

Aled Edgell Assignment 2

by Aled Edgell

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Assignment 2

Aled Edgell

Electrical Principles,
Method And
Simulation
PSDE 5009

13/05/2018

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Figure 17: P, PI and PID controller Simulink results.

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1. First order control system

In this part of the assignment the overall transfer function will be found to determine weather or not the first order system stable.

The transfer function for this circuit is found by carrying out the following calculations:

$$\frac{G(s)}{1+G(s)+1(s)} \quad G(s) = \frac{3.6}{s-0.42} \quad H(s) = 1$$

+ 1(s) is incorrect, should be simply multiplied by 1

$$T(s) = \frac{\frac{3.6}{(s-0.42)}}{1 + \frac{3.6}{(s-0.42)} * 1}$$

The top and bottom of the equation is then multiplied by s-0.42

$$T(s) = \frac{3.6}{s-0.42+3.6} = \frac{3.6}{s+3.18}$$

To manually calculate the pole the following equation will be used

$$s+3.18=0$$

$$s=-3.18$$

This will place the pole in the left hand plane indicating that this is a stable circuit while it is a closed loop pole. However if it were an open loop pole.

$$s-0.42=0$$

$$s=0.42$$

Which will place the pole in the right hand plane making it unstable and because of the type of circuit this will result in a continuous rise. To resolve this issue the minimum gain required to make the first order control system stable must be used the calculations for this can be seen below.

$$H(s) = K \quad T1(s) = \frac{\frac{3.6}{(s-0.42)}}{1 + \frac{3.6}{(s-0.42)} + 3.6k} = \frac{3.6}{s+(3.6k-0.42)}$$

K is missing here

Pole is found when $s+3.6k-0.42=0$

So pole at $s=0$

$$0+3.6k-0.42=0$$

$$3.6k=0.42$$

$$k=0.117$$

This can be confirmed by placing the following equation into the matlab software

```
Num[3.6];
```

```
Den[1-0.42];
```

```
Rlocus(Num,Den);
```

Which will generate a root locus that will show the position of the pole and when a pointer is placed on 0 the minimum gain required to make the circuit stable (Figure 1).

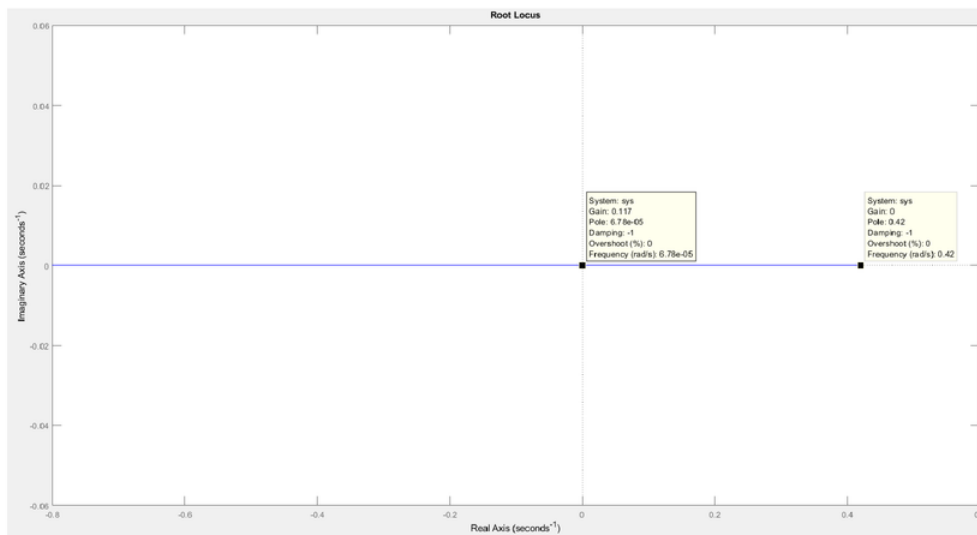


Figure 1: Root locus of first order control system.

As can be seen the pole has been marked on the far right with an x at 0.42 and the minimum gain has been found by placing a pointer as close to the 0 as possible.

The next step in this task is to create a Simulink model to test this. Three circuit were created with different gains to analyse the effect of changing the gain. The first one shows the circuit at its minimum point of stability as measured using the root locus (Figure 2).

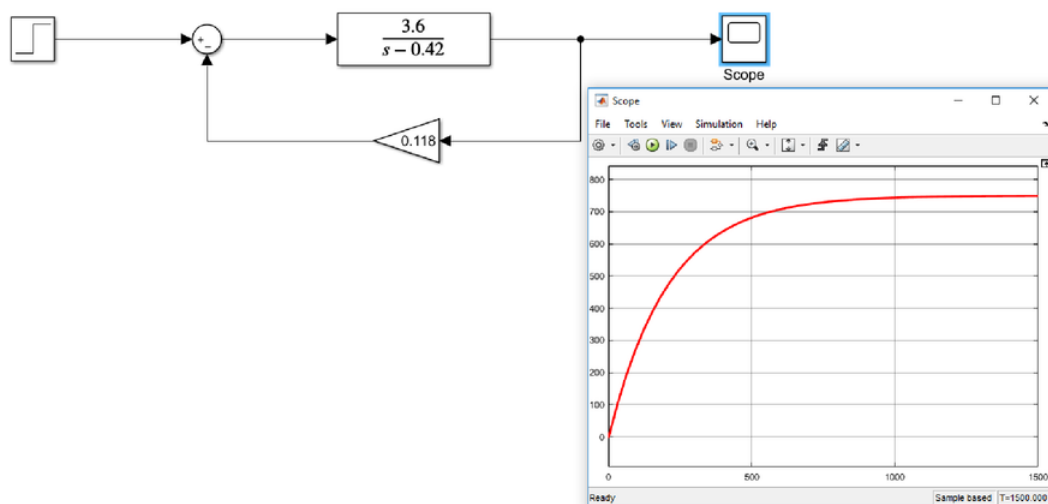


Figure 2: Minimum gain applied to first order control system.

