FACULTY OF ENGINEERING, UNIVERSITY OF JAFFNA

CONTROL SYSTEMS – EC5030

LABORATORY SESSION 3

ANALYSING THE CONTROL SYSTEMS IN TIME DOMAIN AND FREQUENCY DOMAIN USING CONTROL & INSTRUMENTATION PRINCIPLES

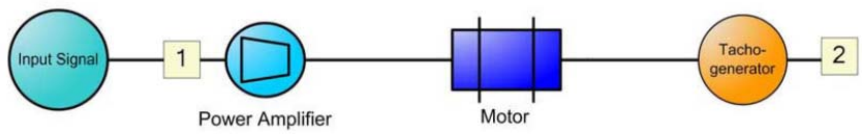
SECTION A – ANALYSING THE CONTROL SYSTEMS IN TIME DOMAIN

Part 1 - Speed Measurement using a Tacho-generator

Objectives and Background

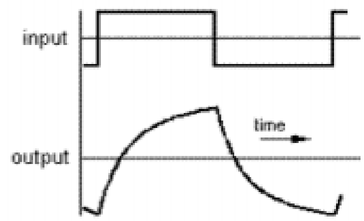
To observe the output of the tacho-generator and understand how it relates to motor speed, and to learn about delay in motor response to an applied input signal, by comparing the input signal to the power amplifier that drives the motor, to the output signal of a tacho-generator.

Block diagram



Perform Practical

1. Launch the Espial software associated with the product.
2. Select **Analogue Transducers ------> Practical 1**
3. Use the Make Connections diagram to show the required connections on the hardware.
4. Ensure the power amplifier zero offset control is set so the motor is static (approximately half scale), when no input signal is applied to the power amplifier.
5. Set the variable dc control to half scale (motor static).
6. Set the output amplitude control on the sweep function generator to minimum.
7. Set the min freq control on the sweep function generator to minimum.
8. Open the Data Logger and the Bar Display.
   The input signal can be seen on the blue trace, with the yellow trace representing the output from the tacho-generator.
9. Adjust the variable dc control and observe the resulting output from the tacho-generator.
10. Remove connection 1, and add connections 2 and 3.
    This arrangement enables the square wave test signal to be applied to the power amplifier when the sweep function generator controls are adjusted as follows.
11. Set the output amplitude to half scale.
12. Set the min freq control to give a frequency of about 0.2Hz using the Data Logger display.
    The motor should rotate in both directions, giving speed displays as shown in Figure below.



13. Examine the effect of increasing or decreasing the test frequency using the sweep function generator min freq control.

This practical shows that there is a delay in the motor response to an input, which is due to the mechanical inertia of the armature.

Observations & Discussion

1. Use the capture facility on the data logger, and either print or export the display to a folder and include in the report.
2. Comment on the effect of increasing or decreasing the test frequency.

Part 2 - Closed Loop Speed Control

Objectives

To learn that velocity feedback can be used (without position feedback) to enable a speed to be closely regulated. The polarity of the feedback is important (as for position feedback).

To learn that effectiveness of the control depends mainly on the gain employed.

Speed Control

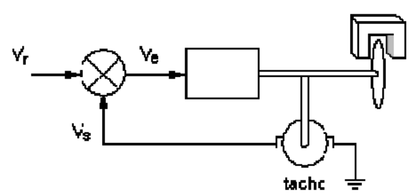


Figure: Essential Features of a Closed Loop Speed Control

The feedback signal is an output velocity signal Vs, normally from a tacho-generator, which is compared with a reference voltage V_r to give an error:

$$V_e = V_r - V_s$$

In operation the reference is set to a required value, which drives the motor to generate Vs, which reduces the error until the system reaches a steady speed.

