

PLCs

PLC assignment 1 (Theory)

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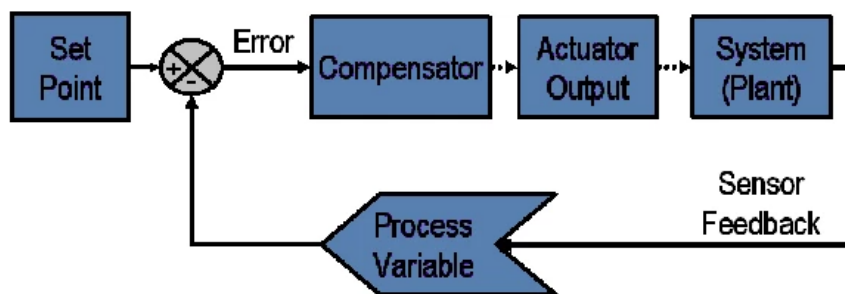
<u>Contents</u>	<u>Page</u>
Title page	1
Contents	2
Task 01 – PID Control	3 - 6
Task 02 – System Representation (Signal Flow Diagrams)	7 - 8
Task 03 – System Representation (State Space Modelling)	9 - 10
Task 04 – Time Domain Analysis	11 - 17
Task 05 – Frequency Domain Analysis	18
Bibliography and references	19

Task 01 – PID Control

A. Using suitable diagrams, explain the principles of PID control in a PLC system. Your explanation should include a description of the benefits and relative effects of each of the three terms (Proportional, Integral and Differential).

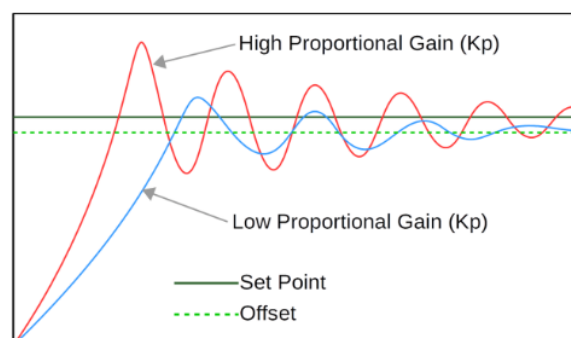
PID control is used where there is a process variable that needs to be controlled. PID control works by taking a reading from some form of sensor that is monitoring the process variable, calculating the required response by the system to keep or bring the process variable within the desired set points and sending a signal that drives the output.

A specific example would be the central heating within a home. The set point may be set to 24°C and the thermostat (sensor) may be reading 19°C. The system will calculate an error of -5°C and therefore turn the boiler on and being pump hot water around the central heating system. As the process variable (ambient temperature) gets closer to the set point, the boiler may switch off but allow the system to continue to pump hot water around the radiators. Once the set point is met, reducing the error to 0, the system may shut off completely. The nature of a central heating system means that the ambient temperature is likely to continue to rise after the system is shut off. In more advanced systems, where maintaining a precise temperature is important (e.g. battery storage rooms or server rooms) this error above the set point may bring on an air conditioning/cooling system to prevent the ambient temperature from overshooting the set point by too much.



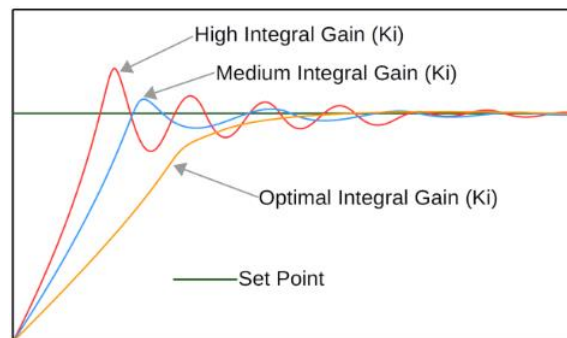
Block diagram of a typical closed loop system. (NI, 2023).

Proportional – As the name suggests, the response of a proportional control system is directly proportional to the magnitude of the error. The magnitude of error is found by subtracting the process variable from the set point. The ratio of the response is determined by the proportional gain (K_p) that is programmed into the controller. Proportional gain acts a multiplier to ensure that even small errors produce an output significant enough to affect the process variable. Generally speaking, the larger the proportional gain, the faster the process variable should move toward the set point. It is important, however, to understand that if the proportional gain is set too high, the process variable will continually overshoot the set point causing the value to oscillate about the set point. Similarly, if the proportional gain is set too low, the process variable may come up too slowly or may never reach the set point.



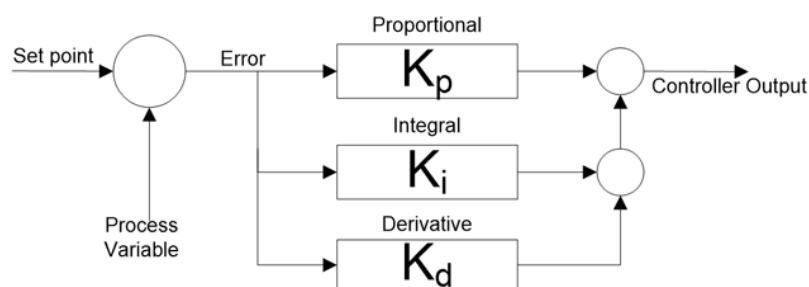
(Coder Tronics, 2014).

Integral – The integral part of a PID system is used to improve the accuracy of the response. It takes the sum of the error and divides it by the duration of the error. This allows the system to understand the average response required previously and to correct its proportional response to bring the error magnitude towards zero as quickly as possible. The integral factor is shown as K_i .



(Coder Tronics, 2014).