As can be seen the circuit is critically damped when using the value for the minimum stability. The graph from the scope shows that it is stable as mentioned earlier if it were unstable it would continuously rise. For the next simulation the gain was increased past the minimum value required and the results were again recorded using the scope (Figure 3).

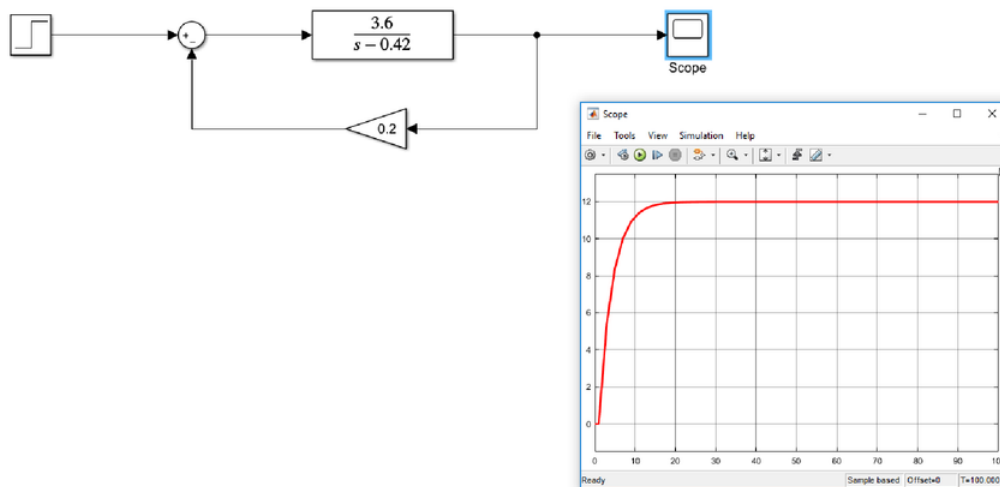


Figure 3: Higher value gain applied to first order control system.

you could have calculated the overall gain and the time constant

As can be seen the circuit has a much sharper reaction time because of the increased feedback, however it has also meant its reached a much lower value than the first as it

stabilized at 12. For the final simulation the value of the gain has been set below the minimum gain required to make it unstable (Figure 4).

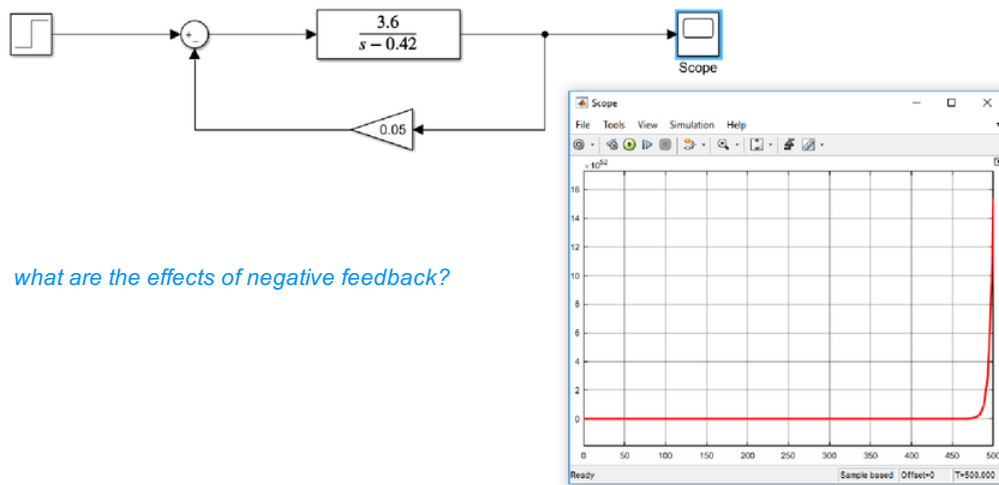


Figure 4: Lower value gain applied to first order control system.

As expected creating an unstable circuit has made it continuously rise, if the simulation had been run for longer it would have continued to rise, indicating that the first order control system is unstable.

The results from the three simulations carried out confirm the findings that were made using the calculations showing that the minimum gain calculated was correct and that if it was below that value the circuit would become unstable.

2. DC Motor Model Analysis

In this task a motor model will be created that will be simulated using the Simulink software to analyse the DC permanent magnet motor with the parameters set in the assignment. The first task is to develop the motor model and transfer function when the disturbance initially set to 0.

