UNIVERSITY OF JORDAN
Mechatronics Engineering Department
Measurements & Control Lab. 0908448
Experiment no.1
DC Servo Motor

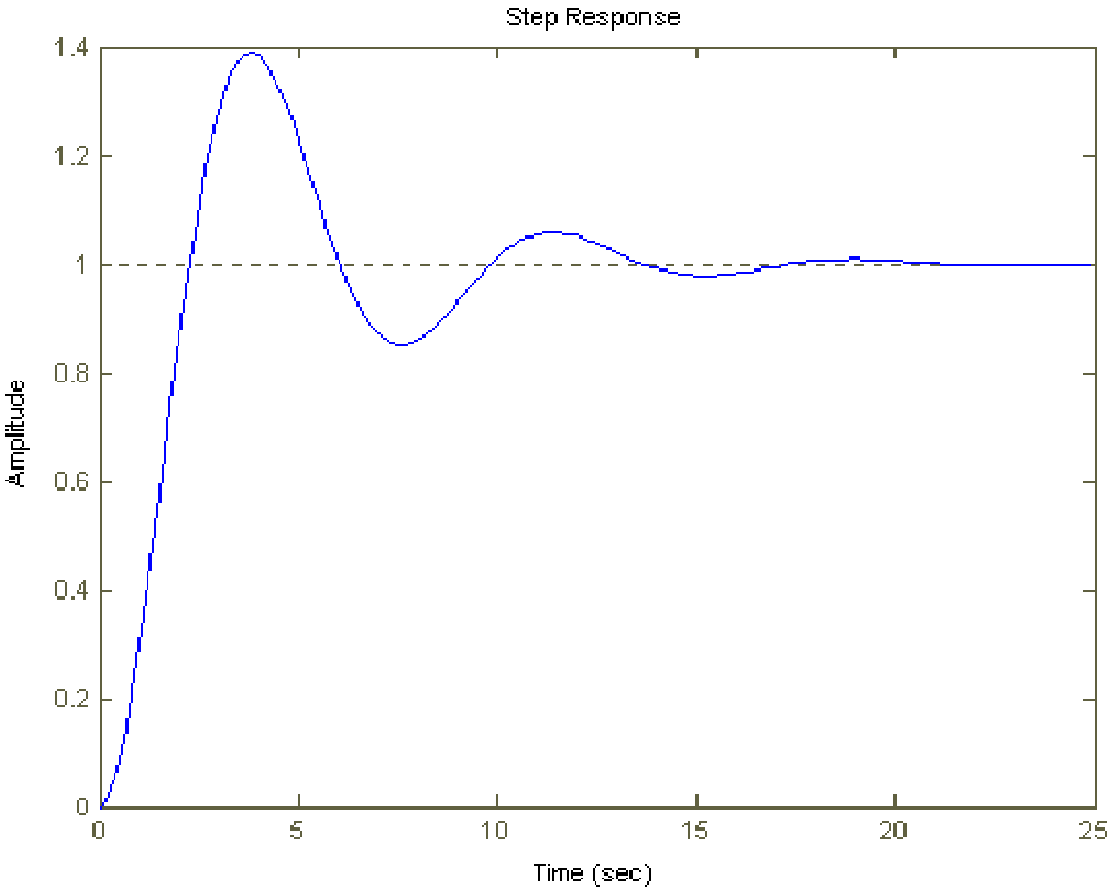
OBJECTIVES:

The aim of this experiment is to provide students with a sound introduction to the principles of analogue servomechanisms, and by extension to those of closed-loop systems more generally.

PRE-LAB:

1. In this experiment, what type of DC motors is used?
2. Draw the speed torque characteristics for DC motor, what is the equation that performs the relationship between torque and speed?
3. From the following step response for a second order system, determine the following:

- What is the behavior of this system?
- What is the supposed valu for ζ?
- The overshoot.
- The settling time.
- The rise time.