Differential – The differential element of a PID controller looks at the rate of change of the process variable. It evaluates the instantaneous error value and previous error value to calculate the rate of change. It then uses the rate of change to determine if the current response is too quick or too slow and will adjust the output appropriately. It is used particularly where overshoot of the desired set point can be dangerous. The differential factor is shown as K_d .



(Circuit Digest, 2018)

A PID controlled system will always have some magnitude of error. This is because if the error was exactly 0 then the system would shut down. For this reason, PID systems should not be used where absolute precision is required.

B. Provide a detailed description of the two Zeigler-Nichols tuning methods for PID control. You should give examples of where each method could and could not be applied. Also explain any limitations of the techniques.

Ziegler-Nichols came up with two methods for tuning PID controllers which were published in 1942. The step response method and the frequency response method. Both of which aim to calculate the values of K_p , K_i and K_d by way of formula.

The step response method can only be used on open loop systems which means the PID controller has to be removed and the system connected to a step signal generator.

The frequency response method, also known as critical/ultimate gain method, is limited to systems that would be unstable in an open loop environment.

Step response (open loop) method – For this method, with the PID controller removed, a step signal is applied to the actuator. The response to the signal is measured and variables are recorded then applied to the table below, where $K_o = (dX \cdot T_2) / (dY \cdot T_1)$.

Controller Type	Kp	Ki	Kd
P	K_o		
PI	$0.9 \cdot K_o$	$(0.27 \cdot K_o) / T_1$	
PID	$1.2 \cdot K_o$	$(0.6 \cdot K_o) / T_1$	$0.6 \cdot K_o \cdot T_1$

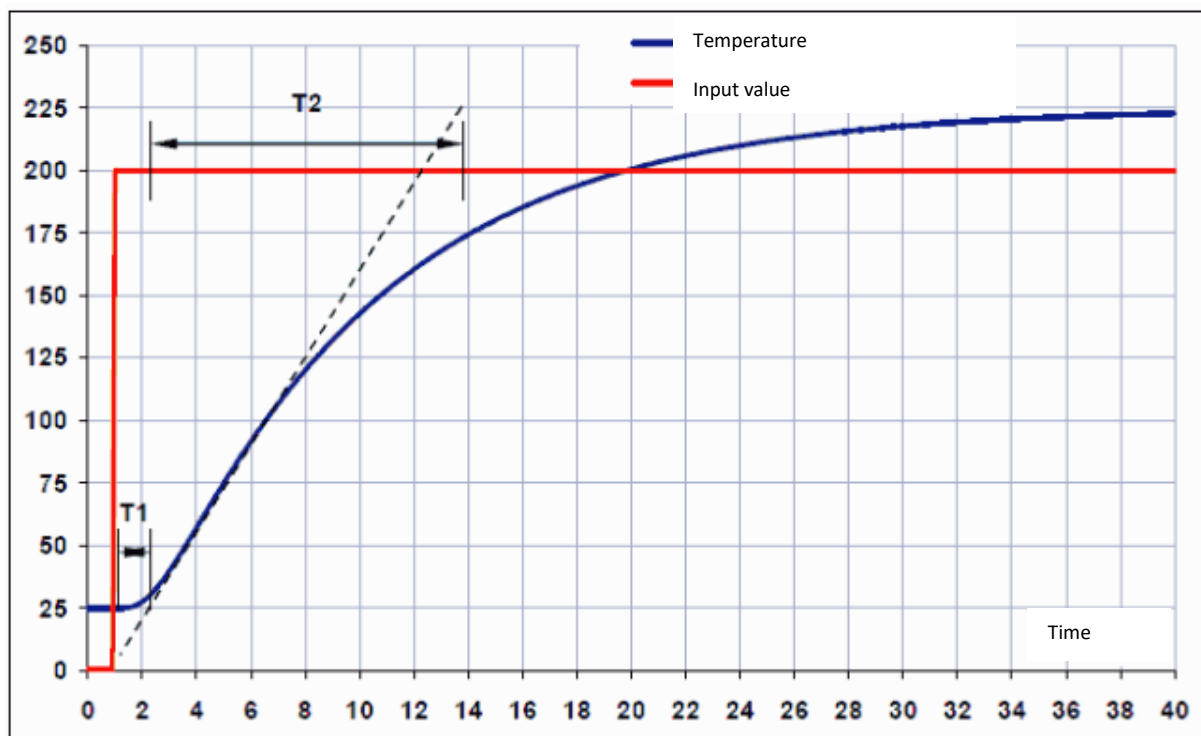
dX is the difference in magnitude of the step signal measured in volts.

dY is the difference in magnitude of the output signal measured in volts.

T_1 is the dead time given by drawing tangent line on the curved line that shows the measured value. It is the time taken from the start if the tangent line to the point where the tangent line hits the initial input value.

T_2 is the rise time according the tangent line, so from when the system begins to respond (end of T_1) to the point at which system reaches its final output value.

A representation of these values is shown below.



“To calculate system parameters, a step response is forced by setting the control signal to 0 volts with a 5 volt step. The system responds by changing from 25 degrees Celsius (0.25V) to 225 degrees Celsius (2.25V). The times are those that appear in the previous graphs, with which the values of the response curve of the system are the following:

$$dX = 5 - 0 = 5 \text{ volts}$$

$$dY = 2.25 - 0.25 = 2 \text{ volts}$$

$$T_1 = 2.2 - 1 = 1.2 \text{ seconds}$$

$$T_2 = 13.8 - 2.2 = 11.6 \text{ seconds}$$

From these values, the parameters of the PID regulator can be calculated:

$$K_o = (dX \cdot T_2) / (dY \cdot T_1) = (5 \cdot 11.6) / (2 \cdot 1.2) = 24.2$$

(Martín C, 2018)