To calculate the transfer function for the motor the following calculations were used with the values given in the assignment.

$$G(s) = \frac{\frac{KT}{LaJ}}{s^2 + s\left(\frac{b}{J} + \frac{Ra}{La}\right) + \frac{Rab + KTK_e}{LaJ}} = \frac{8411.215}{s^2 + 156.0725s + 838.135}$$

you could have put the block diagram first

$$\frac{KT}{LaJ} = \frac{0.09}{0.05 * 0.000214} = 8411.215$$

$$\frac{b}{J} + \frac{Ra}{La} = \left(\frac{15.519 \times 10^{-6}}{0.000214}\right) + \left(\frac{7.8}{0.05}\right) = 156.0725$$

good development, well presented

$$\frac{Rab + KTK_e}{LaJ} = \left(\frac{7.8 * 15.519 \times 10^{-6} + 0.09 * 0.0983}{0.05 * 0.000214}\right) = 838.135$$

The values given in the assignment have been used to create a motor model in the Simulink software which can be seen below (Figure 5).

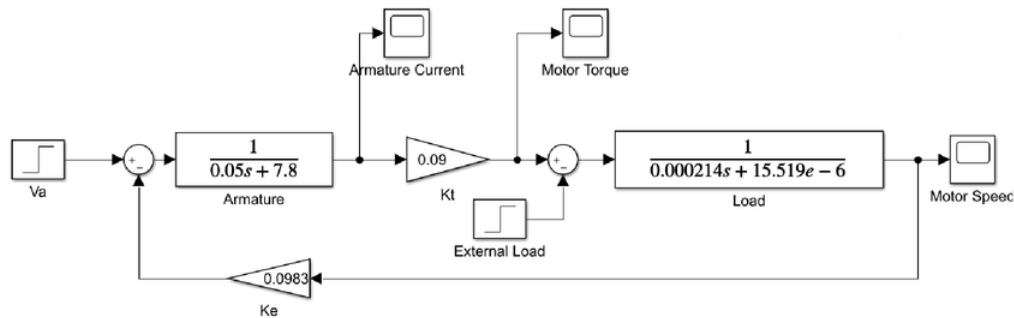


Figure 5: Motor model for DC Motor.

Using mathematical equations the damping factor, stall torque, no load speed and load speed with a disturbance of 0.025Nm can be found the workings out for these are shown below.

Using the following formula the damping effect of the circuit can be found if the value is 1 it is criticallydamped anything higher is overdamped and below is underdamped

$$\frac{kwn^2}{s^2 + 2\zeta wn + wn^2}$$

$$wn^2 = 838.135$$

$$wn = \sqrt{838.135} = 28.95\text{rad/s}$$

$$2\zeta\omega_n = 156.0725$$

$$\zeta = \frac{156.0725}{2 * 28.95} = 2.7$$

As stated earlier since the answer to the equation is higher than one this shows that the circuit is overdamped. The stall torque is calculated using.

$$\frac{KTv_a}{Ra} = 0.277Nm$$

No load speed is calculated using the equation.

$$\frac{KTv_a}{bRa + KTK_e} = 240.86rad/s$$

And the speed when there is a load applied is calculated using the following equation.

$$\frac{v_a - \frac{RaTL}{KT}}{\frac{RaL}{KT} + K_e} = 219.11rad/s$$

As with the first order control system an argand diagram can be produced to determine if the motor will be stable or unstable.

$$S^2 + 156.0725S + 838.135 = 0$$

Using a quadratic formula where a=1, b=156.0725 and c=838.135

$$s = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$= \frac{-156.0725 \pm \sqrt{156.0725^2 - 4 * 1 * 838.135}}{2}$$

$$= -5.57, -150.5$$

The argand diagram for this motor can be seen below (Figure 6). As can be seen in the argand diagram both poles are in the left hand plane indicating that this motor is stable, however as there are 2 poles the one located at -5.57 is the dominant pole as it is the closest to the 0 point.

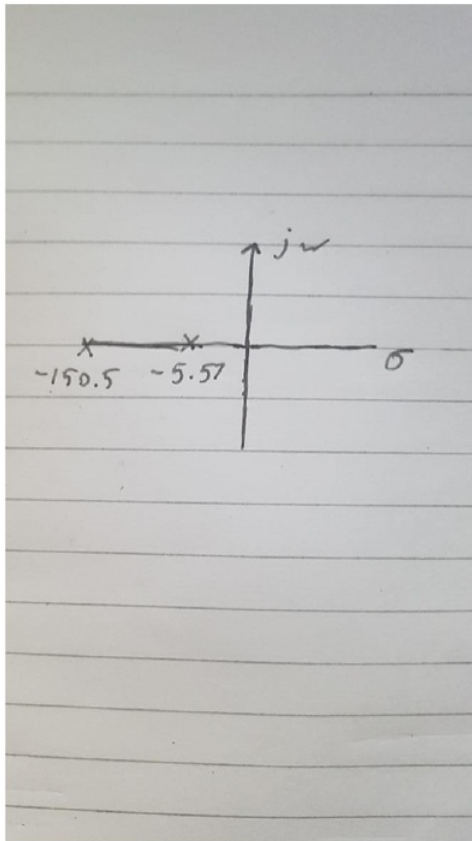


Figure 6: Argand diagram of DC Motor.

poor image

Spelling

Now that the mathematical calculations have been completed the motor model that was created earlier will be tested using Simulink. The first test that will be carried out will be to measure the speed and torque response over a 20 second period to a step input of 24V and no disturbance (Figure 7).

