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Homework 2 No 1

Make a model of a single–link manipulator for the following data:

Jm = 2.5e^{-4} kg*m2;

Kb = 0.105 V/(rad/s);

Km = 0.105 N*m/A;

L = 0.9 e^{-3} H;

R = 0.76 Ω;

Bm = 4e^{-4} N*m/(rad/s);

r=156;

under saturation limits of the manipulator input signal: **Vmin** = –35 V, **Vmax** = 35 V.

For this first step, a model is created using Simulink, each variable is declared with a corresponding name in the workspace, a final gain of 1/r is added to get from the arm position. Torque load disturbance is eliminated because in this case, it is 0.

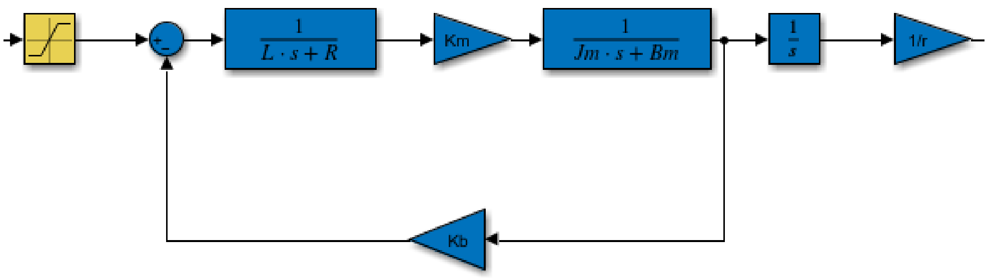

Figure 1. Image of the accurate model.

The figure 1 shows the simulated model in which every variable has the given data declared in the workspace as the figure 2.

B	0.0149
Bm	4.0000e-04
J	2.5000e-04
Jm	2.5000e-04
Kb	0.1050
Km	0.1050
L	9.0000e-04
r	156
R	0.7600

Figure 2. Image of declared variable of accurate and simplified model.

For the simplified model, we have calculated the effective damping (B) from equation (1) and the model is also created, the torsional load disturbance is eliminated because in this case, it is still 0N*m.

$$\boldsymbol{B} = Bm + \frac{Kb*Km}{R} = 4e^{-4} + \frac{0.105*0.105}{0.76} = 0.0149 \tag{1}$$

Figure 3. Image of simplified model.

To corroborate that the impact of model simplification in our results is a minimum simulation using a step signal (Step time: 0.5s, Initial value: 0, Final value: 1) is run. The step signal is input to both systems and the scope is connected to the output of both systems and the resulting step.

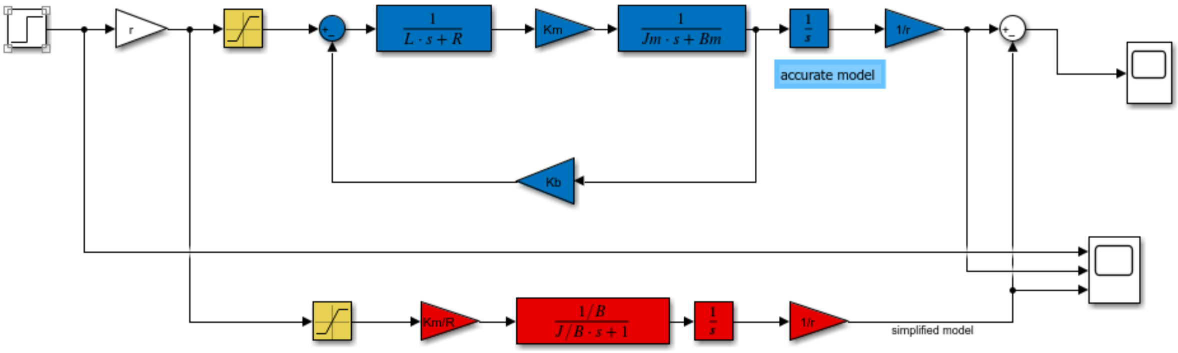

Figure 4. Image of accurate model vs simplified model.

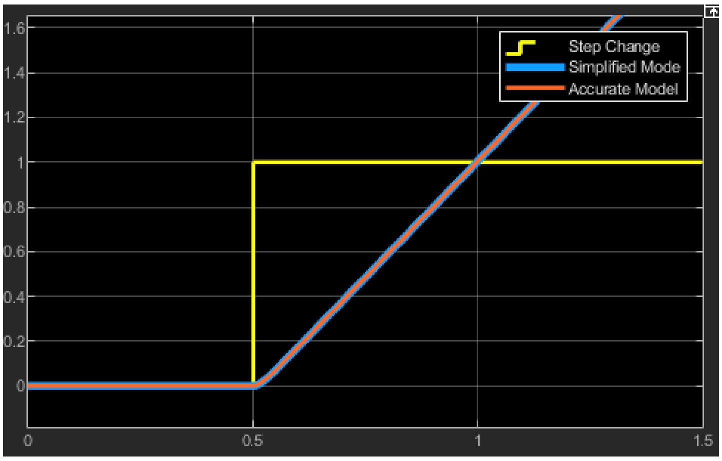

Figure 5. Image of accurate model vs simplified model output vs time.

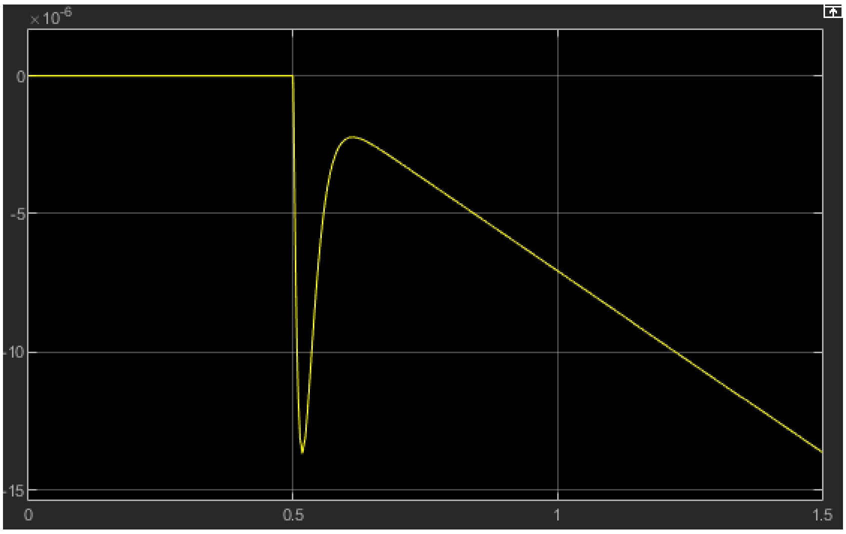

Figure 6. Image of difference between accurate model vs simplified model.

As we can observe for a short period of time (1.5s) of simulation the error is less than 0.00001358 [rad] in the arm's position.

For the next step we want to apply PD control it is necessary to calculate the value of de Kp and Kd for this we know that we want a maximum control error of 0.01 and a minimum of 0.005 (from the path of a cubic polynomial with s(0) = 0, Θ's(0) = 0, s(1) = 0.5 's(1) = 0) so we will propose some w and as a basis this modification to get the desired result. For simulating trajectories of cubic polynomials created using the polynomial trajectory tool from the robot tool for MATLAB.

