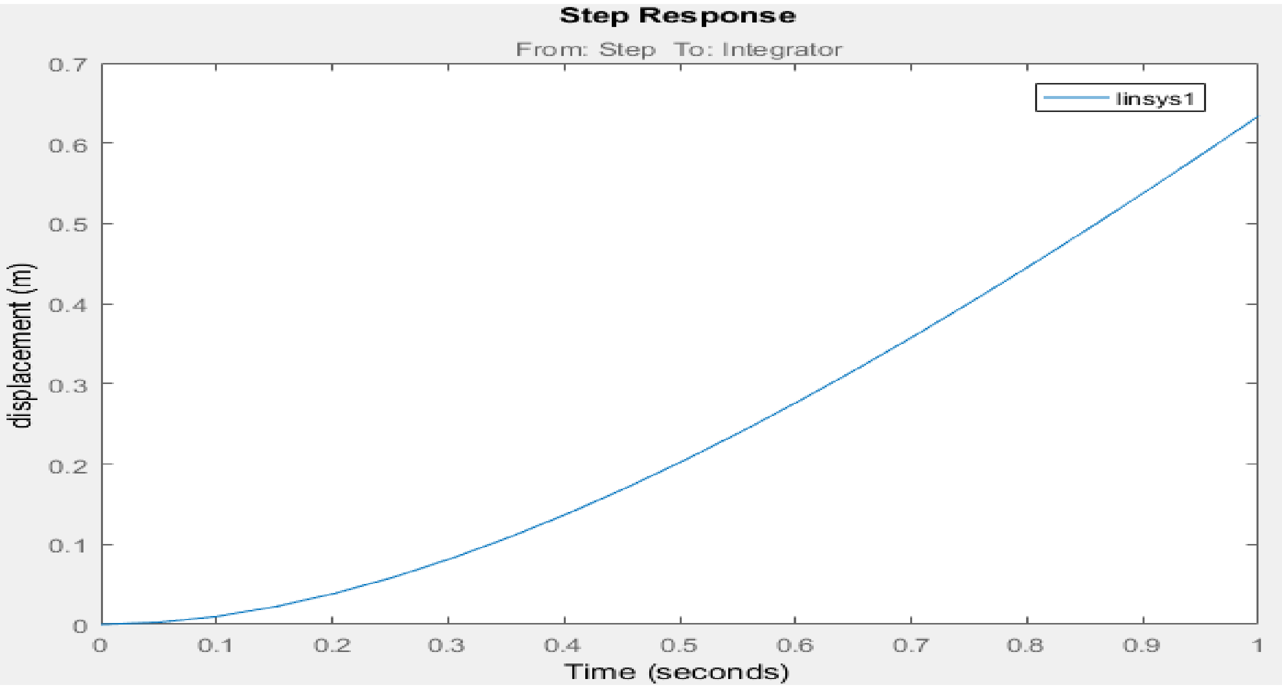

Figure 5: Uncompensated system displacement step response.

APPENDIX C

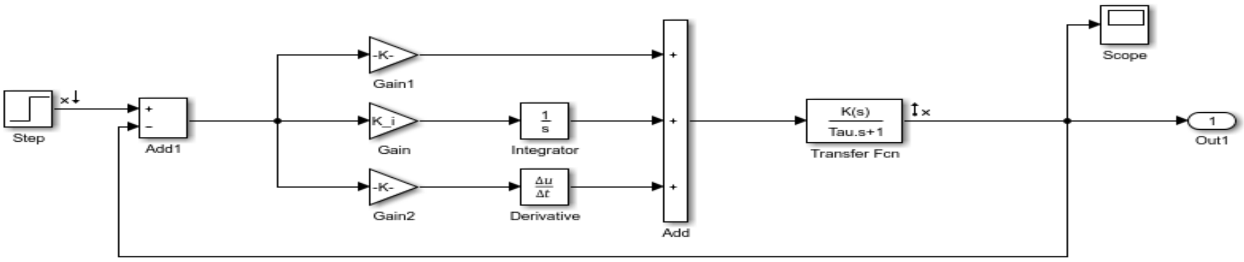

Figure 6: Plant with PID controller.