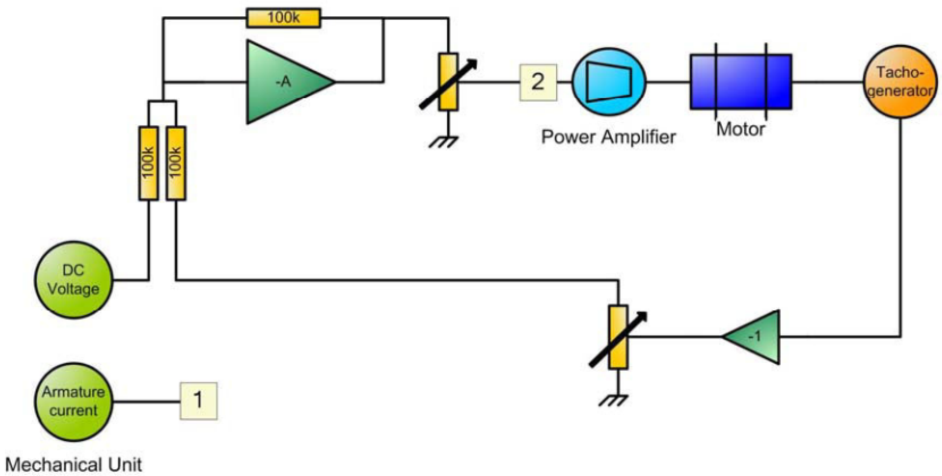
If the motor is loaded, e.g. with the magnetic brake on the 33-100 Mechanical Unit, the speed falls; this tends to increase the error, increasing the motor drive and thus reducing the speed fall for a given load. Note that this implies negative feedback around the loop.

The speed fall with load, sometimes termed *droop*, is a very important characteristic in speed control systems.

Closed Loop Speed Control with Brake Loading

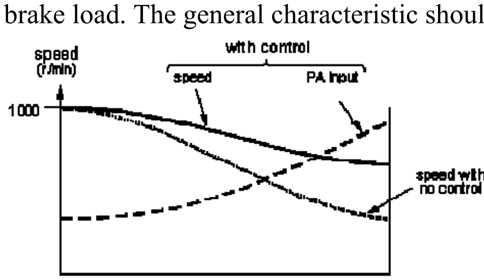
Objectives and Background

This assignment shows the general principle of speed control and that increasing the velocity feedback and the system gain, can give the system less speed fall at full load.



Perform Practical

1. Launch the Espial software associated with the product.
2. Select **Closed Loop Speed Control ------> Practical 1**
3. Use the Make Connections diagram to show the required connections on the hardware.
4. Ensure the power amplifier zero offset control is set so the motor is static (approximately half scale), when no input signal is applied to the power amplifier.
5. Set the attenuator control for the tacho – generator signal to minimum.
6. Set the summing and error amplifier attenuator control to full scale.
7. Open the Voltmeter.
8. Set the variable dc control to read approximately 0V on the meter.
9. The amplifier feedback resistor is set to 100kΩ, this gives G = 1.
10. Adjust the variable dc control (rotate clockwise) to run the motor at 1000 r/min (31.25 r/min at output).
11. Turn up the attenuator control for the tacho-generator signal slightly. If the speed decreases the loop feedback is negative (as required). If the speed increases, however, use the other tacho-generator polarity.
    Note that if the system has negative feedback and both the tacho-generator polarity and the power amplifier input are reversed, the system still has negative feedback, but the motor runs in the opposite direction.
12. Set the attenuator control for the tacho-generator to minimum and plot the speed against the 6 brake settings to full brake load. The general characteristic should be as in Figure



Note that the armature current is displayed on the Voltmeter. The signal for this comes from connector 8 which connects from the Control & Instrumentation Principles work board to the Mechanical Unit armature current output.