EQUIPMENT and APPARATUS:

1. Power supply.
3. Feedback, 33-002 Servo Fundamentals Trainer, which consists of the following:
    - Mechanical Unit 33-100
    - Analogue Unit 33-110

Mechanical Unit 33-100

Contains a **power amplifier** to drive the motor from an analogue or switched input. The motor drives the output shaft through a **32:1 belt reduction.** The motor shaft also carries a **magnetic brake disc** and an **analogue speed transducer (tachogenerator).** A two-phase pulse train for digital speed and direction sensing is also derived from tracks on the brake disc.

The output shaft carries **analogue (potentiometer) and digital (64 location Gray code) angle transducers.**

The unit contains a simple signal generator to provide low frequency test signals; sine, square and triangular waves, and requires an external power supply providing:

+15 V, 0, .15 V at 1.5 A
+5 V, 0, at 0.5 A

The Mechanical Unit

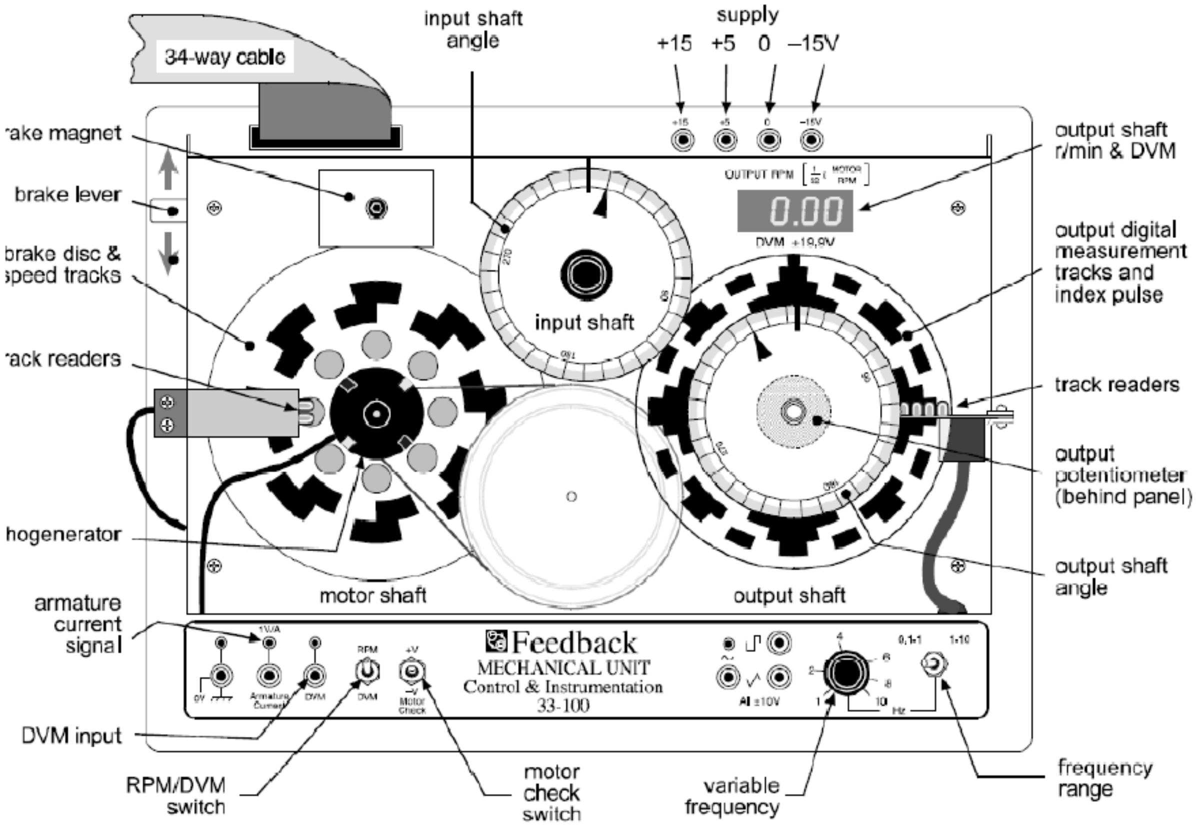


Figure 1. Feedback Mechanical unit 33-100.