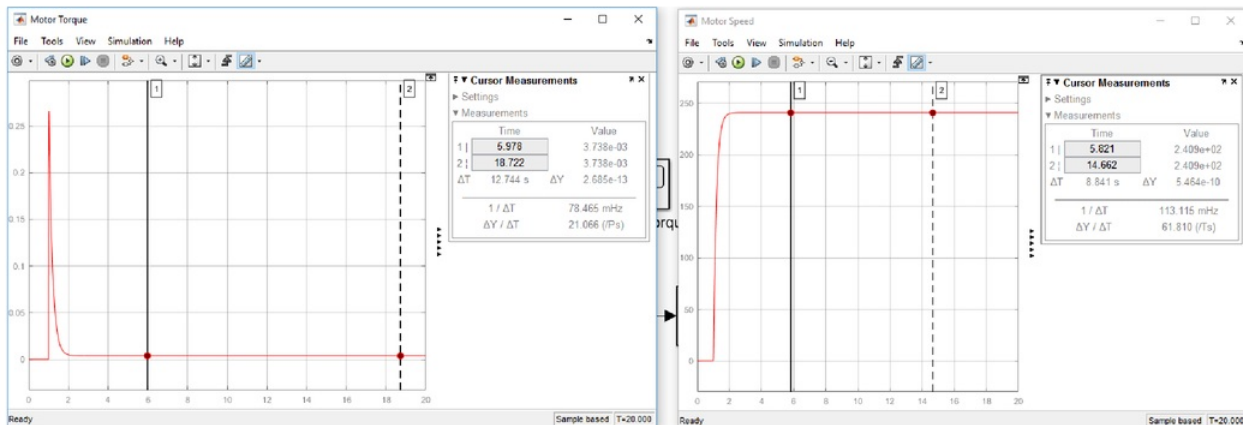


Figure 7: No load speed and torque response from simulation.

As can be seen when the step input was applied the torque increased to a point where it was just below its stall point and as this took place the motor sped up to its no load speed, this was measured using data points which shows the final no load speed of the motor was measured at 240.9 rad/s which was almost exactly that which was calculated earlier, this shows that the motor model that has been created matches the results from the calculations. However, to confirm this the simulation will be run again however, this time it will have be measuring the loaded speed (Figure 8).

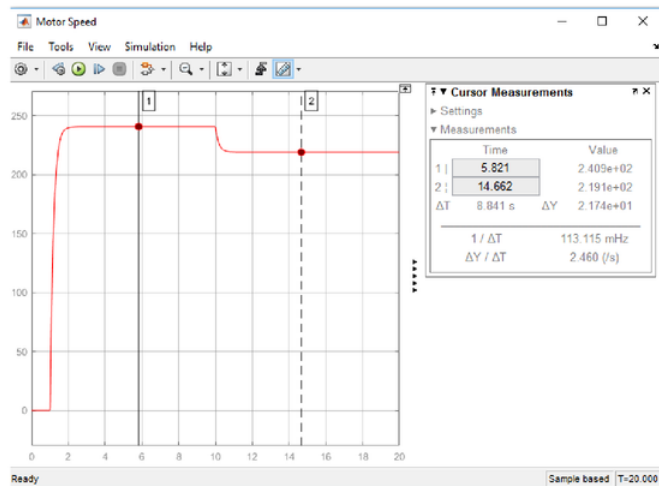


Figure 8: Loaded speed response from simulation.

As can be seen from the results of the simulation before the load was applied at the 10 second mark the no load speed was the same as before which matches the calculated values, and once the load was applied the speed dropped to 219.1 rad/s which confirms the calculations carried out earlier were correct. So far during the simulation tests the no load and loaded speed have matched the calculations as well as the torque. The final test that must be carried out to confirm the results of all the calculations is to apply the calculated stall torque after 10 seconds have passed to monitor the change in the motors behaviour (Figure 9).

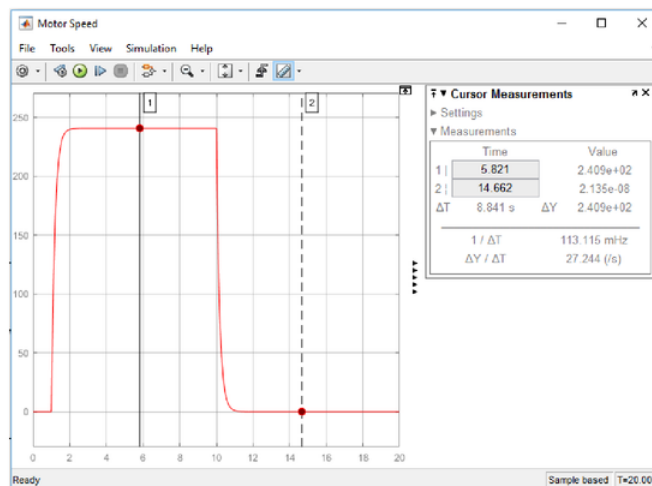


Figure 9: Effect of applying stall torque on speed.

As can be seen when the motor's stall torque is applied the motor's speed changes from running at its no load speed to stopping entirely, this confirms that at the calculated stall torque value the motor will stall and come to a stop.

All the simulations run using the Simulink software confirm that the mathematical calculations carried out were correct and that when simulated using a motor model and monitored the motor performed as expected.

3. Types of Motor Speed Controller

There are multiple control methods that can be used when controlling the speed of the motor, the three common ones are a P controller, PI controller and PID controller. All three of these systems control the motor in a similar way however the effect of adding additional variables can effect the motor in different ways, the letters in the controllers stand for the type of variable that is used to control the motor. P stands for proportional, I stands for integral and D stands for derivative.

In this task a comparison will be made between the three as well as analysis on what altering the values of each will cause on the circuit. To achieve this the motor model that was created for the DC motor analysis will be converted into a subsystem which the different controllers will be connected to with a 100 rad/s speed setpoint will be used with the same disturbance in place as used earlier, additionally a limiter will be placed between the controller and the motor model to limit the armature voltage to 40Vdc.