13. Drag the blue pointer on connection point 1 and place it on point 2. The Voltmeter will now display the error signal input into the power amplifier.
14. Set the attenuator control for the tacho-generator to full scale and readjust the variable dc control to give 1000 r/min with the brake off. Replot the speed characteristic and error (power amplifier input) up to full brake load. Change the feedback resistor to 330kΩ so G = 3.3 (remove connection 2 and add connection 3), adjust the variable dc control to give 1000 r/min with no load, and replot the load characteristic. The droop should be reduced.
15. Repeat with G = 10 (remove connection 3 and add connection 4, adjusting the variable dc control as required, and the droop should be less.

    In some cases a tacho-generator output can contain a ripple component which will be amplified in the forward path, and with high gain could saturate the power amplifier.

    Note the ripple can be reduced by connecting a capacitor across the error amplifier output resistor, but the will introduce a time-constant and reduces the response to fast signals as seen in a previous assignment.

Part 3 - Using Derivative of Error

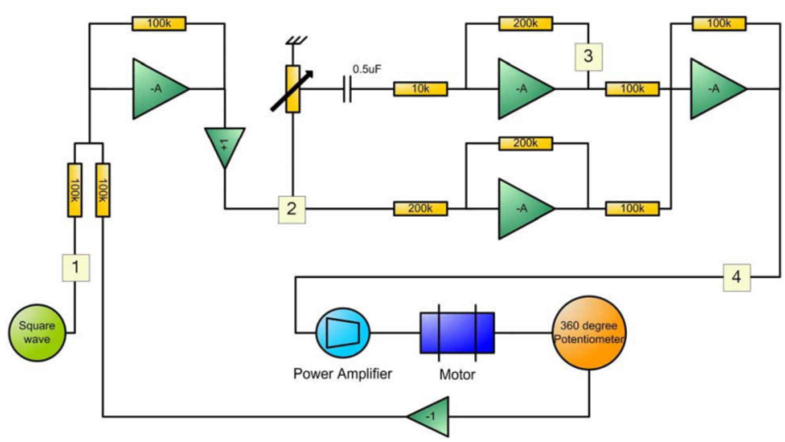
Objectives

In principle a higher gain leads to improved performance in respect of reduction of dead band and following error and also to a reduction of droop with increasing load for a speed control system.

The disadvantage of high gain is that the transient response deteriorates, giving overshoots or oscillations. This can be corrected by the use of velocity (tacho generator) feedback, but that increases the steady following error.

A more general method to improve system performance is to arrange that the drive signal to the motor or other output element is a combination of the direct error, with components of the derivative (rate of change), and integral of the error.

Block Diagram



Perform Practical

1. Launch the Espial software associated with the product.
2. Select **Deriving Velocity Feedback from the Error Signal ------> Practical 2**
3. Use the Make Connections diagram to show the required connections on the hardware.

4. Ensure the power amplifier zero offset control is set so the motor is static (approximately half scale), when no input signal is applied to the power amplifier.
5. Set the derivative gain control to minimum.
6. Set the sweep function generator min freq control to minimum.
7. Set the sweep function generator output amplitude control to 20% of scale.
8. Open the Data Logger.
9. Observe the display on the Data Logger. Step input = blue signal, error signal = yellow signal, derivative of error = orange signal and the green signal = error + derivative of error signal.
10. Set the derivative gain to half scale and note the change in the displayed signals as well as the effect on the motor behaviour.
11. Set the derivative gain to full scale, this should have the similar effect as introducing velocity feedback into a closed loop control system.

Observations & Discussion

1. Use the capture facility on the data logger, and either print or export the display to a folder and include in the report.
2. Discuss about the effect on the motor behaviour and velocity feedback when changing the derivative gain.