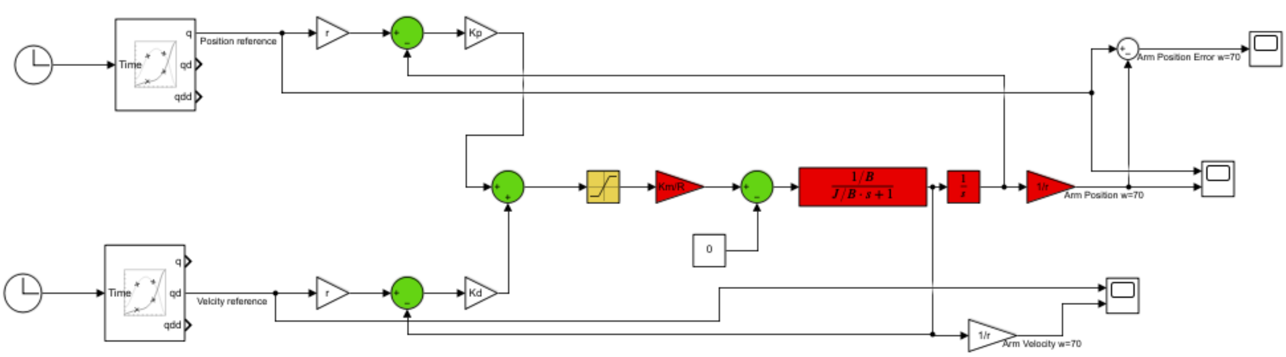

Figure 7. Simplified model with PD implemented.

We start with w = 60 then:

$$\boldsymbol{Kp} = \frac{W^2 JR}{Km} = \frac{60^2 * 2.5e^{-4} * 0.76}{0.105} = 6.514 \tag{2}$$

$$\boldsymbol{Kd} = \frac{R}{Km}(2wJ - B) = \frac{0.76}{0.105}(2 * 60 * 2.5e^{-4} - 0.0149) = 0.1092 \tag{3}$$

The error is bigger than 0.01 so this value of w is no useful, now a value of w=75 is proposed:

$$\boldsymbol{Kp} = \frac{W^2JR}{Km} = \frac{75^2 * 2.5e^{-4} * 0.76}{0.105} = 10.1785 \qquad (4)$$

$$\boldsymbol{Kd} = \frac{R}{Km}(2wJ - B) = \frac{0.76}{0.105}(2 * 75 * 2.5e^{-4} - 0.0149) = 0.163 \qquad (5)$$

With this value the error is around 0.008 so is a value acceptable, we will work with this value.

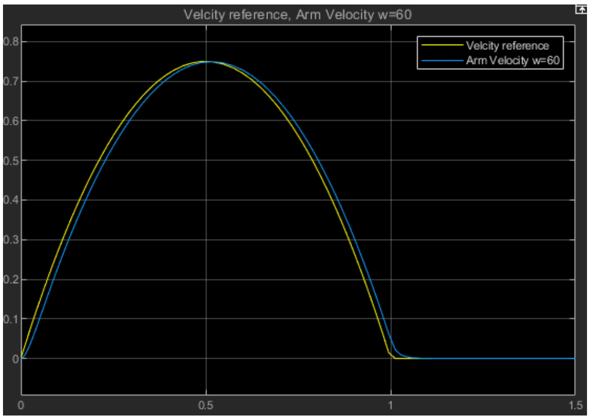

Figure 8. Reference vs Arm velocity w=60

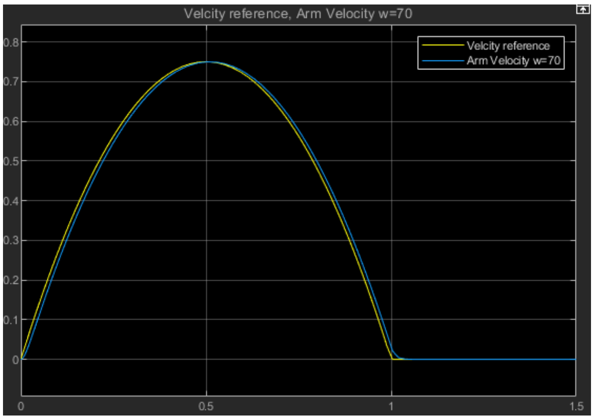

Figure 9. Reference vs Arm velocity w=70

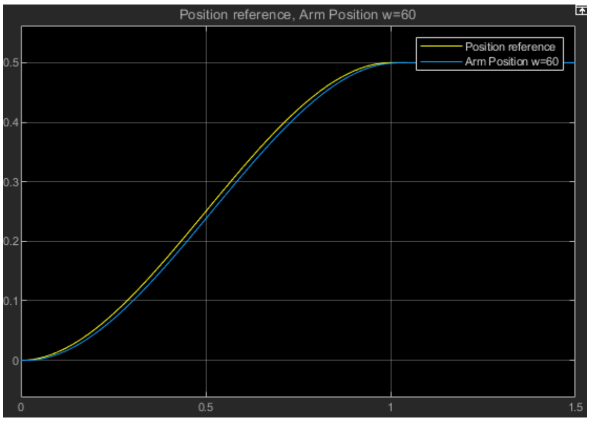

Figure 10. Reference vs Arm position w=60

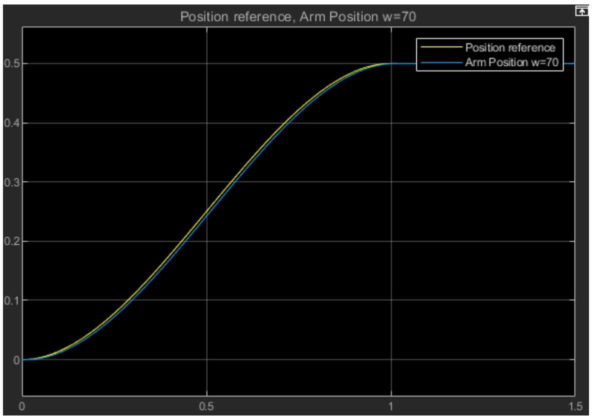

Figure 11. Reference vs Arm position w=70

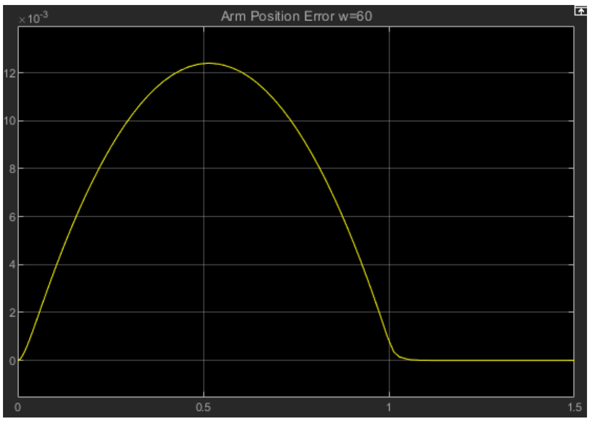

Figure 12. Arm position error w=60

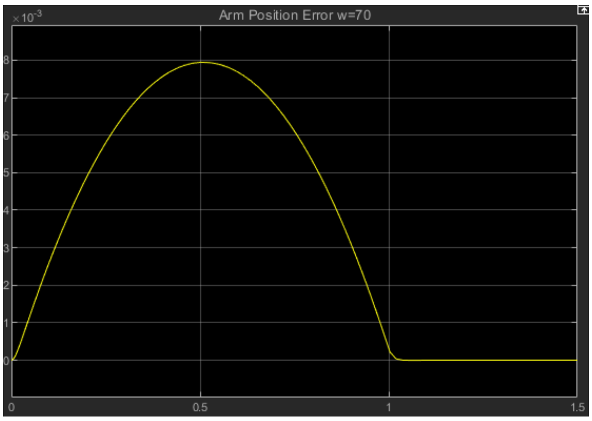

Figure 13. Arm position error w=70

Modifying the structure of the control system we will analyze the behaviour for a step change with a path from s(0) = 0 to s(1) = 0.5.