Motor shaft	This carries the brake disc, together with a 2-phase speed track and tachogenerator.
Brake disc and magnet	The brake is applied by the lever projecting at the left. The lever scale is provided to enable settings to be repeated.
Speed tracks and readers	These provide two-phase, 0-5 V square waves at 8 cycles per revolution. These signals are available on the 34-way socket but are not used in the Analogue system.
Motor check switch	This enables the motor to be rotated as an initial check.
Armature current signal	This is a voltage waveform indicating the armature current with scale of 1 V/A.
Input shaft	This carries the input potentiometer and scale and gives a signal i in the range ±10 V.

Test signal frequency and range switch	These control the internal oscillator to provide ±10 V square, triangular and sine waveforms with nominal frequency 0.1 to 10 Hz in two ranges. The square and triangular waveforms are connected to the 34-way socket.
Output shaft	This carries the output potentiometer and digital angular measurement tracks. The potentiometer provides o in the range ±10V.
Digital measurement and Readers	The digital tracks give 6 bit Gray code (64 locations) information and are read by infra-red readers. The 6-bit information is supplied as 0 or 5 V to six pins on the 34-way socket.
Index pulse	At one pulse per revolution this provides an output shaft reference point for incremental control connected to a pin on the 34-way socket.
Output speed display	This provides a direct reading of output shaft speed in r/min in the range 00.0 to 99.9, derived from the tachogenerator. Since the reduction ratio is 32:1, a motor speed of 1000 r/min gives 31.1 r/min at the output shaft.