The first controller that will be simulated is the P controller which is the common variable in the three controllers, below is the Simulink circuit that was created to test the effect changing the P controller will have on the motor (Figure 10).

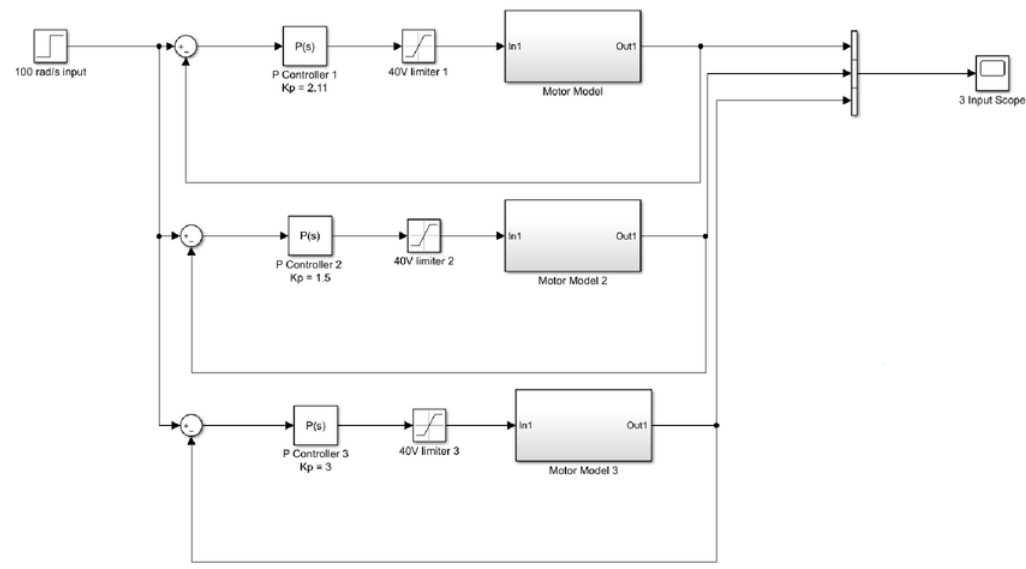


Figure 10: P controller Simulink comparison.

The P controller at the top was set to the autotuned value which was determined to be the optimal value by the Simulink software. Using the tuned value, the second P controller was set lower than the optimal value and the third p controller was set higher. The effect this had on the motor was recorded using a 3-input scope and can be seen blow (Figure 11).

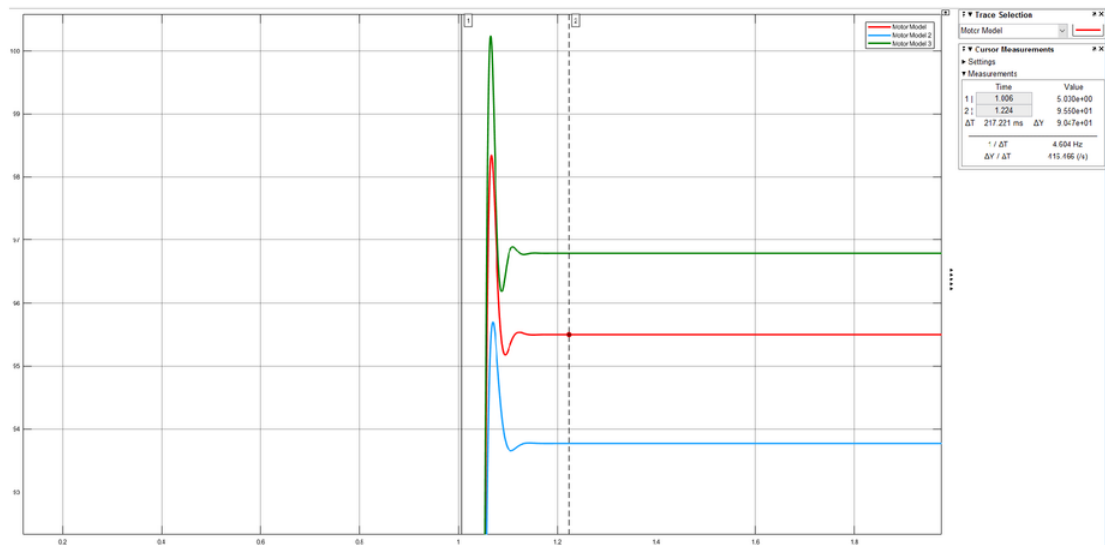


Figure 11: P controller Simulink results.

As can be seen from the results. The tuned p controllers peak didn't exceed 100rad/s and had very little disturbance afterwards however it became at 95.5 rad/s while this is not far off the setpoint it is still below. The effect of increasing the P variable meant an increase in the overshoot and slightly more unstable after the initial overshoot however it was closer to the set point when it became steady, the opposite is true for decreasing the P variable the overshoot and disturbance were reduced however it was further away from the setpoint. The results of this simulation show the effecting the P variable effects the overshoot and how close it is to the setpoint once it becomes steady. The next simulation that will be carried out similar to the previous will involve 3 PI controllers with 1 tuned value and 2 manually adjusted values, for this simulation the P parts will be left on the tuned value so that the only difference will be in the I part. The Simulink circuit can be seen below (Figure 12).

results could have been tabulated for comparison for percentage overshoot, steady state error and settling time