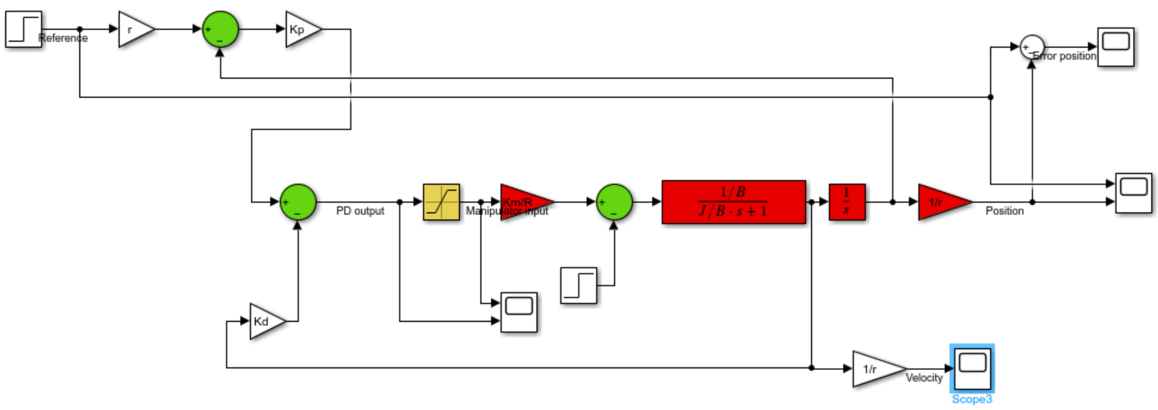

Figure 14. Modified PD control with input step.

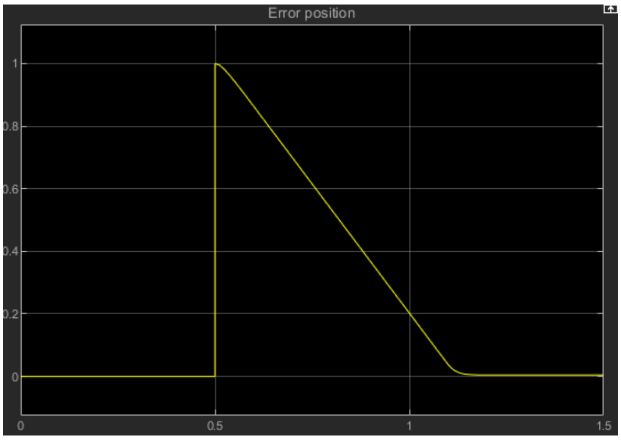

Figure 15. Arm position error for step change.

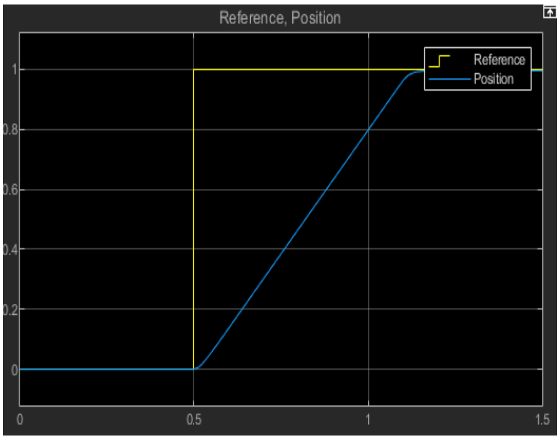

Figure 16. Reference vs arm position for step change.

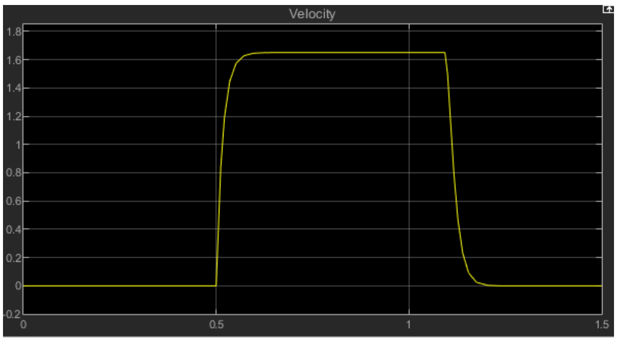

Figure 17. Velocity for step change.

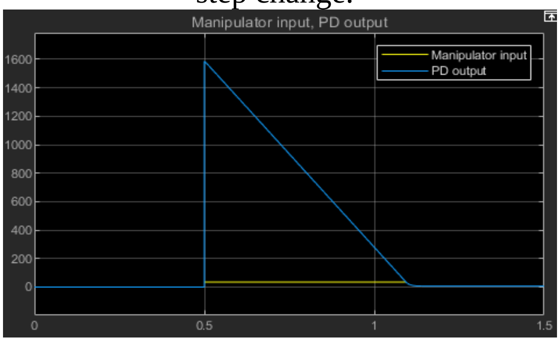

Figure 18. PD output vs manipulator input for step change.

For the next step the cubic path is replaced with the LSPB path with s(0) = 0, s(1) = 0,5, t0 = 0, tf=1 and tb = 0,2, the control system remains the same unless the input signal is changed to trapezoid Velocity Profile Trajectory, also from the robotic toolbox for MATLAB, w remains 75 so that Kp = 10.1785 and Kd = 0.163.

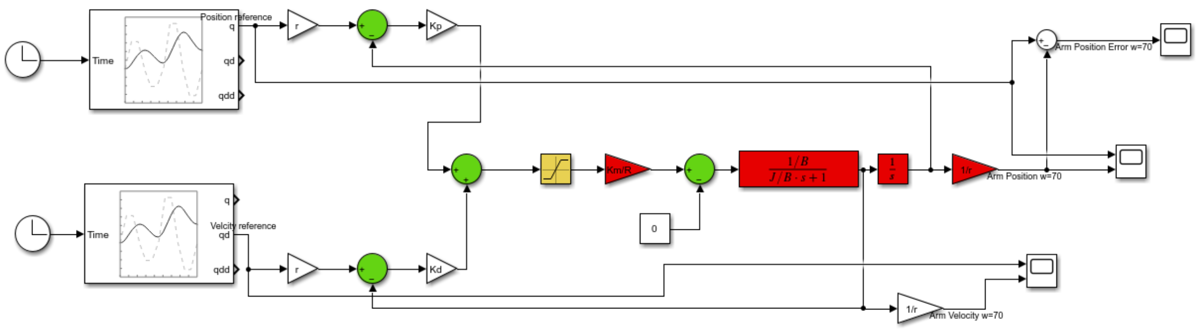

Figure 19. Control system with LSPB trajectory.

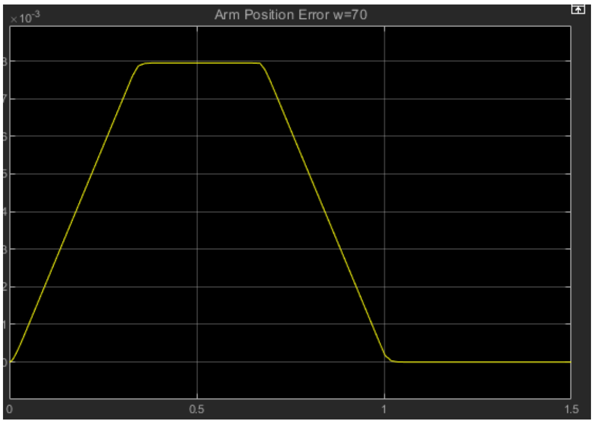

Figure 20. Arm position error, PD control, LSPB trajectory, w=75, d(t)=0N*m.