Part 4 - Integral Control

Objectives

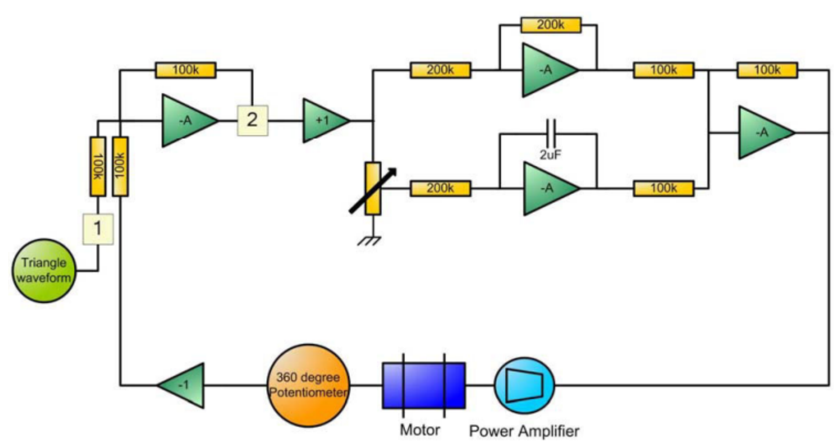
To learn that a very versatile control signal can be obtained by combining the error, the derivative of the error, and on the integral of the error signals.

To learn that with a capacitor in the feedback path, an operational amplifier can act as an integrator.

It has been shown that an important application of integral control is to eliminate steady following error. In this application integral control alone can give a poor transient response, which can be much improved by derivative control.

The integral and derivative control adjustments which give a satisfactory following error transient may not be those that give the best step response, so that some compromise in adjustments may be necessary.

Block Diagram



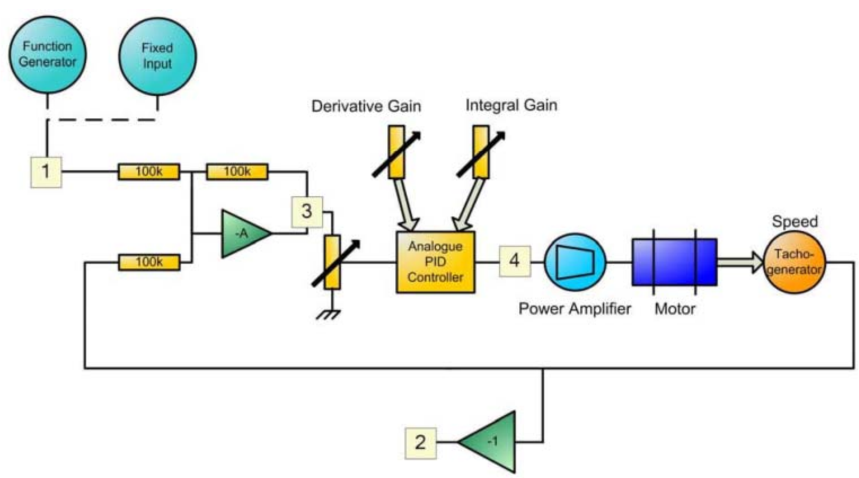
Perform Practical

1. Launch the Espial software associated with the product.
2. Select **Integral Control ------> Practical 2**
3. Use the Make Connections diagram to show the required connections on the hardware.
4. Ensure the power amplifier zero offset control is set so the motor is static (approximately half scale), when no input signal is applied to the power amplifier.
5. Set the sweep function generator min freq control to minimum.
6. Set the sweep function generator output amplitude control to half scale.
7. Set the analogue controller integral gain to half scale.
8. Set the capacitor discharge switch to its right-hand position – leave it in this position.
9. Open the Data Logger.
10. Drag the Data Logger window to make the display larger.
11. Select Overlay.
12. Note the error waveform (yellow) compared to the input signal (blue), in particular the following error.
13. Use the capture facility on the data logger, and either print or export the display to a folder and include in the report.
14. Now set the integrator capacitor circuit to its left-hand position.
15. Observe the change in the error signal by introducing the integrator signal to the control loop.
16. Use the capture facility on the data logger, and either print or export the display to a folder and include in the report.

Part 5 - Three Term Speed Control

In this practical the behaviour of an analogue speed control system is investigated. The controller is a PID block such that the relative amounts of derivative and integral control may be varied.