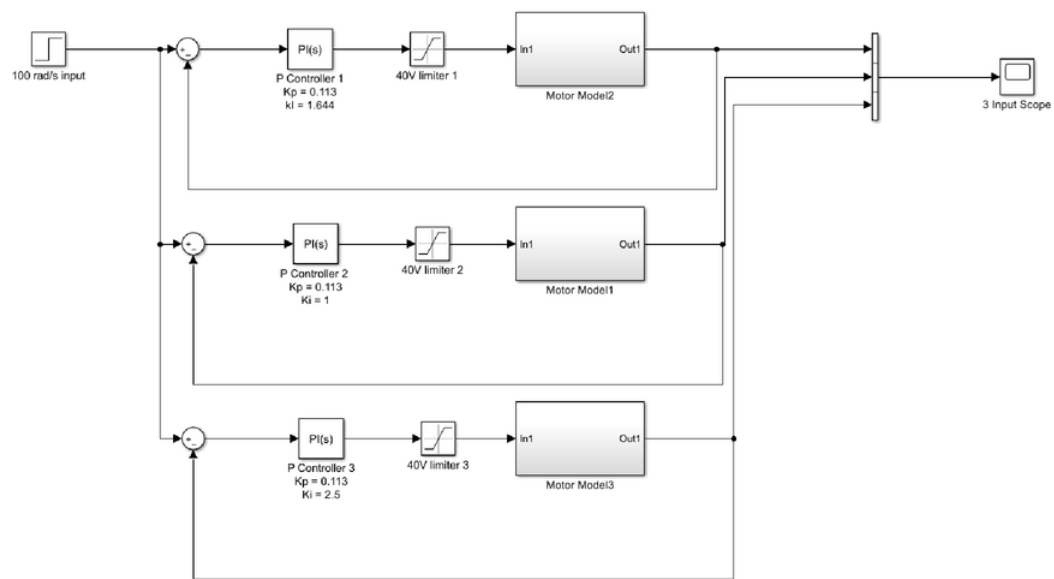


Figure 12: PI controller Simulink Comparison.

As can be seen the first PI controller has been left at the tuned values, the second has been set below that of the tuned value while the third has been set higher than the tuned value. As before the results will be recorded using the 3-input scope, the results of the test can be seen below (Figure 13).

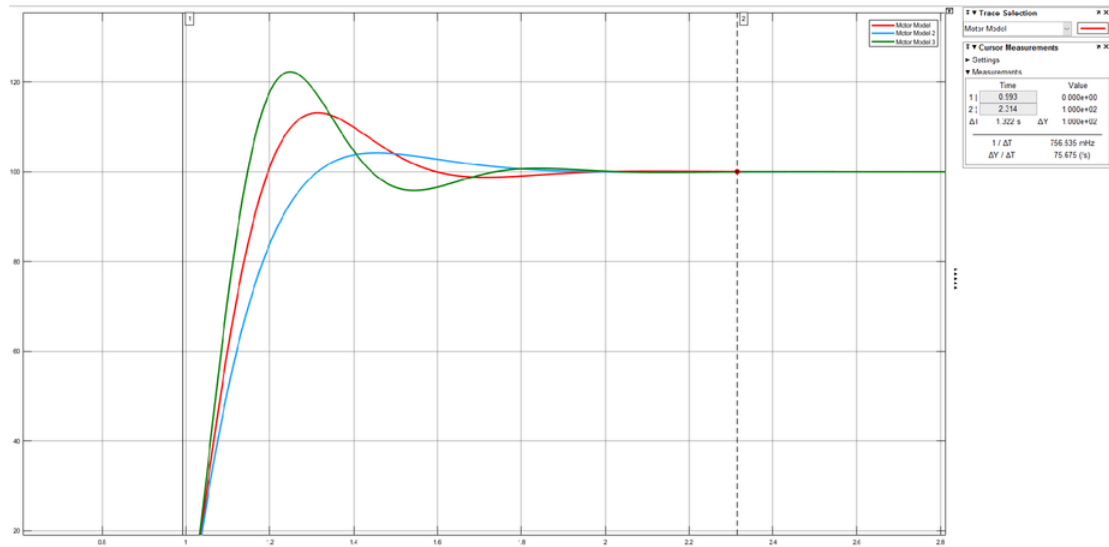


Figure 13: PI controller Simulink Results.

As can be seen from comparing the difference I the 3 PI controllers the first which was set to the tuned values overshoots the setpoint then starts to undershoot slightly before becoming stable. The second PI controller which has a lower value for the I part doesn't overshoot as much however it stays above the setpoint for a longer period of time before it becomes stable. The third PI controller overshoots more than the other 2 however it tries to correct itself faster and goes below the setpoint before the other 2. The change in the I part show that an increase in the value increases the rate at which the circuit will correct itself, therefore increasing the I part will result in sharper corrections. Because of this if it is increased to much it could lead to oscillation. For the third controller the PID controller the same test was carried out while leaving the P and the I part as the tuned values and varying the D part. The Simulink circuit that was created can be seen below (Figure 14).