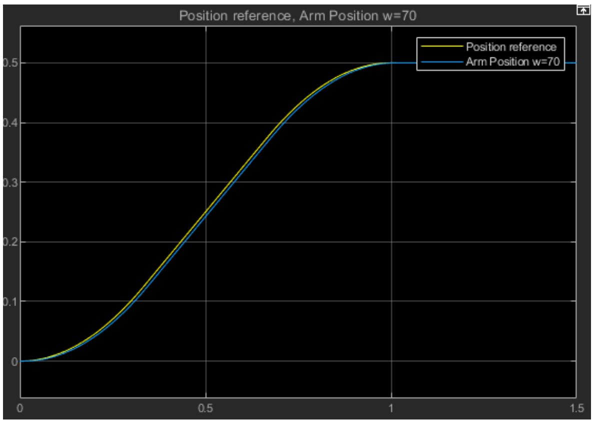

figure 21. Reference vs Arm position, PD control, LSPB trajectory, w=75, d(t)=0N*m.

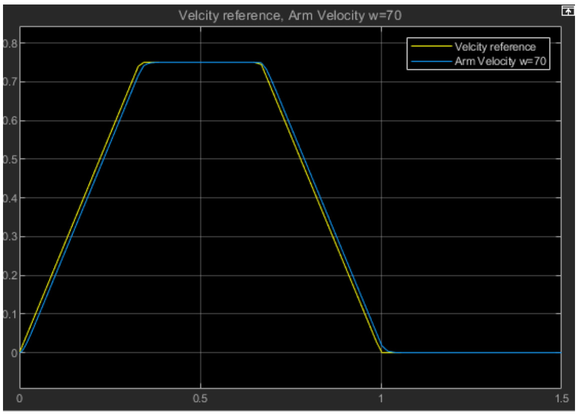

Figure 22. Reference vs Arm velocity, PD control, LSPB trajectory, w=75, d(t)=0N*m.

Now we will simulate the same PD control system, but we will have the load disturbance as a constant of 2 N*m, which means we will make slight modifications to our system (simply add a constant disturbance load) and again generate information for the cubic and LSPB track as well.

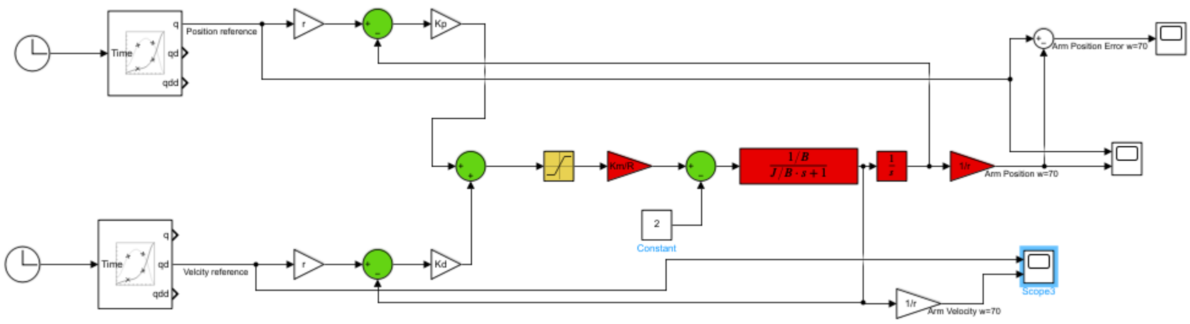

Figure 23. Control PD system with constant load disturbance = 2, cubic trajectory.

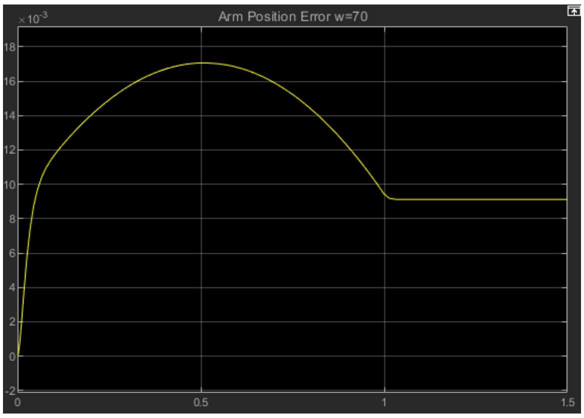

Figure 24. Arm position error, PD control, cubic trajectory, w=75, d(t)=2N*m.

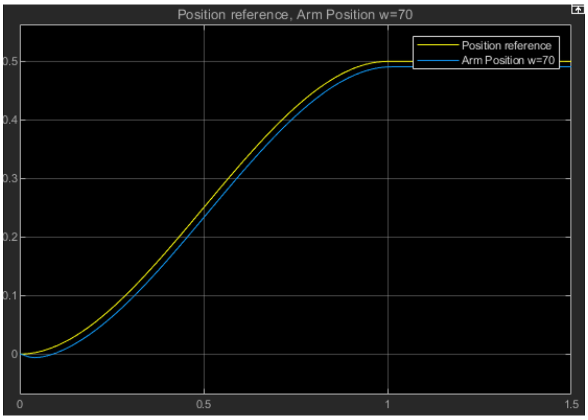

figure 25. Reference vs Arm position, PD control, cubic trajectory, w=75, d(t)=2N*m.

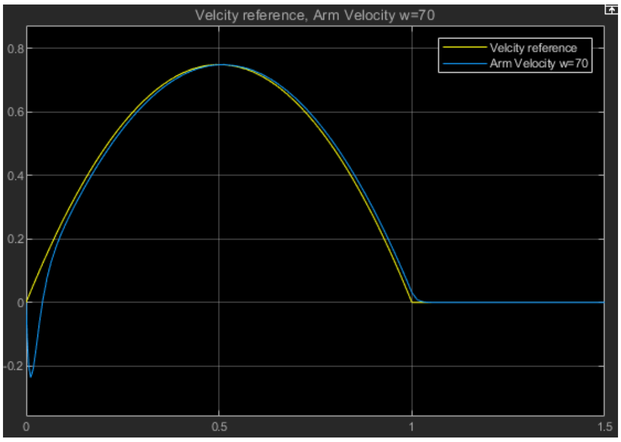

Figure 26. Reference vs Arm velocity, PD control, cubic trajectory, w=75, d(t)=2N*m.

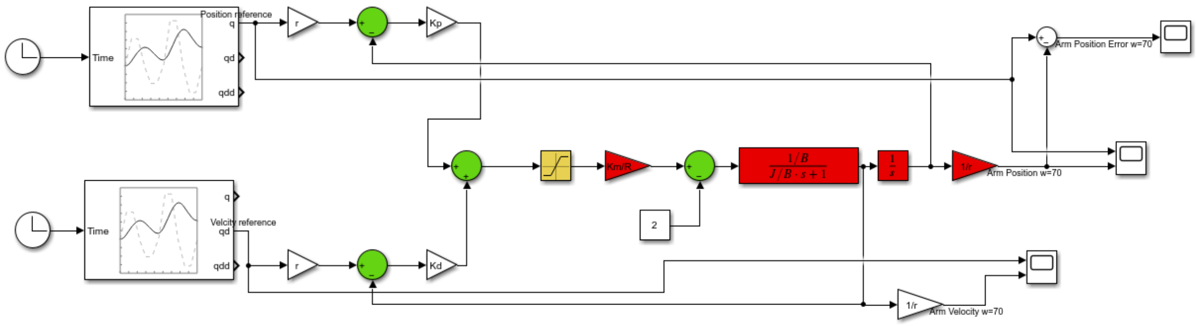

Figure 27. Control PD system with constant load disturbance = 2, LSPB trajectory.