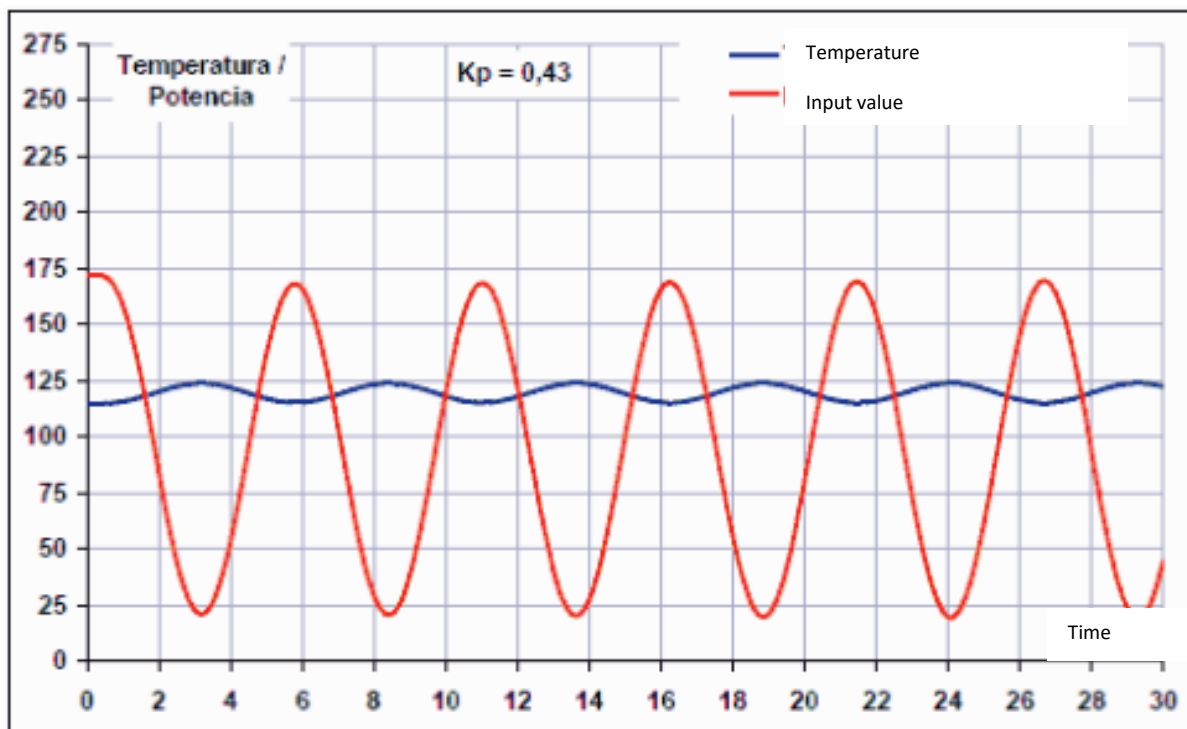
Controller Type	K_p	K_i	K_d
P	24.2		
PI	$0.9 \cdot 24.2 = 21.8$	$(0.27 \cdot 24.2) / 1.2 = 5.44$	
PID	$1.2 \cdot 24.2 = 29$	$(0.6 \cdot 24.2) / 1.2 = 12.1$	$0.6 \cdot 24.2 \cdot 1.2 = 17.4$

Frequency response (close loop) method – This method uses the full closed loop system so does not require removing the PID controller. It, too, uses a table like the one above to calculate K_p , K_i and K_d , but with slightly different values. The table is below.

Controller Type	K_p	K_i	K_d
P	$0.5 \cdot K_c$		
PI	$0.45 \cdot K_c$	$(0.54 \cdot K_c) / T_c$	
PID	$0.6 \cdot K_c$	$(1.18 \cdot K_c) / T_c$	$0.075 \cdot K_c \cdot T_c$

K_c is the “critical gain” value. This is found by reducing the integral and derivative values to 0 so that the control is working purely on the proportionate gain. The proportionate gain then has to be gradually increased to the highest value before it becomes unstable. This is shown when the oscilation of the output signal is linear and stable. At this point, you have to take the value of K_c that you are using and take the value of T_c from the graph. T_c is the time taken for one full oscilation of the output signal of the sensor.

An example is below.



“In this case, therefore, the critical gain and the period are:

$$K_c = 0.43 \quad T_c = 21/4 = 5.3 \text{ s}$$

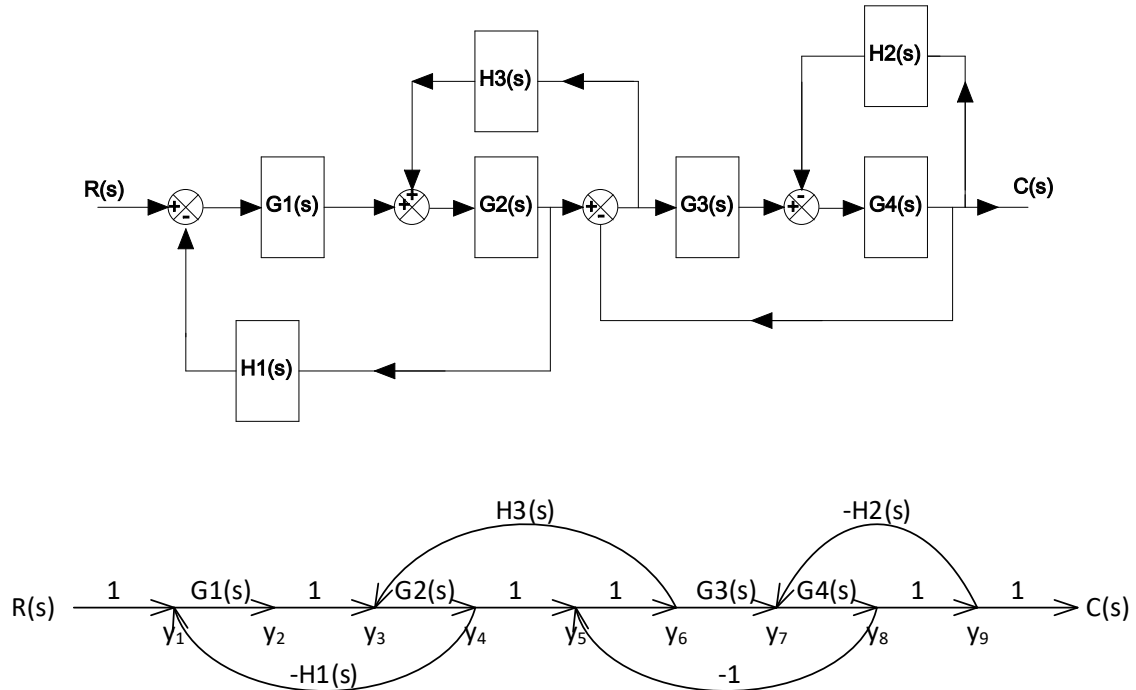
From these values the parameters of the PID controller are calculated:”