The Analogue Unit

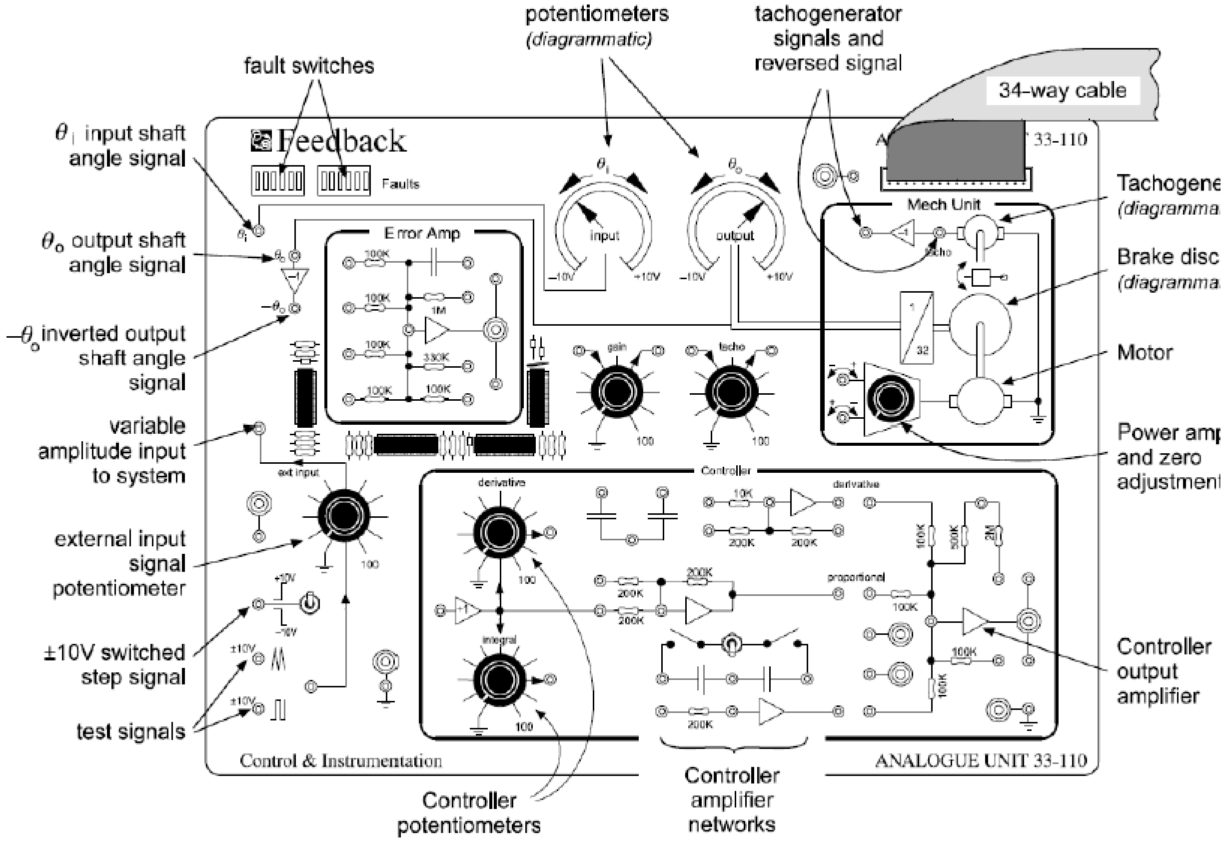


Figure 2. Feedback Analogue Unit 33-110.

Figure 2 shows the general arrangement of the panel, interconnections are made by 2 mm plug leads and there are a few 4 mm sockets for conversion or oscilloscope connections.

Upper portion of panel From left to right θ i,θo	These sockets give the voltage signals from the input and output shaft potentiometers. These are represented diagrammatically in the centre of the panel, the potentiometers themselves being in the Mechanical Unit.
- θo	This socket provides a reversed output shaft signal required for certain applications.
Fault switches	These enable faults to be introduced. For normal (no fault) operation all switches should be down.
Error Amplifier	This is used to combine potentiometer signals to provide the error.
Potentiometers P1 and P2	These provide system gain control and tachogenerator signal adjustment.

Power amplifier	This drives the motor. The two inputs drive the motor in opposite directions for a given input. The zero adjustment enables the motor to be rotated with no amplifier input.
Motor	This is in the Mechanical Unit and drives the brake disc and tachogenerator directly, and the output shaft through a 32:1 belt reduction.
Brake disc and magnet	These are in the Mechanical Unit and provide an adjustable load for the motor.
Tachogenerator	This is mounted on the motor shaft and provides a voltage proportional to motor speed; the voltage is available with reversed polarity.
Lower portion of panel from left to right ±10 V step	This enables a manually switched 10 V step input to be obtained.
Test signals	These sockets provide ±10 V low frequency (nominally 0.1 to 10 Hz) square and triangle waveforms. The frequency control and range switch are on the Mechanical Unit. A sine wave test input is available from the Mechanical Unit.
External input potentiometer P3	This can be linked to any input to provide an adjustable input to the error amplifier.
Controller	This contains operational amplifiers with associated networks to enable various compensating and control circuits to be introduced to improve the performance of a basic system.

Introduction:

The servo is an automatic electromechanical device that uses error-sensing feedback to correct the performance of a mechanism. The term applies only to systems where the feedback or error-correction signals help control mechanical position or other parameters.

A common type of servomotors provides position control. Servos are commonly electrical or partially electronic in nature, using an electric motor as the primary means of creating mechanical force. Other types of servos use hydraulics, pneumatics, or magnetic principles. Usually, servos operate on the principle of negative feedback, where the control input is compared to the actual position of the mechanical system as measured by some sort of transducer at the output. Any difference between the actual and wanted values (an "error signal") is amplified and used to drive the system in the direction necessary to reduce or eliminate the error. An entire science known as control theory has been developed on this type of system.

The Closed-Loop Control System

The difference or error signal may be thought of as producing effects which move forward, from the point of comparison to the resulting action. The comparison itself depends on a signal which is fed back from the output of the process to be compared with the reference or input signal. The forward flow and feedback of signals form a loop around which information flows, see Figure 3. Such a system is therefore called a closed-loop system.