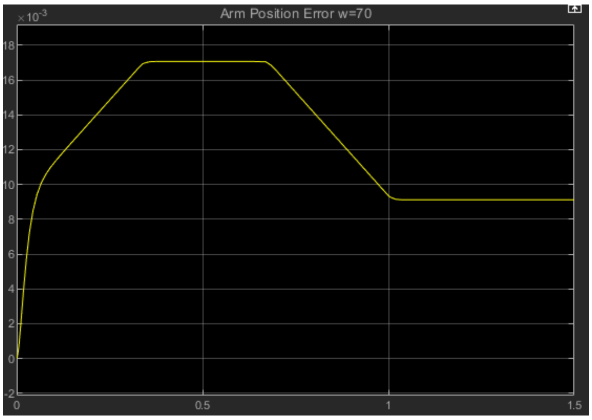

Figure 28. Arm position error, PD control, LSPB trajectory, w=75, d(t)=2N*m.

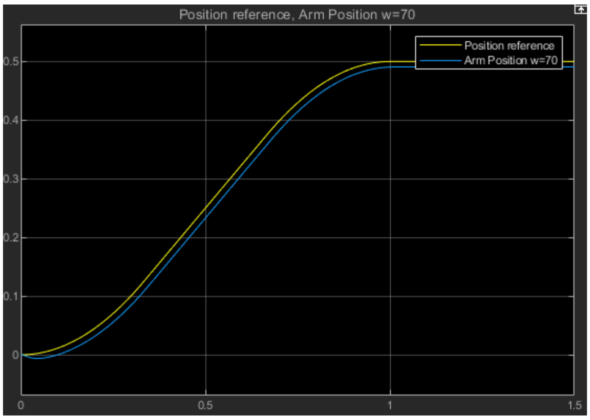

figure 29. Reference vs Arm position, PD control, LSPB trajectory, w=75, d(t)=2N*m.

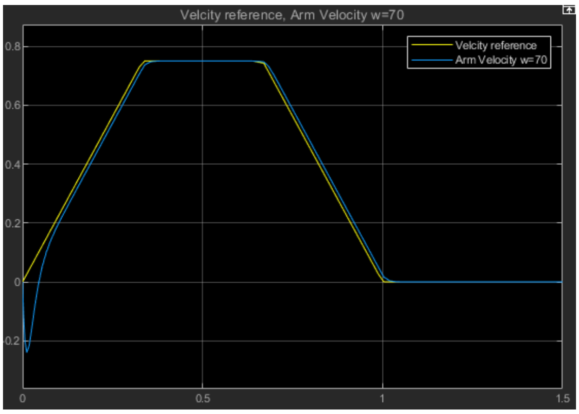

Figure 30. Reference vs Arm velocity, PD control, LSPB trajectory, w=75, d(t)=2N*m.

Now it's time to design the PID control, we'll start with the same w=75 and see how it goes.

$$\boldsymbol{Kp} = \frac{3JRw^2}{Km} = \frac{3*2.5e^{-4}*0.76*75^2}{0.105} = 30.535 \tag{6}$$

$$\boldsymbol{Kd} = \frac{R}{Km}(3wJ - B) = \frac{0.76}{0.105}(3 * 75 * 2.5e^{-4} - 0.0149) = 0.299 \tag{7}$$

$$\boldsymbol{Ki} = \frac{JRw^3}{Km} = \frac{2.5e^{-4}*0.76*75^3}{0.105} = 763.392 \tag{8}$$

We implemented this control system with PID.

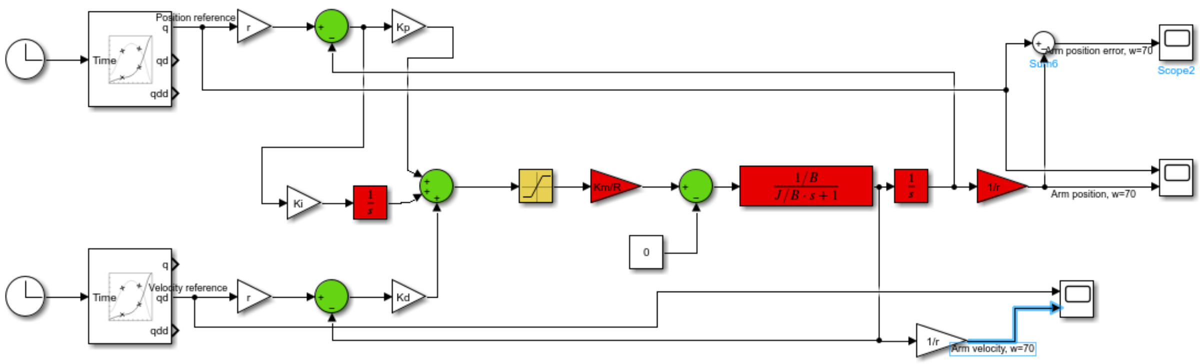

Figure 31. PID control system.

But the results in the arm error position it is too small, around 0.000377 we will try with w=25.

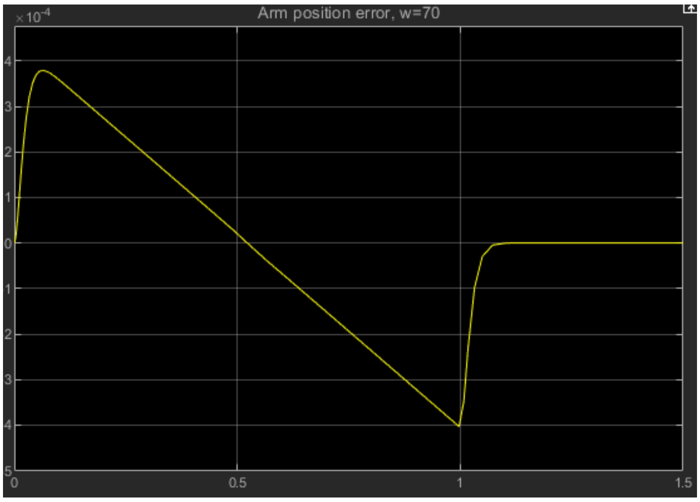

Figure 32. Arm position error, PID control, cubic trajectory, w=75, d(t)=0N*m.

Now we will use w = 25 to obtain the PID value and the better error.

$$\boldsymbol{Kp} = \frac{3JRw^2}{Km} = \frac{3*2.5e^{-4}*0.76*25^2}{0.105} = 3.392 \tag{8}$$

$$\boldsymbol{Kd} = \frac{R}{Km}(3wJ - B) = \frac{0.76}{0.105}(3 * 25 * 2.5e^{-4} - 0.0149) = 0.027 \tag{9}$$

$$\boldsymbol{Ki} = \frac{JRw^3}{Km} = \frac{2.5e^{-4}*0.76*25^3}{0.105} = 28.273 \tag{10}$$

And the results are satisfactory, the error is around 0.08 so is acceptable to work with this value.

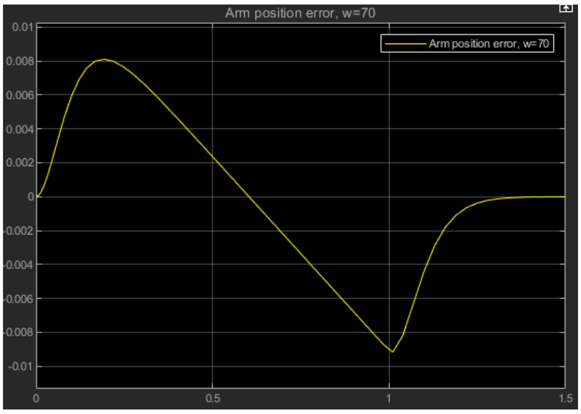

Figure 33. Arm position error, PID control, cubic trajectory, w=25, d(t)=0N*m.