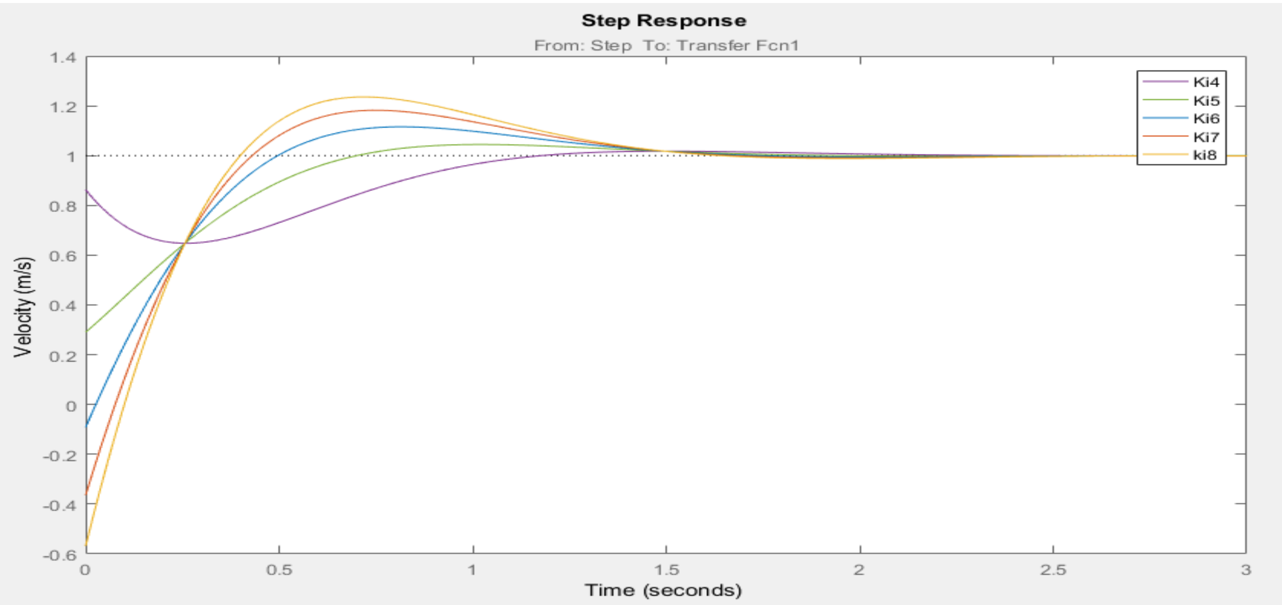

Figure 7: Step response for varies values of K_I.

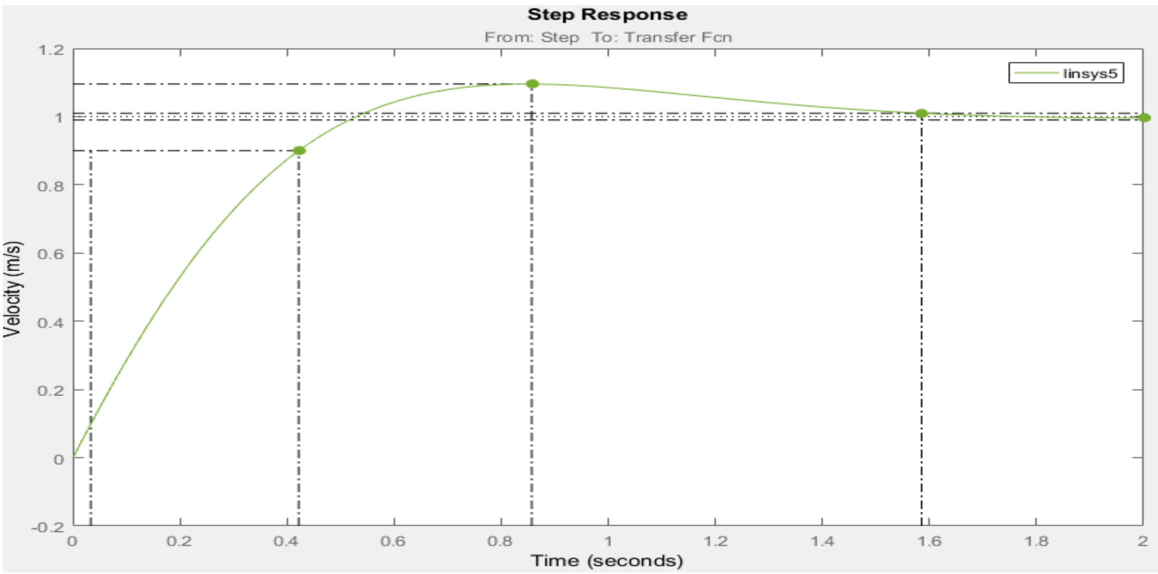

Figure 8: Step response for varies values of K_I.