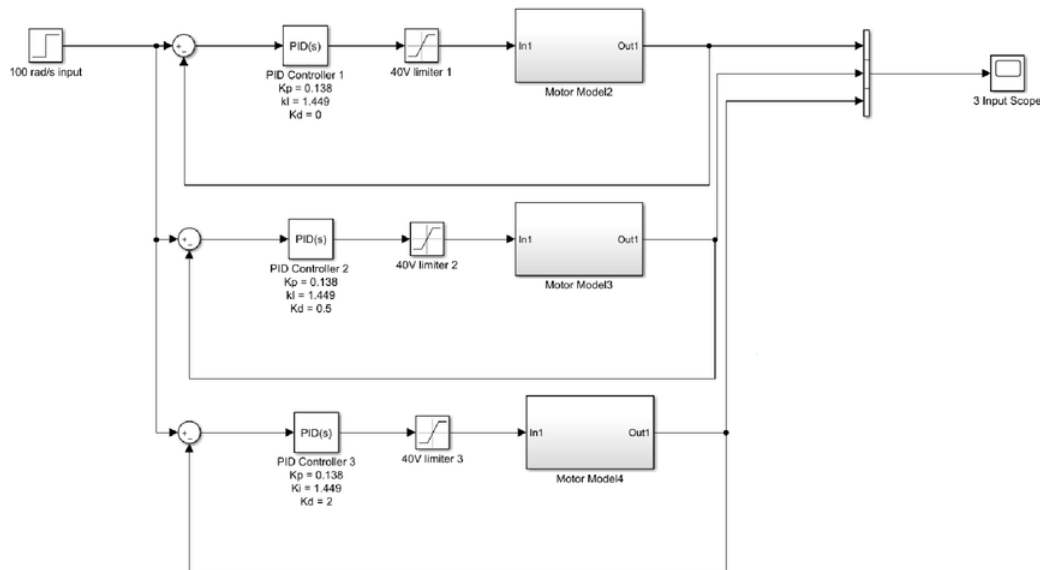


Figure 14: PID controller Simulink Comparison.

As the tuned value for the PID controller D part was 0 the second PID controller was set a slight increase and the third was set to a larger increase than the second to be able to analyse the difference between the controllers when the D part is changed, the results for the test can be seen below (Figure 15).

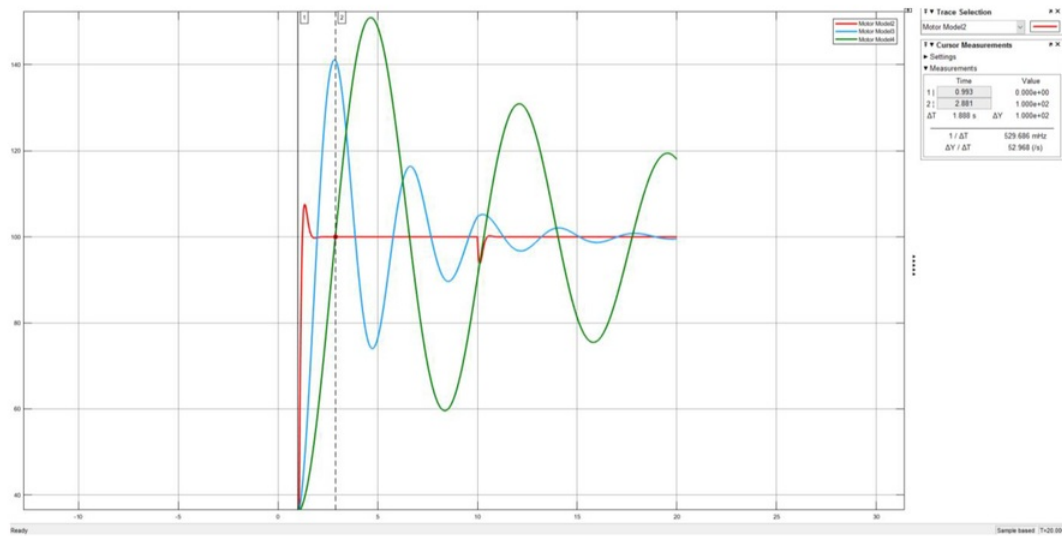


Figure 15: PID controller Simulink Results.

As can be seen from the results the optimal PID controller that was tuned has a small overshoot and becomes steady shortly afterwards, and once the disturbance is applied it corrects itself with no overshoot, where the D part was slightly increased for the second PID controller it overshoots at a much larger rate and oscillates slightly before settling down which was after the 20 second period of the simulation. The third PID controller which had a much higher D part took the longest to respond and oscillated for a much longer period of time with sharper changes in the output, resulting in the motor becoming slightly unstable as it will require a long period of time to settle down. The final comparison that was carried out between the controllers was between the 3 different types while using the tuned values for all 3 of them, below is the Simulink circuit that was created to compare the 3 (Figure 16).

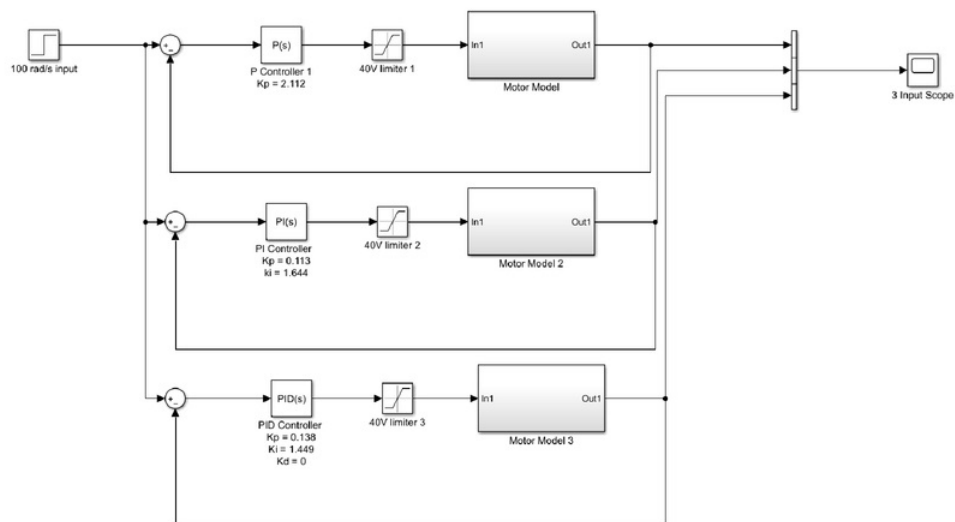


Figure 16: P, PI, PID controller Simulink Comparison.