Block Diagram



Perform Practical

1. Launch the Espial software associated with the product.
2. Select **PID Three Term Control ------> Practical 3**
3. Use the Make Connections diagram to show the required connections on the hardware.
4. Ensure the power amplifier zero offset control is set so the motor is static (approximately half scale), when no input signal is applied to the power amplifier.
5. The input is initially a square wave.
6. Set the sweep function generator output amplitude control to minimum and the min freq control to minimum.
7. Set the derivative and integral gain controls to minimum.

8. Set the capacitor discharge switch to its right-hand position.
9. Set the attenuator control for the main proportional gain to half scale.
10. Open the Data Logger and the Bar Display.
11. Increase the sweep function generator output amplitude control to about half scale. The speed control loop should start to generally follow the input signal (blue). Check that the period of the input signal is approximately 6 seconds and adjust the sweep function generator min freq control if necessary.
12. Note that the measured speed (yellow) never reaches the set speed because the motor speed is purely proportional to error. This means that if the error were zero there would be no drive to the motor.
13. Change the proportional gain and note that the final error decreases with increasing gain (orange).
14. Set the attenuator control for the main proportional gain back to half scale.
15. Set the capacitor discharge switch to its left-hand position.
16. Increase the integral gain. Note how the error is reduced to zero by the integrator supplying the drive to the motor even when the error is zero but that the response is quite slow.
17. Remove connection 2 and add connection 22. This changes the input signal to be a fixed voltage supplied by the input potentiometer.
18. Set the speed to be about positive one third of the input potentiometer range and set the integral control to be about half scale.
19. Set the capacitor discharge switch to its right-hand then left-hand position to discharge it.
20. The error should fall to zero as the required speed matches the measured speed.
21. Apply the brake and note how the speed falls but then recovers as the integrator supplies more drive to the motor. Remove the brake and note that the motor drive signal falls to maintain zero error.

Observations & Discussion

1. Use the capture facility on the data logger, and either print or export the all display as you need, to a folder and include in the report.
2. Comment on your conclusion about the PID controllers for the stability and fast response of the control systems.

SECTION B – ANALYSING THE CONTROL SYSTEMS IN FREQUENCY DOMAIN

Part 1 – Transfer Function and Frequency Response Principles

Transfer Function of a CR Circuit

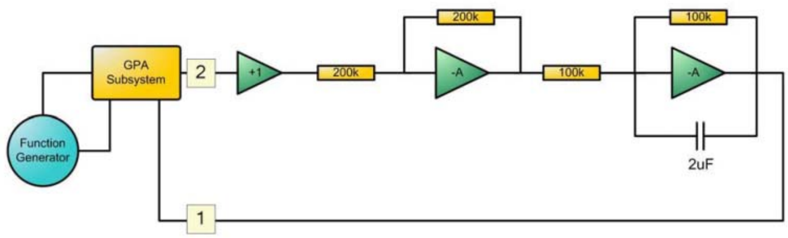
Objectives and Background

In frequency response testing a sinusoidal input is applied to some object which may be a circuit or part of a control system and the relation is considered between input and output signals. Magnitude and phase between the two signals are the important factors. This relationship is mathematically represented in the form of a transfer function. A transfer function for a system can be used to calculate the output of a system for a given input.

In this practical the frequency response for a CR circuit (also known as time constant) will be recorded using the GPA instrument. This will give the magnitude ratio and phase relationship between the input and output signals over a range of frequencies.

The frequencies applied to the CR circuit are set by the max and min freq controls in the Sweep function generator on the Control & Instrumentation Principles work board. By using these settings the digital controller will apply frequencies between them to the circuit whilst recording the response of the circuit.