APPENDIX D

Table 2: Step response data for various values of K_I.

K_I value	Rise time (s)	Overshoot (%)	Settling time (s)
4	1.10	1.74	1.97
5	0.56	4.5	1.55
6	0.37	11.6	1.46
7	0.35	18.2	1.43
8	0.33	23.6	1.42

Table 3: Effect of PID on the Design requirements.

	Rise time	Steady State	Overshoot
P	Decrease	Decrease	Increase
I	Decrease	Eliminated	Increase
D	None	None	Decrease

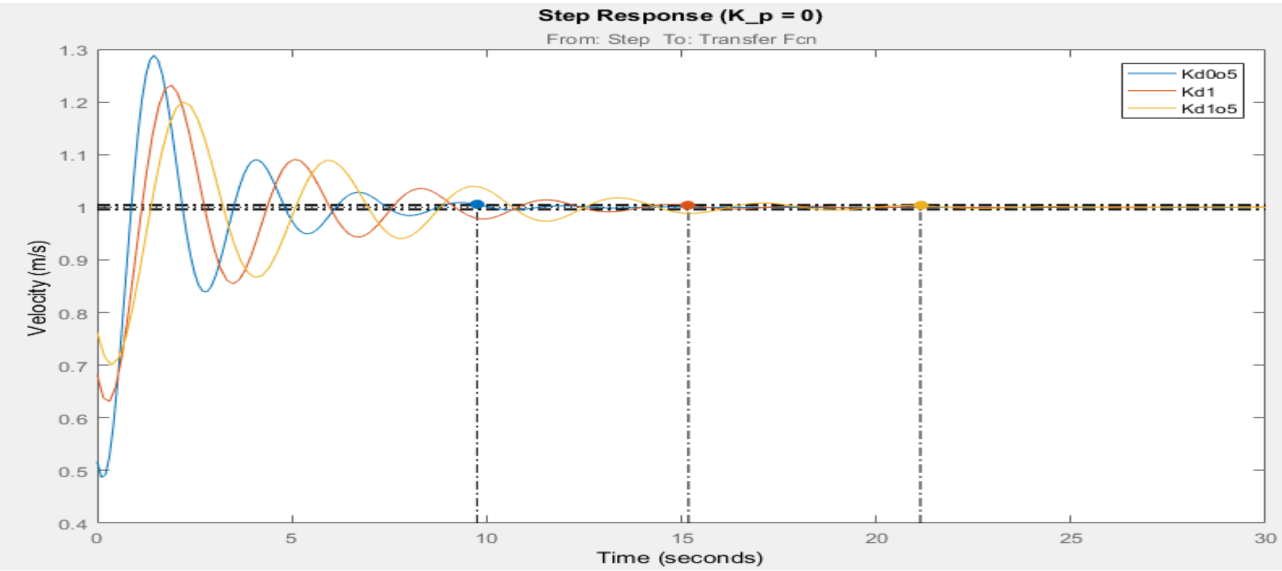

Figure 9: Step response with locked K_I at 5.72 and K_p set to zero.