Controller Type	K_p	K_i	K_d
P	$0.5 \cdot 0.43 = 0.215$		
PI	$0.45 \cdot 0.43 = 0.195$	$(0.54 \cdot 0.43) / 5.3 = 0.044$	
PID	$0.6 \cdot 0.43 = 0.254$	$(1.18 \cdot 0.43) / 5.3 = 0.096$	$0.075 \cdot 0.43 \cdot 5.3 = 0.169$

(Martín C, 2018)

Task 02 – System Representation

Control systems are often represented by signal flow diagrams. Produce a signal flow diagram that corresponds with the system block diagram below then apply Mason Gain formula to derive a transfer function for the system.



Number of forward paths: $N = 1$

Forward path is: $y_1 \rightarrow y_2 \rightarrow y_3 \rightarrow y_4 \rightarrow y_5 \rightarrow y_6 \rightarrow y_7 \rightarrow y_8 \rightarrow y_9$

Forward path gain is: $P_1 = G_1(s) * 1 * G_2(s) * 1 * 1 * 1 * G_3(s) * G_4(s) * 1 = G_1(s) * G_2(s) * G_3(s) * G_4(s)$

Number of individual loops: $L = 4$

Loops are: $y_1 \rightarrow y_2 \rightarrow y_3 \rightarrow y_4 \rightarrow y_1$, $y_3 \rightarrow y_4 \rightarrow y_5 \rightarrow y_6 \rightarrow y_3$, $y_5 \rightarrow y_6 \rightarrow y_7 \rightarrow y_8 \rightarrow y_5$, $y_7 \rightarrow y_8 \rightarrow y_9 \rightarrow y_7$

Loop gains: $l_1 = G_1(s) * 1 * G_2(s) * -H_1(s)$, $l_2 = G_2(s) * 1 * 1 * H_3(s)$, $l_3 = 1 * G_3(s) * G_4(s) * -1$, $l_4 = G_4(s) * 1 * -H_2(s)$

Number of two non-touching loops = 2

First non-touching loop pair: $y_1 \rightarrow y_2 \rightarrow y_3 \rightarrow y_4 \rightarrow y_1$, $y_5 \rightarrow y_6 \rightarrow y_7 \rightarrow y_8 \rightarrow y_5$

Gain product of first non-touching pair: $l_1 * l_3 = (G_1(s) * 1 * G_2(s) * -H_1(s)) * (1 * G_3(s) * G_4(s) * -1)$

Second non-touching loop pair: $y_3 \rightarrow y_4 \rightarrow y_5 \rightarrow y_6 \rightarrow y_3$, $y_7 \rightarrow y_8 \rightarrow y_9 \rightarrow y_7$

Gain product of second non-touching pair: $l_2 * l_4 = (G_2(s) * 1 * 1 * H_3(s)) * (G_4(s) * 1 * -H_2(s))$

$$T = \frac{C(s)}{R(s)} = \frac{\sum_{i=1}^N P_i \Delta_i}{\Delta}$$

$$\Delta = 1 - (\text{sum of all individual loop gains}) \\ + (\text{sum of gain products of all possible two nontouching loops}) \\ - (\text{sum of gain products of all possible three nontouching loops}) + \dots$$

$$\Delta = 1 - ((G1s * G2s * -H1s) + (G2s * H3s) + (G3s * G4s * -1) + (G4s * -H2s)) \\ + (((G1s * G2s * -H1s) * (G3s * G4s * -1)) + ((G2s * H3s) * (G4s * -H2s))) \\ - (0)$$

$$\Delta = 1 - (G2H3 - G1G2H1 - G3G4 - G4H2 + G1G2H1G3G4 - G2H3G4H2)$$

$$P1 = G1G2G3G4$$

$\Delta1 = 1$ because no loops are not touching the first forward path.

$$T = \frac{C(s)}{R(s)} = \frac{\sum_{i=1}^1 P_i \Delta_i}{\Delta}$$

$$T = \frac{C(s)}{R(s)} = \frac{G1G2G3G4 * 1}{1 - (G2H3 - G1G2H1 - G3G4 - G4H2 + G1G2H1G3G4 - G2H3G4H2)}$$

$$T = \frac{C(s)}{R(s)} = \frac{G1G2G3G4}{1 - (G2H3 - G1G2H1 - G3G4 - G4H2 + G1G2H1G3G4 - G2H3G4H2)}$$

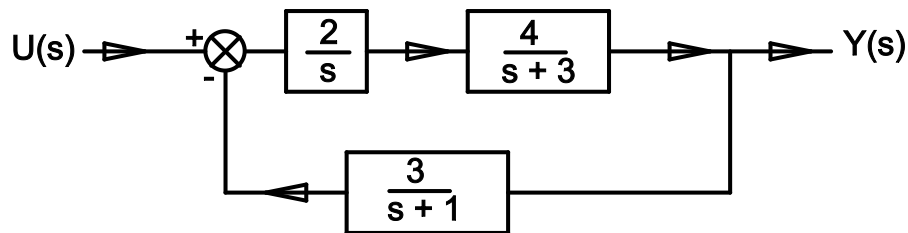
Task 03 – System Representation

A. Explain the concept of State Space modelling.

State space modelling is a mathematical way of showing the behaviour of a control system. It includes the input, output and any state variables. In control engineering, space state models can be used to design and check the stability and performance of a system.