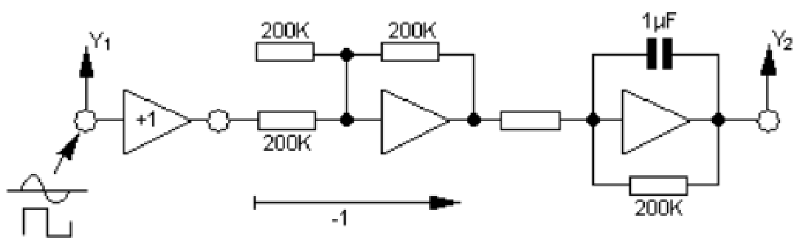
Block Diagram



Perform Practical

1. Launch the Espial software associated with the product.
2. Select **Concepts of Transfer Function Analysis ------> Practical 1**
3. Use the Make Connections diagram to show the required connections on the hardware.

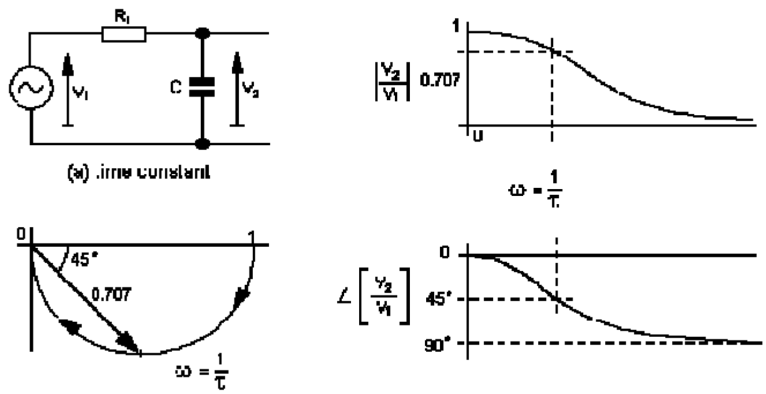
   The CR circuit is constructed using the amplifiers in the controller and summing & error parts of the Control & Instrumentation Principles work board.

   Note an additional "-1" amplifier is arranged before the CR amplifier so that the overall response is identical with a passive component CR circuit.

4. Set function generator output amplitude control to half scale.
5. Open the GPA.
6. Set min freq control to minimum (approx 0.04Hz) will take a while for the frequency to be displayed (wait for progress bar to travel fully across in each case), select max frequency button and set the max freq control to approx 2Hz, gain the set frequency will take a while to be displayed (wait for progress bar to travel fully across in each case).
   Hi resolution can be selected but this will greatly increase the time to carry out the frequency response plot, but will give a more detailed plot.
7. Currently the GPA is set to provide a Bode style plot, if you require a Nyquist plot then select this although it is possible to switch between the two whilst plotting.
8. Set the capacitor switch to its left-hand position.
9. Select Plot.
10. Now the plot will take place. This could take 15–20 minutes to complete due to the readings being recorded for values between the two set frequencies. When the plot is complete, it will repeat from the lowest frequency again, writing over the existing plot.

11. While the plot is in progress, a progress bar will keep incrementing across the top of the GPA display, when the progress bar reaches the end a set amount of data will be written to the screen and the sweep function generator frequency is automatically incremented by the digital controller, and then the progress bar starts over again to show that it is still active.
    As the circuit under test represents a CR circuit, the frequency response (magnitude and phase characteristics) will be similar to Figure below



(c) polar plot

(b) magnitude and phase

τ= CR =100k x 2μF = 0.2 sec

12. Print or export the plot from the GPA in Bode mode.
13. Select Nyquist to see how the results are represented using this type of plot, the result should be similar to the polar plot above.
14. Print or export Nyquist plot.

Part 2 – Closed Loop Transfer Function

Objectives

To learn that closing a feedback loop round a system can have a marked effect on the overall transfer.

To learn how gain in a closed loop system affects the transfer function.