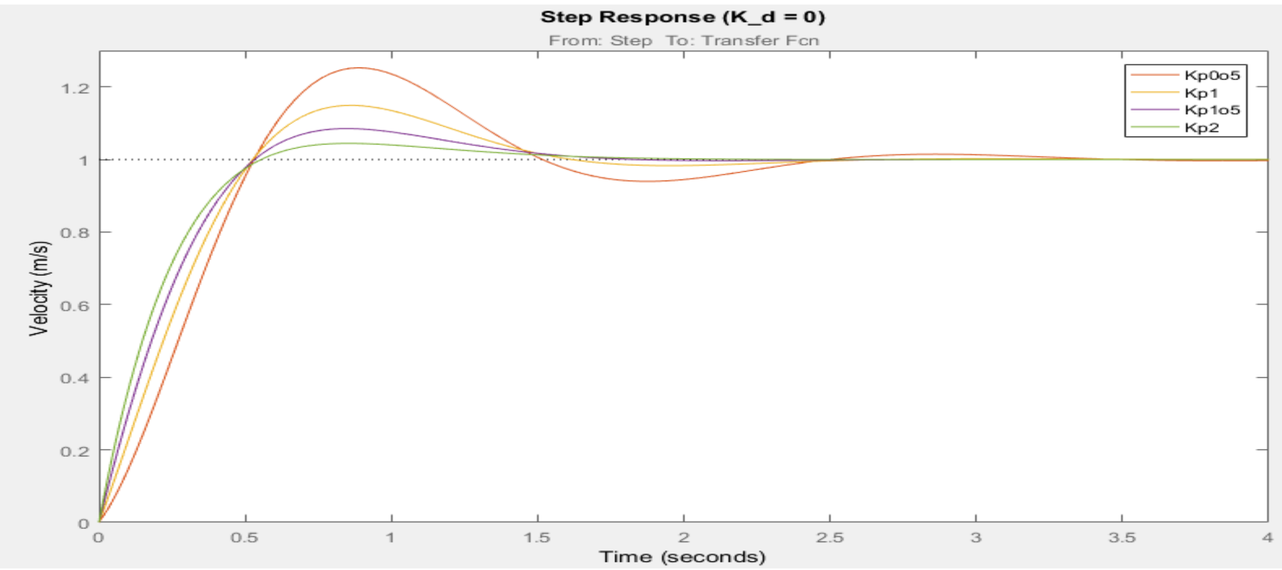

Figure 10: Step response with locked K_d at 5.72 and K_d set to zero.

APPENDIX E

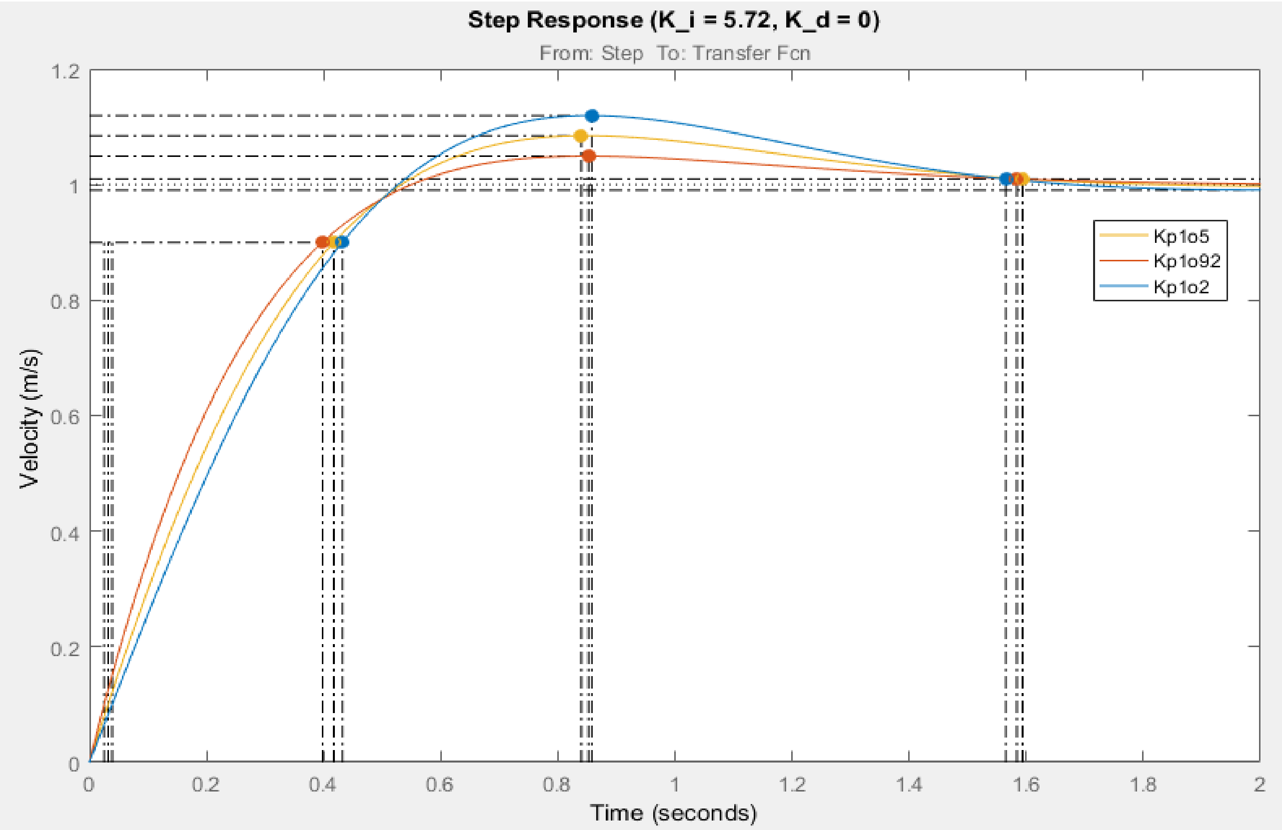

Figure 11: Selecting step response that meet the design requirement and to obtain the value of K_p.