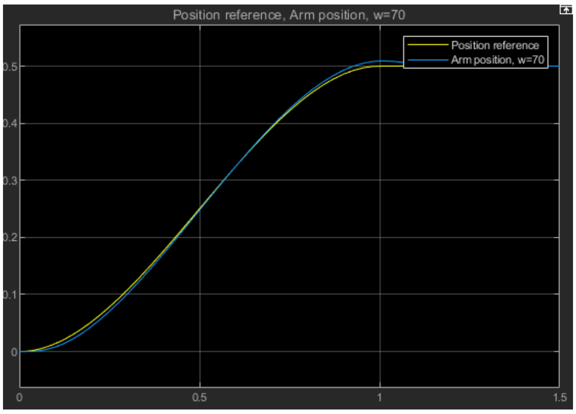

figure 34. Reference vs Arm position, PID control, cubic trajectory, w=25, d(t)=0N*m.

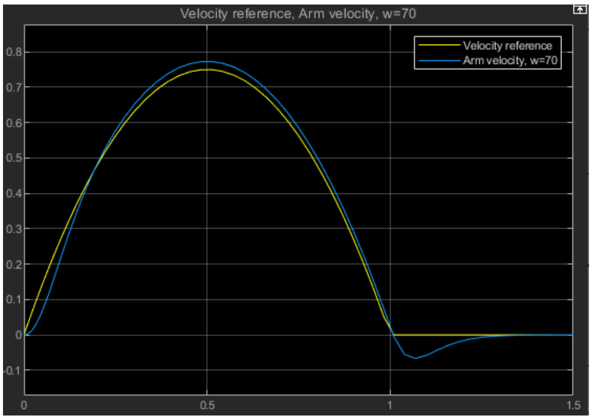

Figure 35. Reference vs Arm velocity, PID control, cubic trajectory, w=25, d(t)=0N*m.

Now we will simulate the same cubic trajectory but with a constant torque load disturbance = 2N*m, the results are these:

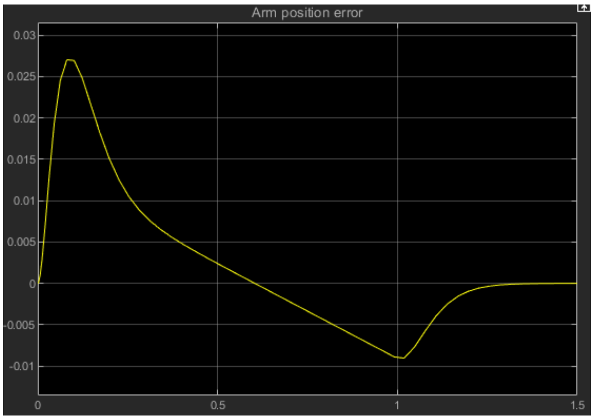

Figure 36. Arm position error, PID control, cubic trajectory, w=25, d(t)=2N*m.

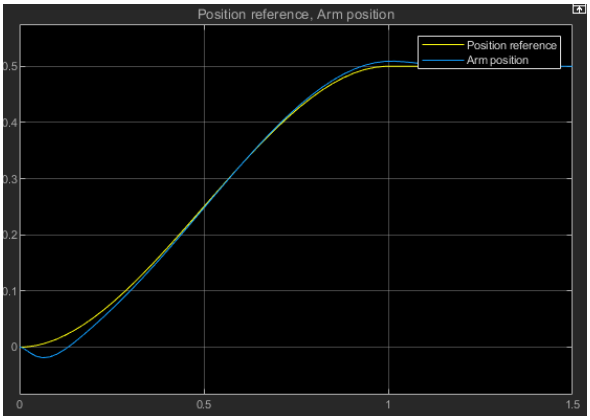

Figure 37. Reference vs Arm position, PID control, cubic trajectory, w=25, d(t)=2N*m.

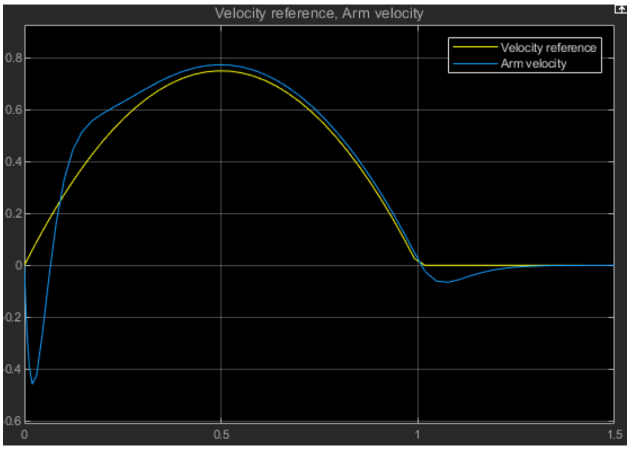

Figure 38. Reference vs Arm velocity, PID control, cubic trajectory, w=25, d(t)=2N*m.

Now we will modify the trajectory to a LSPB, and we will simulate the system with the same w=25.

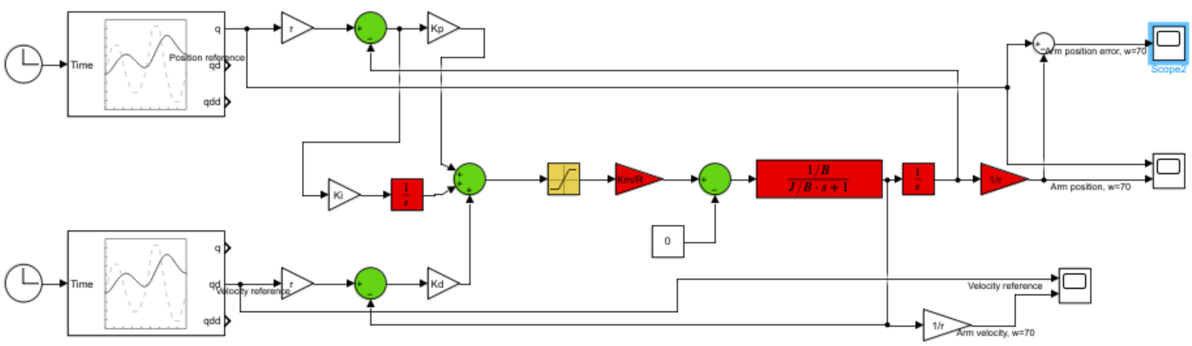

Figure 39. Control PID system with constant load disturbance, LSPB trajectory.

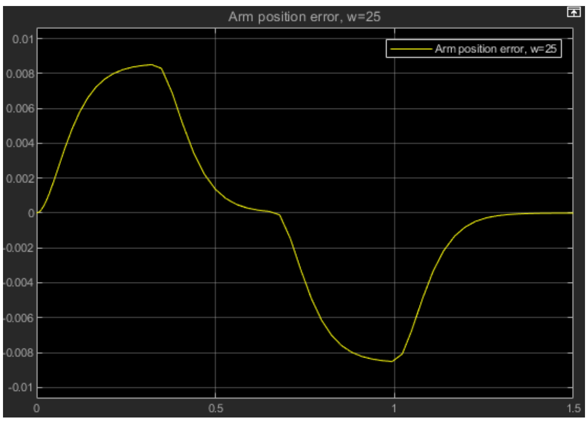

Figure 40. Arm position error, PID control, LSPB trajectory, w=25, d(t)=0N*m.