Using the Simulink auto tune the 3 controllers were set to their optimal values, the purpose for this test is to be able to compare the 3 controllers to analyse the difference between them and to simulate which would be the best one to use as the controller for this motor, below are the results of the test that was run (Figure 17).

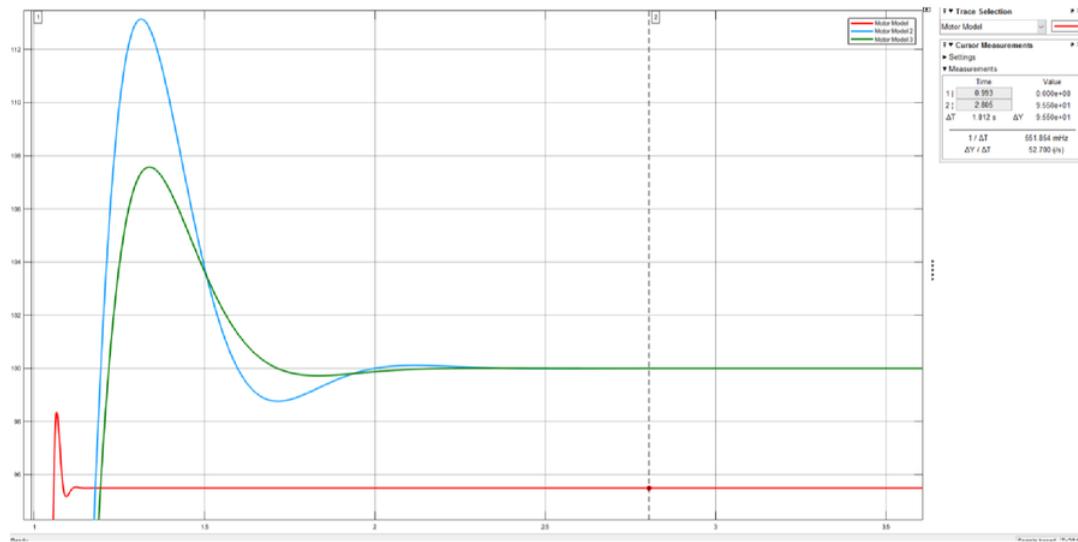


Figure 17: P, PI, PID controller Simulink Results.

When comparing the results of the test it can be seen that the P controller will respond much faster however it won't reach the setpoint, therefore of the 2 remaining controllers the PI and PID the best controller for this system is the PID controllers as it overshoots less than the PI controller and becomes stable slightly sooner. Therefore, in conclusion to the tests carried out on the 3 controllers the best one for use with this motor is the PID controller.

4. Conclusion

After carrying out the tests on the first order control system a conclusion could be drawn that calculating the minimum gain for the circuit is important in order to create a functional circuit that won't enter a state of constant rise, otherwise the circuit would not be able to function correctly. Recommendations that could be made to further improve the circuit would be to make it a close loop pole to move the pole further into the left hand domain which will increase the tolerance before it moves into the right hand plane and becomes unstable.

After analysing the speed and the torque from the DC motor model that was created using Simulink the results for the tests matched those that were calculated. Carrying out the tests demonstrated the need to fine tune the motor and to calculate the stall torque to ensure the motor doesn't exceed its limit and cause it to stall.

The tests carried out on the different control methods show the different aspects that each controller controls which ended up with the testing proving the best controller to use on the motor model given is the PID controller.

you could have summarize the effects of changing K_p , K_i , K_d

Aled Edgell Assignment 2

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FINAL GRADE

GENERAL COMMENTS

Instructor

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ALED EDGELL

63

RESEARCH-INFORMED LITERATURE

 n/a

KNOWLEDGE AND UNDERSTANDING



Section 1: Explanation of first order system – Good, equations are well presented, good predicted values with a few mistakes. (6/10) Section 2: Explanation of DC motor model – Good though the order of development would be better if the block diagram was given first and the equations developed after with more details about each block. Good predicted values. (7/10) Section 3: Explanation of types of speed controllers – 8(/10)

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ANALYSIS



Section 1: Testing of first order system – Very good evidence of testing and comparison of results with theory. (7/10) Section 2: Testing of DC motor model – Very good evidence given and comparison with theory. (7/10) Section 3: Testing of speed controllers – Good evidence of testing but some data is missing and results should be tabulated for comparison. (10/20) Section 4: Conclusions and recommendations – Brief but rather vague and no recommendations. (4/10)

28

PRACTICAL APPLICATION AND DEP.



Sections 1, 2 and 3: Use of Simulink and presentation quality of results - Good use of the software but some data is missing, no evidence of the use of the auto-tune feature. (6/10)

6

SKILLS FOR PROFESSIONAL PRAC.



All sections – Very good structure and presentation except for one image. (8/10)

8