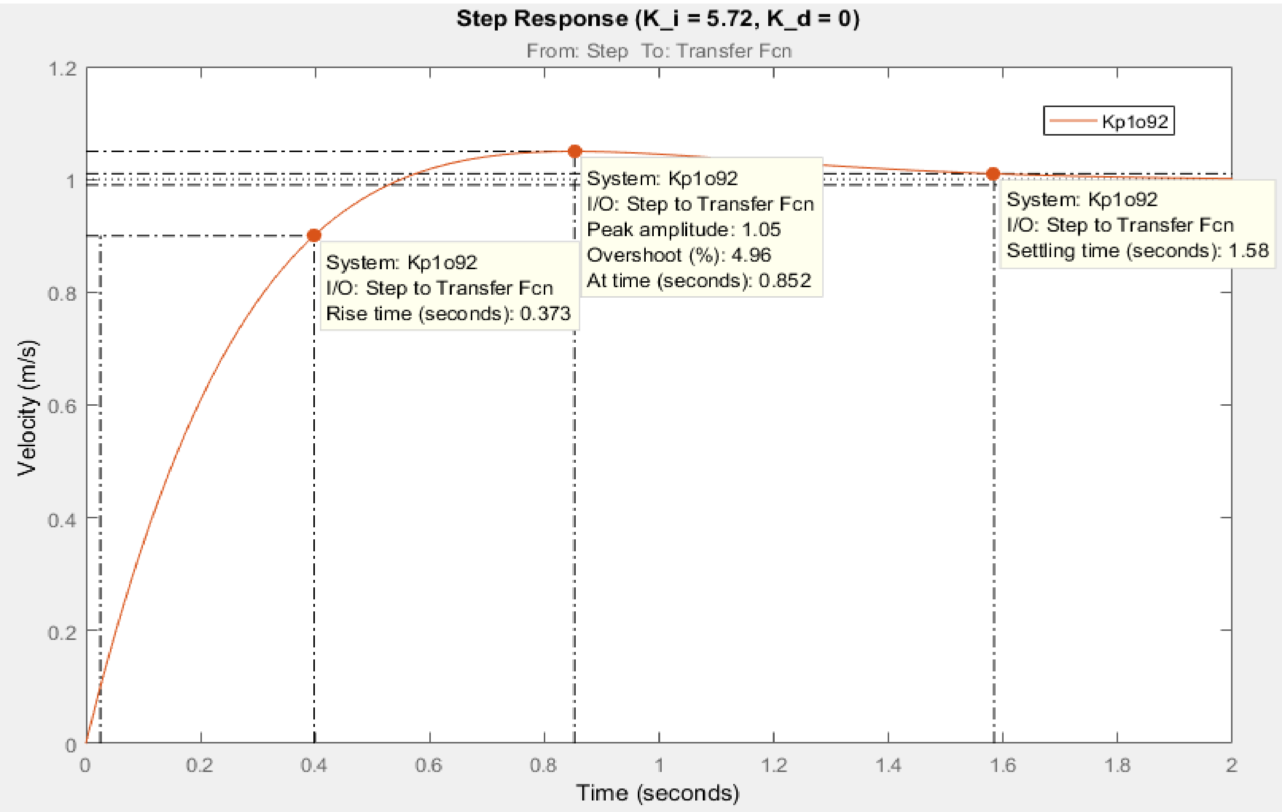

Figure 12: The final compensated system step response that satisfy the design requirements.