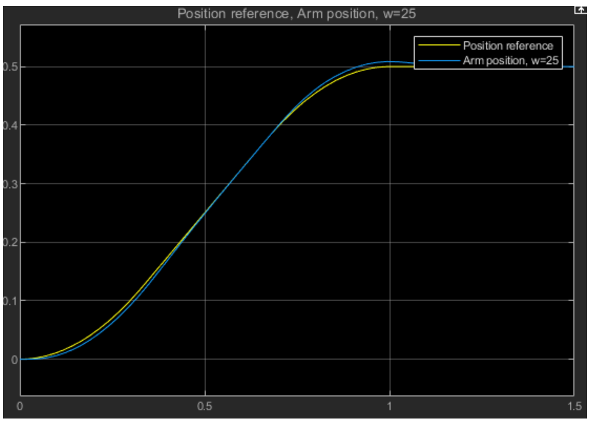

Figure 41. Reference vs Arm position, PID control, LSPB trajectory, w=25, d(t)=0N*m.

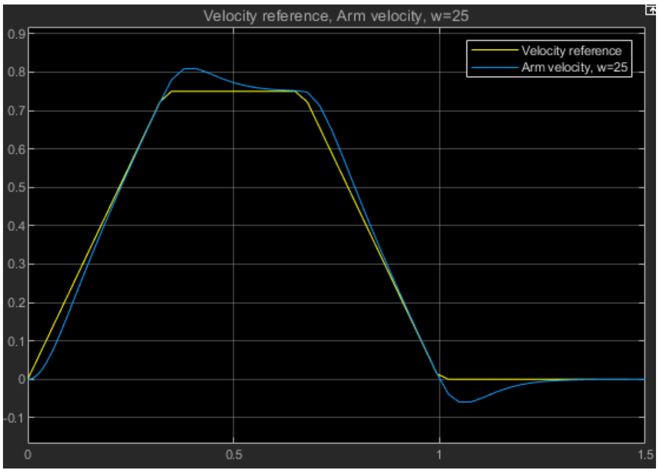

Figure 42. Reference vs Arm velocity, PID control, LSPB trajectory, w=25, d(t)=0N*m.

Now for a constant load disturbance = 2N*m.

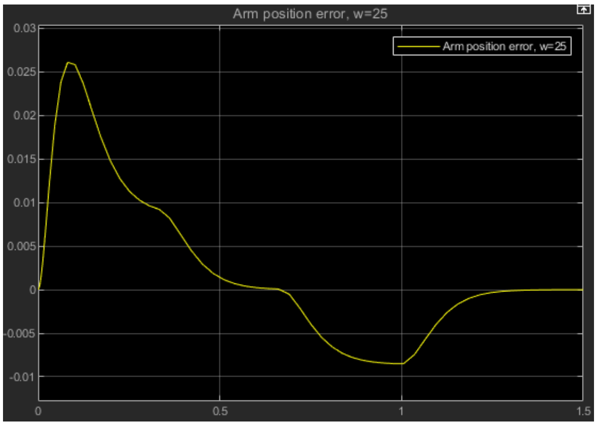

Figure 43. Arm position error, PID control, LSPB trajectory, w=25, d(t)=2N*m.

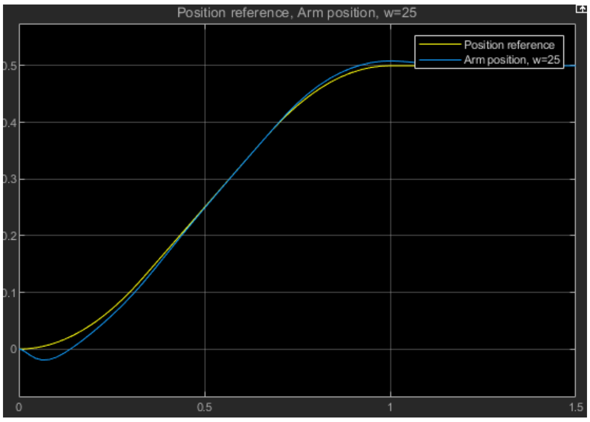

Figure 44. Reference vs Arm position, PID control, LSPB trajectory, w=25, d(t)=2N*m.

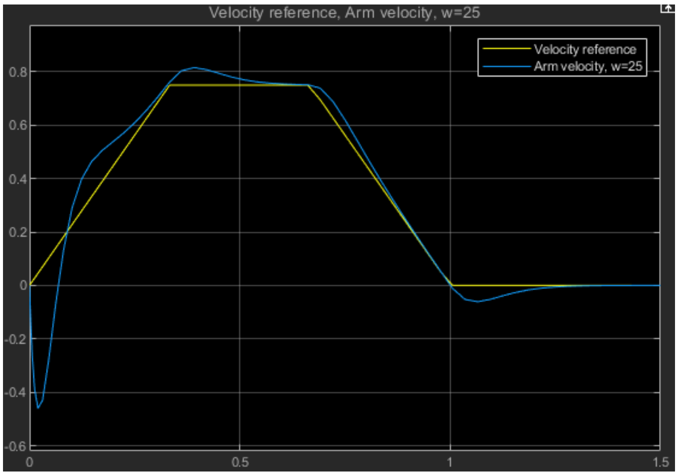

Figure 45. Reference vs Arm velocity, PID control, LSPB trajectory, w=25, d(t)=2N*m.

Now we will examine the behaviour of the PID controller, for this, we will modify the structure of the control system and we will add anti-windup, where K=Ki/Kp. This is the result:

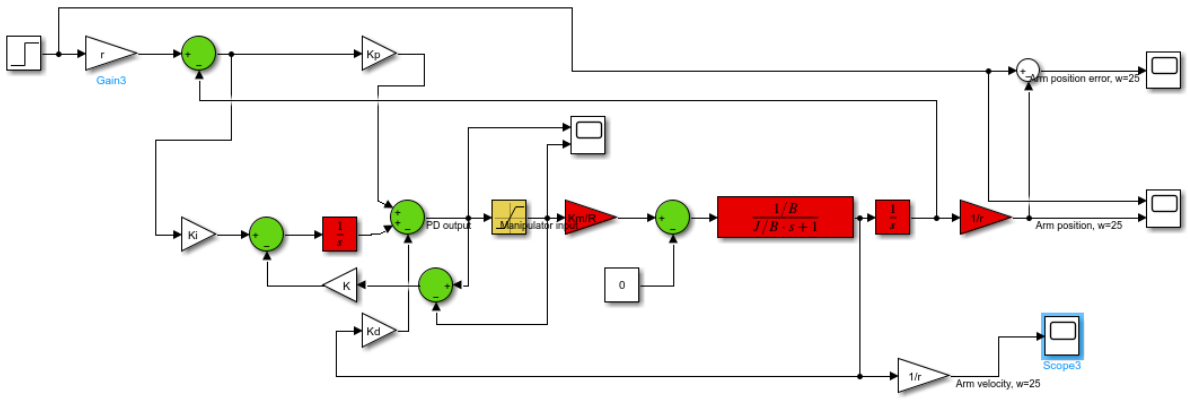

Figure 46. PID control system with anti-windup implemented.

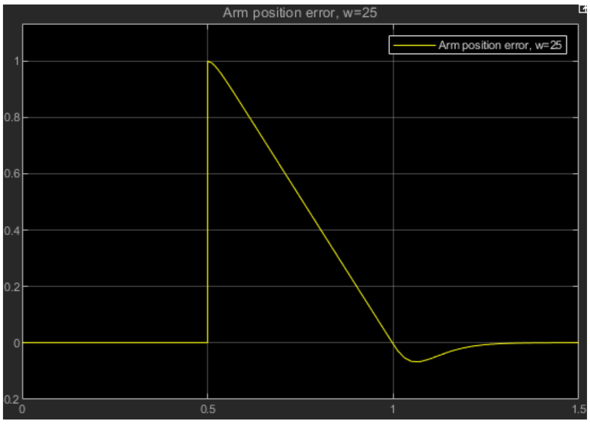

Figure 47. Arm position error, PID control, Step change, w=25, d(t)=0N*m.