State space modelling is a way of representing complex, multi-input and multi-output systems in a compact manner which makes it easier to see.

B. Obtain a state space model for the system shown below.



Unanswered

C. Determine the transfer function for a system represented by the following state space model.

$$\dot{X} = \begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} -2 & 2 \\ 1 & 3 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ 1 \end{bmatrix} [u]$$

$$Y = \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} \quad D = \begin{bmatrix} 0 \end{bmatrix}$$

$$A = \begin{bmatrix} -2 & 2 \\ 1 & 3 \end{bmatrix} \quad B = \begin{bmatrix} 0 \\ 1 \end{bmatrix} \quad C = \begin{bmatrix} 0 & 1 \end{bmatrix} \quad D = 0$$

$$G(s) = \frac{Y(s)}{U(s)}$$

$$\dot{X} = Ax + Bu$$

$$y = Cx + Du$$

$$\int \dot{X} \rightarrow sX(s) = AX(s) + BU(s) \rightarrow X(s)[Is - A]^{-1} = BU(s) \rightarrow X(s) = [Is - A]^{-1}BU(s)$$

$$\int Y \rightarrow Y(s) = CX(s) + DU(s)$$

Substitute in X(s)

$$Y(s) = C[Is - A]^{-1}BU(s) + DU(s)$$

Divide both sides by U(s)

$$\frac{Y(s)}{U(s)} = C[Is - A]^{-1}B + D = G(s)$$

I can use this to now find the transfer function inputting our values of A, B, C and D from above.

$$A = \begin{bmatrix} -2 & 2 \\ 1 & 3 \end{bmatrix} \quad B = \begin{bmatrix} 0 \\ 1 \end{bmatrix} \quad C = [0 \quad 1] \quad D = 0$$

$$\frac{Y(s)}{U(s)} = [0 \quad 1] \begin{bmatrix} s-2 & -2 \\ -1 & s+3 \end{bmatrix}^{-1} \begin{bmatrix} 0 \\ 1 \end{bmatrix} + 0$$

Simplify;

$$\begin{bmatrix} s-2 & -2 \\ -1 & s+3 \end{bmatrix}^{-1} = \frac{1}{(s+2)(s-3)-2} \begin{bmatrix} s-3 & 2 \\ 1 & s+2 \end{bmatrix} = \frac{1}{s^2-s-8} \begin{bmatrix} s-3 & 2 \\ 1 & s+2 \end{bmatrix}$$

$$\frac{Y(s)}{U(s)} = [0 \quad 1] \frac{1}{s^2-s-8} \begin{bmatrix} s-3 & 2 \\ 1 & s+2 \end{bmatrix} \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

$$\frac{Y(s)}{U(s)} = [0 \quad 1] \frac{1}{s^2-s-8} \begin{bmatrix} 2 \\ s+2 \end{bmatrix}$$

$$\frac{Y(s)}{U(s)} = \frac{1}{s^2-s-8} [0 + s + 2]$$

$$G(s) = \frac{Y(s)}{U(s)} = \frac{s+2}{s^2-s-8}$$

Task 04 – Time Domain Analysis

A. Explain the concept of root locus analysis.

Root locus analysis is a graphical way of showing how the roots of a system's equation change as parts of the system change. Most commonly, the part that changes is the gain constant (K). It is another method for designing stability within a system.

There are 7 rules for constructing a root locus:

Rule 1 – Locate the open loop poles and zeros in the 's' plane.

Rule 2 – Find the number of root locus branches.

Rule 3 – Identify and draw the real axis root locus branches.

Rule 4 – Find the centroid and the angle of asymptotes.

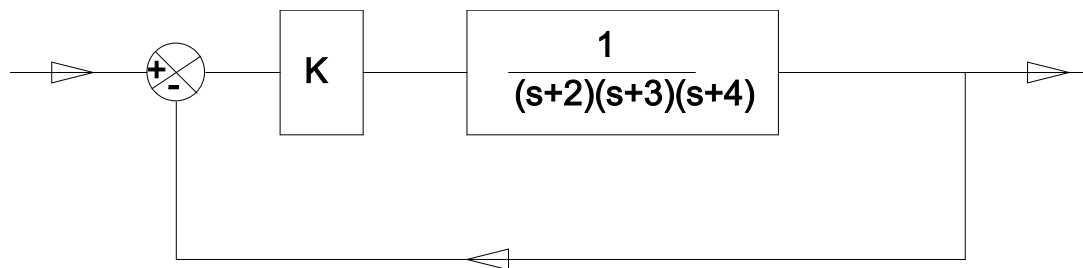
Rule 5 – Find the intersection points of root locus branches with an imaginary axis.

Rule 6 – Find Break-away and Break-in points.

Rule 7 – Find the angle of departure and the angle of arrival.