APPENDIX F

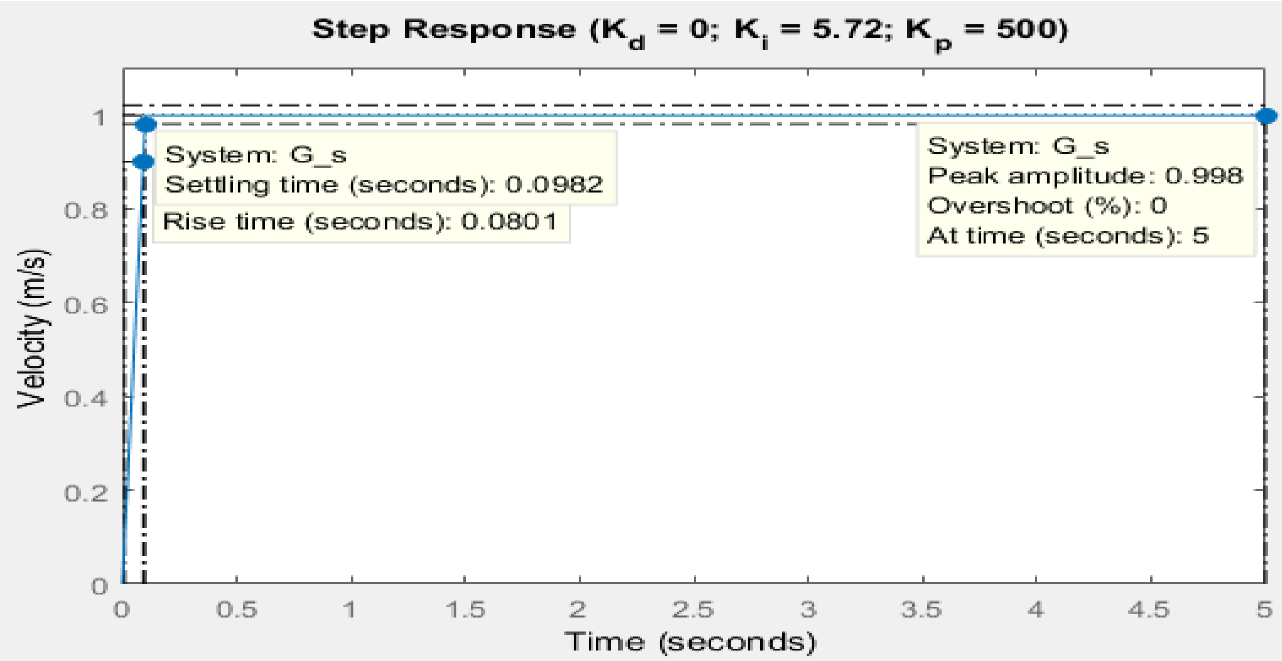

Figure 13: Step response for large value of K_p.

Mathematical proof that PI controller turn to P when K_p approaches infinity

Close loop transfer function of the first order plant compensated with PID controller is represented by equation 1 below.

$$G(s) = \frac{\frac{(K_p \cdot s + K_I + K_d s^2) \cdot K}{\tau + K_d \cdot K}}{s^2 + (\frac{1 + K_p \cdot K}{\tau + K_d \cdot K}) \cdot s + \frac{K_I \cdot K}{\tau + K_d \cdot K}} \tag{1}$$

Since the value of K_d is equal to zero the, system is now compensated by a PI controller instead PID which is shown by equation 2 below.

$$G(s) = \frac{\frac{(K_p \cdot s + K_I) \cdot K}{\tau}}{s^2 + (\frac{1 + K_p \cdot K}{\tau}) \cdot s + \frac{K_I \cdot K}{\tau}} \tag{2}$$

Dividing the numerator and denominator of (2) with K_p, and introducing the limit of K_p approaching infinity gives equation 3 below.

$$\lim_{K_p \to \infty} G(s) = \frac{\frac{K}{\tau} \cdot s + \frac{K_I K}{\tau K_p}}{\frac{1}{K_p} \cdot s^2 + \frac{1}{\tau K_p} \cdot s + \frac{K}{\tau} \cdot s + \frac{K_I K}{\tau K_p}} = \frac{\frac{K}{\tau} \cdot s}{\frac{K}{\tau} \cdot s} = 1 \tag{3}$$

With the results obtained in equation 3, it is clear that $K_p \gg K_I$ and therefore equation 3 under this conditions can be represented by equation 4 below.

$$G(s) = \frac{\frac{K_p K}{\tau} \cdot s}{s^2 + \frac{K_p K}{\tau} \cdot s} = \frac{K_p K}{\tau \cdot s + K_p K} \tag{4}$$

The results of equation 4 gives the close loop transfer function with P controller for a first order plant. The missing value of 1 in the denominator is due to fact that $K_p \gg 1$ and therefore that value add no significance.