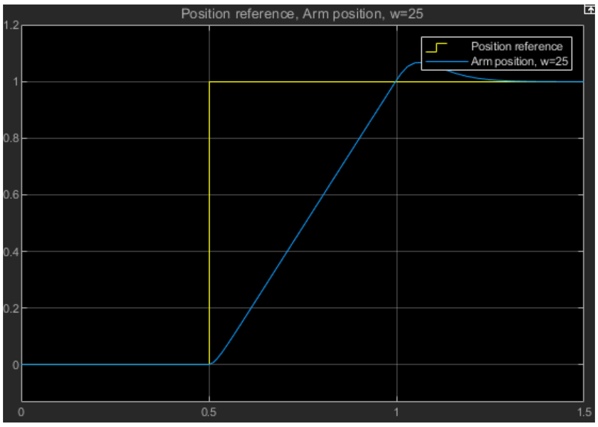

Figure 48. Reference vs Arm position, PID control, Step change, w=25, d(t)=0N*m.

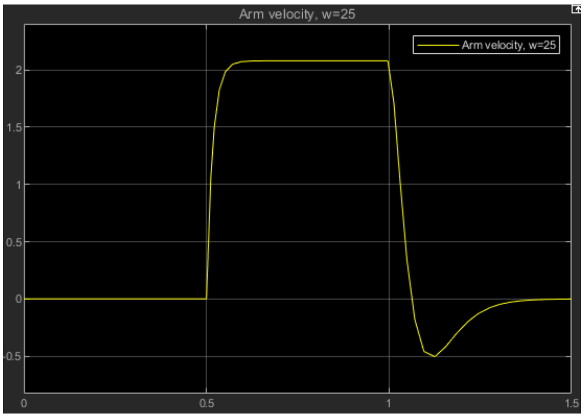

Figure 49. Arm velocity, PID control, Step change, w=25, d(t)=0N*m

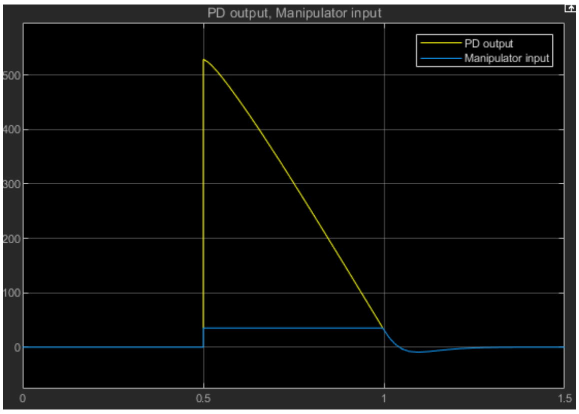

Figure 50. PID output vs manipulator input, PID control, Step change, w=25, d(t)=0N*m.

As a final step, we will apply feedforward control to the existing PID feedback control, the system will have a sinusoidal arm reference path with amplitude Θ max=0.25 [rad] and corner frequency $w^{ref} = \alpha/5$, where $\alpha = 25$. The implemented system looks like this:

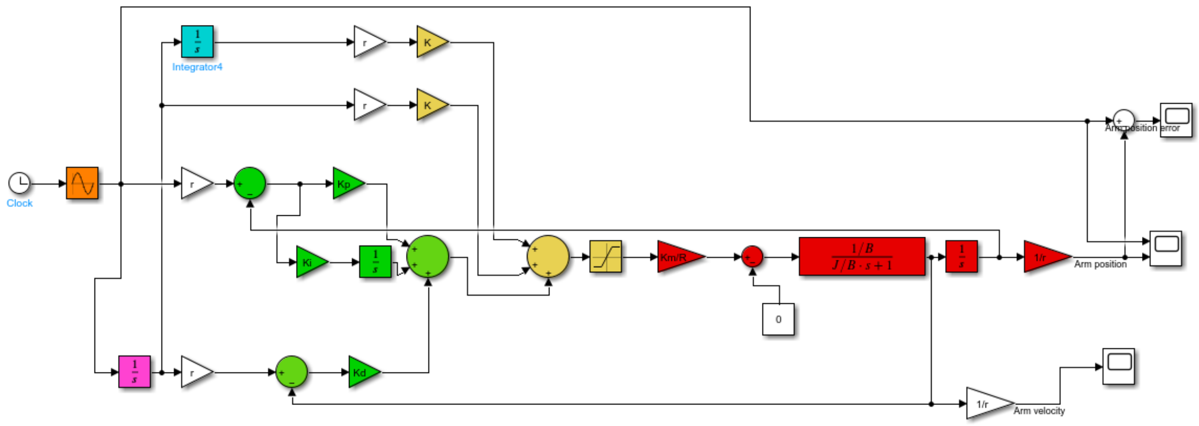

Figure 51. Feedforward PID control system.

In the previous figure the control system is represented in red, PID feedback in green, feedforward in yellow, Θ with orange, Θ’ with magenta and Θ’’ with cyan. The value of w remains 25, with this we make a sinusoidal with an amplitude of 0.25, and a frequency = α /4, then we integrate once to get Θ’ and integrate twice to get Θ’’, the result is as follows.

Figure 52. Arm position error, Feedforward PID control, sinusoidal trajectory, w=25, d(t)=0N*m.

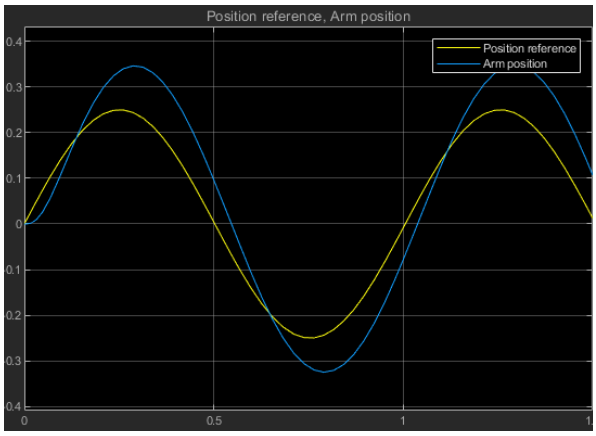

Figure 53. Reference vs Arm position, Feedforward PID control, sinusoidal trajectory, w=25, d(t)=0N*m.

Now the same sinusoidal signal but without the feedforward.

Figure 54. Arm position error, PID control, sinusoidal trajectory, w=25, d(t)=0N*m.

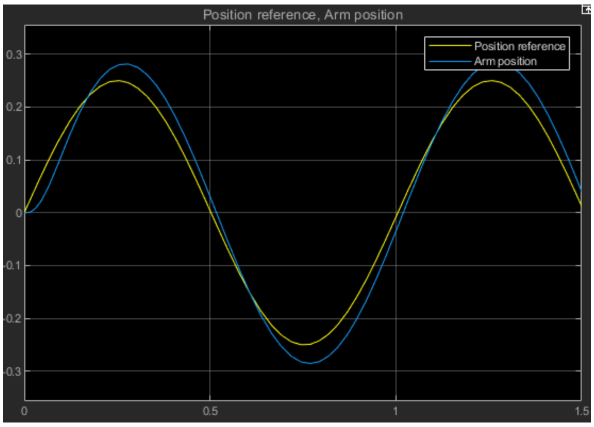

Figure 55. Reference vs Arm position, PID control, sinusoidal trajectory, w=25, d(t)=0N*m.

The results were not similar, and the arm position of the PID control without Feedforward was closer to the reference.