B. Draw by hand a root locus diagram for the systems represented below. In doing so determine the value of K that will cause the system to be unstable.

a)



Open loop poles and zeros:

$$G(s) = \frac{k}{(s+2)(s+3)(s+4)} = \frac{k}{1 + \frac{k}{(s+2)(s+3)(s+4)}}$$

When $k=0$, $(s+2)(s+3)(s+4) = 0$

Therefore, open loop poles are @ $s=-2$, $s=-3$, $s=-4$ and there are no zeros.

As there are three open loop poles, $P=3$. As there are no zeros, $Z=0$. The number of root locus branches, N , is equal to the larger of P and Z . In this case, P is the largest so $N=3$, so there are 3 root locus branches. The portion of root loci located on the real axis are between -1 to -2 and between -3 to $-\infty$.

The centroid is found by:

$$\alpha = \frac{\sum P - \sum Z}{P - Z}$$

In our case:

$$\alpha = \frac{(-2 - 3 - 4) - 0}{3 - 0} = -\frac{9}{3} = -3$$

This is the point of intersection of the asymptotes with the real axis.

The angle of the asymptotes can be found by:

$$\theta_a = \frac{180(2k + 1)}{P - Z}$$

As before, P is the number of finite poles = 3. Z is the number of finite zeros = 0.

We can find the angles of the asymptotes by trialling values of k until we get repeating angles.

When k=0,

$$\theta_a = \frac{180((2 * 0) + 1)}{3} = 60^\circ$$

When k=1,

$$\theta_a = \frac{180((2 * 1) + 1)}{3} = 180^\circ$$

When k=2,

$$\theta_a = \frac{180((2 * 2) + 1)}{3} = 300^\circ$$

When k=3

$$\theta_a = \frac{180((2 * 3) + 1)}{3} = 420^\circ = \text{one full circle plus } 60^\circ$$

Therefore, we know the angles of the asymptotes are 60°, 180° and 300°.

The intercepts with the imaginary axis can be found by substituting s=jω into our equation:

$$(s + 2)(s + 3)(s + 4) + k = 0$$

Giving:

$$(j\omega + 2)(j\omega + 3)(j\omega + 4) + k = 0$$

$$j\omega^3 + 4j\omega^2 + 3j\omega^2 + 12j\omega + 2j\omega^2 + 8j\omega + 6j\omega + 24 + k = 0$$

$$j^3\omega^3 + 9j^2\omega^2 + 26j\omega + 24 + k = 0 \quad j^2 = -1, j^3 = -j$$

$$-j\omega^3 - 9\omega^2 + 26j\omega + 24 + k = 0$$

Equating the imaginary parts gives:

$$-\omega^3 + 26\omega = 0 \rightarrow -\omega(\omega^2 - 26) = 0 \rightarrow \omega^2 - 26 = -\frac{0}{\omega} \rightarrow \omega^2 = 26 \rightarrow \omega = \pm\sqrt{26}$$

This shows that the intercepts on the imaginary axis will be $-j\sqrt{26}$ and $j\sqrt{26}$

Equating the real parts gives:

$$-9\omega^2 + 24 + k = 0 \rightarrow k = (9 * \pm\sqrt{26}^2) - 24 \rightarrow k = 234 - 24 = 210$$

To determine the breakaway point, we can solve the equation mentioned previously:

$$(s + 2)(s + 3)(s + 4) + k = 0$$

$$s^3 + 4s^2 + 3s^2 + 12s + 2s^2 + 8s + 6s + 24 + k = 0$$

$$s^3 + 9s^2 + 26s + 24 + k = 0$$

$$-(s^3 + 9s^2 + 26s + 24) = k$$

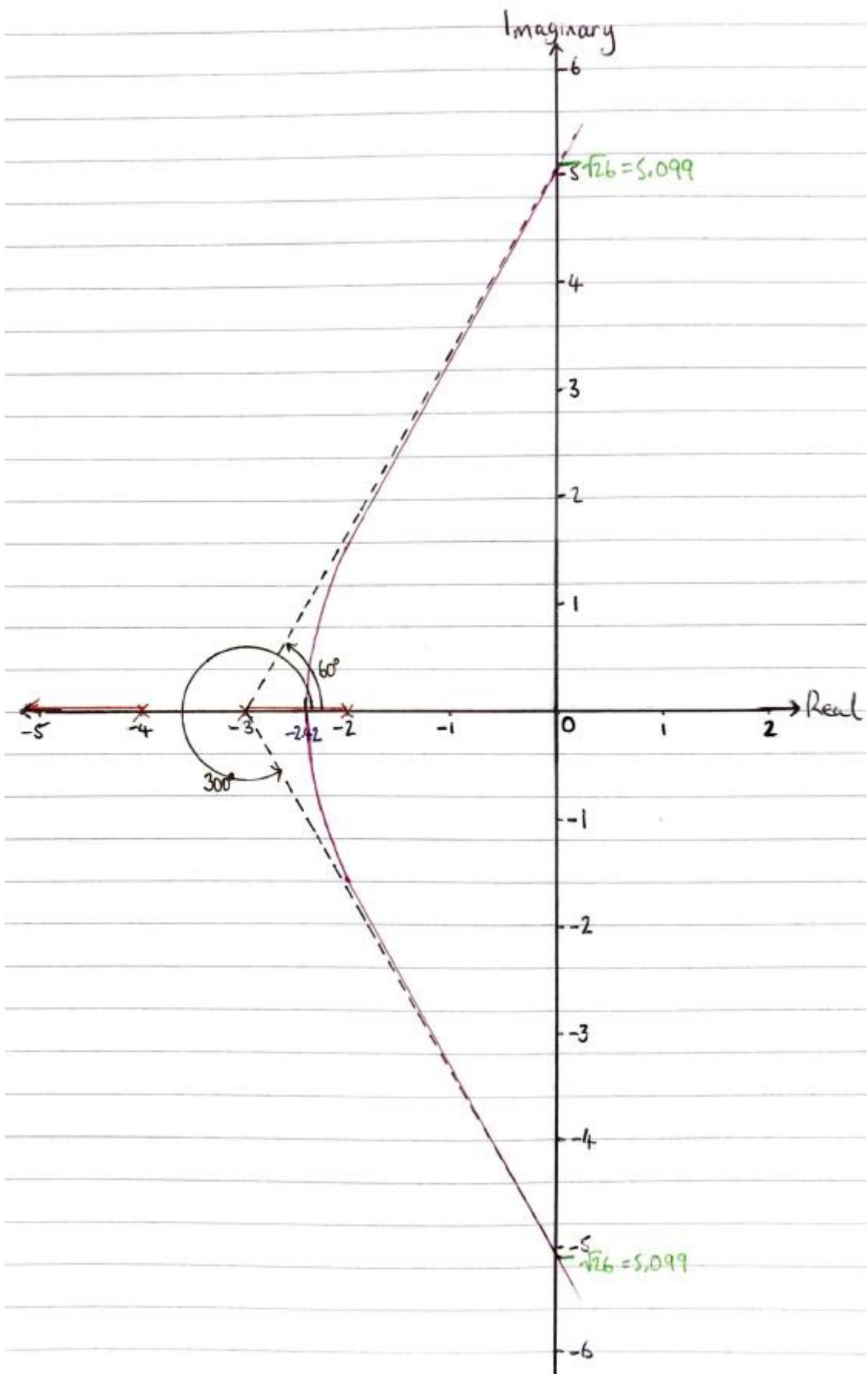
$$\frac{dk}{ds} = -3s^2 - 18s - 26$$

Inputting this the quadratic equations gives:

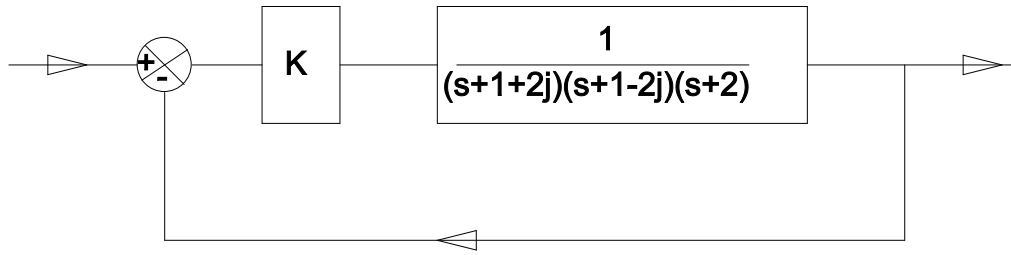
$$x = \frac{-18 \pm \sqrt{18^2 - (4 * 3 * 26)}}{(2 * 3)} = \frac{-18 \pm \sqrt{324 - 312}}{6} = -2.42 \text{ or } -3.58$$

Only -2.42 is feasible since -3.58 does not land on our real axis root locus branches.

My hand drawn root loci plot is on the next page.



b)



$$G(s) = \frac{\frac{k}{(s+1+2j)(s+1-2j)(s+2)}}{1 + \frac{k}{(s+1+2j)(s+1-2j)(s+2)}} = \frac{k}{(s+1+2j)(s+1-2j)(s+2) + k}$$

$$(s+1+2j)(s+1-2j)(s+2) + k \rightarrow (s^2 + 2s + 1 - 4j^2)(s+2) + k$$

$$j^2 = -1, \text{ so } s^2 + 2s + 1 - 4(-1) = s^2 + 2s + 5$$

$$\text{Therefore, } (s+1+2j)(s+1-2j)(s+2) + k = (s^2 + 2s + 5)(s+2) + k$$

When $k=0$,

$$(s^2 + 2s + 5)(s+2) = 0$$

$$s = -2 \text{ or}$$

$$s = \frac{-2 \pm \sqrt{2^2 - 4 * 1 * 5}}{2 * 1} = \frac{-2 \pm \sqrt{4 - 20}}{2} = \frac{-2 \pm \sqrt{-16}}{2} = \frac{-2 \pm \sqrt{j^2 16}}{2} = \frac{-2 \pm 4j}{2} = -1 \pm 2j$$

Open loop poles are:

$$s = -1 - 2j, -1 + 2j, \text{ and } -2$$

Only root loci on the real axis is $s=-2$ so the portion of the root loci located on the real axis is between -2 and $-\infty$.

There are no zeros.

$P=3$, $Z=0$, and $N=3$.

The centroid is found by:

$$\alpha = \frac{\sum P - \sum Z}{P - Z}$$

In our case:

$$\alpha = \frac{(-1 - 2j - 1 + 2j - 2) - 0}{3 - 0} = \frac{0}{3} = 0$$

This is the point of intersection of the asymptotes with the real axis.

The angle of the asymptotes can be found by:

$$\theta_a = \frac{180(2k + 1)}{P - Z}$$

As before, P is the number of finite poles = 3. Z is the number of finite zeros = 0.

We can find the angles of the asymptotes by trialling values of k until we get repeating angles.

When k=0,

$$\theta_a = \frac{180((2 * 0) + 1)}{3} = 60^\circ$$

When k=1,

$$\theta_a = \frac{180((2 * 1) + 1)}{3} = 180^\circ$$

When k=2,

$$\theta_a = \frac{180((2 * 2) + 1)}{3} = 300^\circ$$

When k=3

$$\theta_a = \frac{180((2 * 3) + 1)}{3} = 420^\circ = \text{one full circle plus } 60^\circ$$

Therefore, we know the angles of the asymptotes are 60° , 180° and 300° .