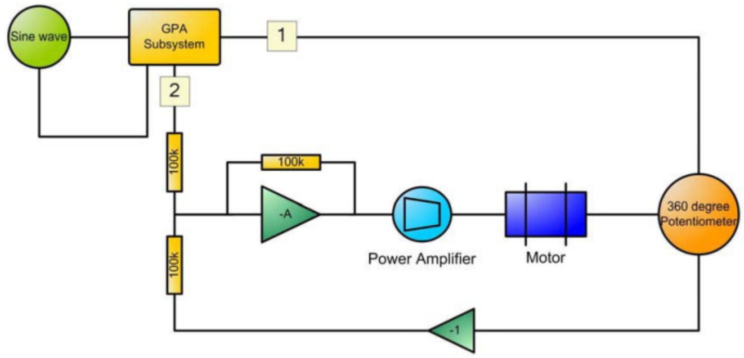
To have an understanding of the relationship between open and closed loop systems and the importance of being able to obtain open loop transfer functions from closed loop transfer functions.

Position Control Loop

Objectives and Background

In this practical a position control loops effect on the motor frequency response (transfer function) is observed. And additionally the effect of increased system gain. The influence of the position control and increased gain can be viewed on the Bode/Nyquist plots produced by the GPA.

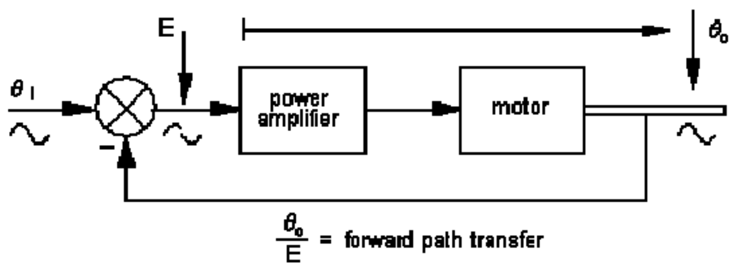
Block diagram



Perform Practical

1. Launch the Espial software associated with the product.
2. Select **Closed Loop Transfer Function ------> Practical 1**
3. Use the Make Connections diagram to show the required connections on the hardware.
4. Ensure the power amplifier zero offset control is set so the motor is static (approximately half scale), when no input signal is applied to the power amplifier.

   The closed loop feedback system is setup as shown in Figure below



5. Set the sweep function generator output amplitude control to half scale.
6. Open the GPA.
7. Set the min freq control to give a frequency of approximately 0.1Hz. The set frequency will take a while to be displayed (wait for progress bar to travel fully across after adjustment). Select max frequency button and set the max freq control to approx 1.6Hz
8. Hi resolution can be selected. This will greatly increase the time to carry out the frequency response plot, but will give a more detailed plot.
9. To begin with the GPA is set to provide a Bode style plot. If you require a Nyquist plot then select this although it is possible to switch between the two whilst plotting.
10. Select Plot.
11. Now the plot will take place. This could take 15–20 minutes to complete due to the readings being recorded for values between the two set frequencies. When the plot is complete, it will repeat from the lowest frequency again writing over the existing plot.
12. While the plot is in progress, a progress bar will keep incrementing across the top of the GPA display, when the progress bar reaches the end, a set amount of data will be written to the screen, and then the progress bar starts over again to show that it is still active. While this is happening the sweep function generator frequency is automatically incremented by the digital controller.
13. With the open loop system the phase shift was over 90°at low frequencies, this is not the case with the position control closed loop. The phase shift at low frequencies is less than 45°
14. Remove connection 4 and add connection 5.
15. This will change the gain of the system to 3.
16. Select Plot
17. The plots produced demonstrate that an increase in gain at low frequencies has little effect on phase and gain of the system. But as frequency increases the zero db crossing point moves

nearer to the 180° phase shift. Also, there is a more pronounced phase shift than previously seen.

Observations & Discussion

1. Print or export the plots from the GPA in Bode and Nyquist mode for both gain.
2. Comment on how has this gain change affected the system frequency response.