The intercepts with the imaginary axis can be found by substituting $s=j\omega$ into our equation:

$$(s^2 + 2s + 5)(s + 2) + k = 0$$

Giving:

$$(j\omega^2 + 2j\omega + 5)(j\omega + 2) + k = 0$$

$$j\omega^3 + 2j\omega^2 + 2j\omega^2 + 4j\omega + 5j\omega + 10 + k = 0$$

$$j^3\omega^3 + 4j^2\omega^2 + 9j\omega + 10 + k = 0 \quad j^2 = -1, j^3 = -j$$

$$-j\omega^3 - 4\omega^2 + 9j\omega + 10 + k = 0$$

Equating the imaginary parts gives:

$$-\omega^3 + 9\omega = 0 \rightarrow -\omega(\omega^2 - 9) = 0 \rightarrow \omega^2 - 9 = -\frac{0}{\omega} \rightarrow \omega^2 = 9 \rightarrow \omega = \pm\sqrt{9}$$

This shows that the intercepts on the imaginary axis will be $-j3$ and $j3$

Equating the real parts gives:

$$-4\omega^2 + 10 + k = 0 \rightarrow k = (4 * \pm\sqrt{5}^2) - 10 \rightarrow k = 20 - 10 = 10$$

To determine the breakaway point, we can solve the equation mentioned previously:

$$(s^2 + 2s + 5)(s + 2) + k = 0$$

$$s^3 + 2s^2 + 2s^2 + 4s + 5s + 10 + k = 0$$

$$s^3 + 4s^2 + 9s + 10 + k = 0$$

$$-(s^3 + 4s^2 + 9s + 10) = k$$

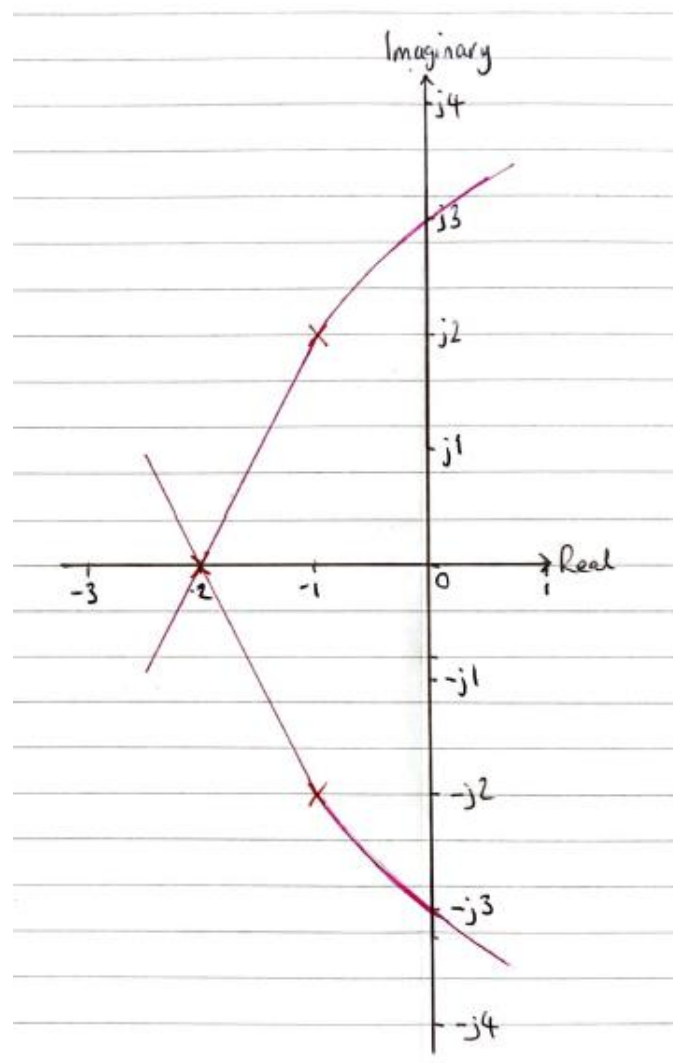
$$\frac{dk}{ds} = -3s^2 - 8s - 9$$

Inputting this the quadratic equations gives:

$$s = \frac{-8 \pm \sqrt{8^2 - 4 * 3 * 9}}{2 * 3} = \frac{-8 \pm \sqrt{64 - 108}}{6} = \frac{-8 \pm \sqrt{-44}}{6} = \frac{-8 \pm \sqrt{j^2 44}}{6} = \frac{-8 \pm 2j\sqrt{11}}{6} = \frac{-4 \pm j\sqrt{11}}{3}$$

I am not sure what this means for the breakaway point.

My attempt at drawing the root loci plot for this example is below.



Task 05 – Frequency Domain Analysis

Explain the principles of Bode diagrams and Nichols chart and give a brief discussion on their applications.

Bode diagrams – Bode diagrams are used to analyse the frequency response of a control system. They are shown as two graphs. The first, the gain plot, shows the change in magnitude, gain or loss, between the input signal and output signal (measured in decibels). The second, the phase plot, shows the phase shift of the input to the output signal (measured in degrees). This shows how the timing of the output signal is affected by changes in the input frequency. Both graphs are plotted against the frequency on a logarithmic scale.

Nichols charts – Similarly to Bode diagrams, Nichols charts also analyse the frequency response of a control system. Nichols charts, however, are plotted on a single graph rather than two individual graphs for magnitude of signal (measured in decibels) and phase shift (measured in degrees).

Both sets of graphs are often used together in control system design to provide in depth insights into system behaviour. Bode diagrams tend to be more intuitive for understanding the frequency response, whilst Nichols charts offer a more integrated view that can simplify certain design and analysis tasks.

Both sets of graphs can be used for design and tuning of systems, stability/robustness analysis and gain/phase margin assessment.

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