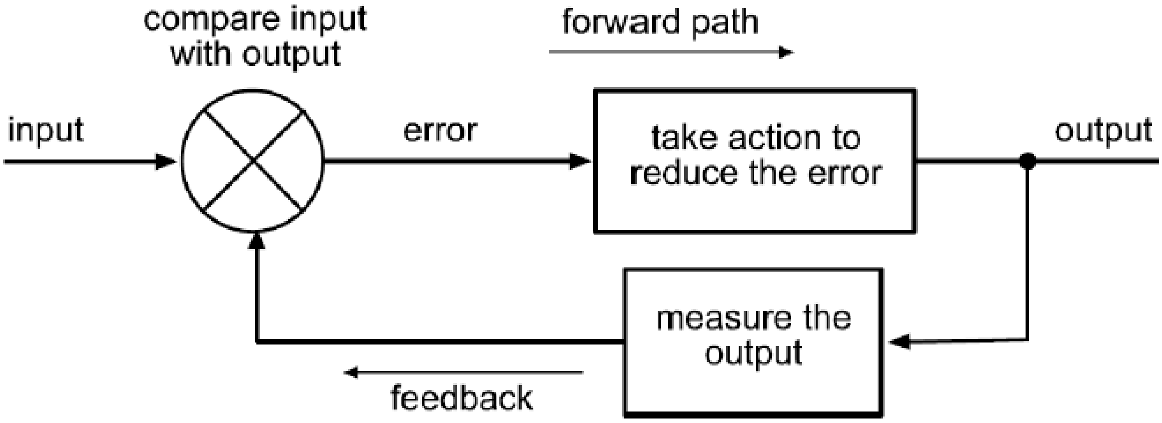


Figure 3. The Closed Control Loop.

Various names are given to the signals in different industrial or other contexts, but the meanings of words in any one of the columns below are much the same:

Difference	**Output**	**Input**
Error	**Actual value**	**Reference value**
Deviation	**Measured value**	**Set value**
	Controlled quantity	**Set point**
		Desired value
		Demanded value

Where the system is electrical, the state will normally be represented by signals expressed in volts; in the strip that being rolled in a steel mill it might be, for the width, a signal representing ten inches per volt.

The difference in the comparison will be called the **error signal** and the part of the system that carries out the comparison is the **error channel**.

There is usually a power amplifying device to drive the **Actuator** (which in Figure 4 is the geared motor).

It is usual for control engineers to describe their systems in a block diagram form. The block diagram below describes the type of system we shall be using in this experiment.

Here there is a comparison by the error channel of the input and output, the error is then amplified to drive a motor and gearing in the forward path so that the speed or position of the output shaft can be modified.

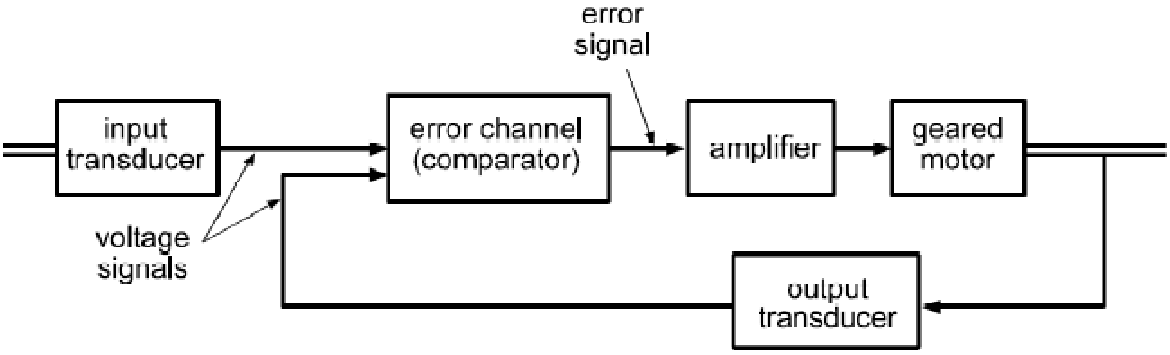


Figure 4. *Block Diagram of an Analogue Closed-Loop System.*

Motor, Tachogenerator and Brake Characteristics

The motor is a **permanent magnet type** and can be represented in idealized form as in Figure 5, where Ra is the armature resistance and T1, T2 are the actual motor terminals.

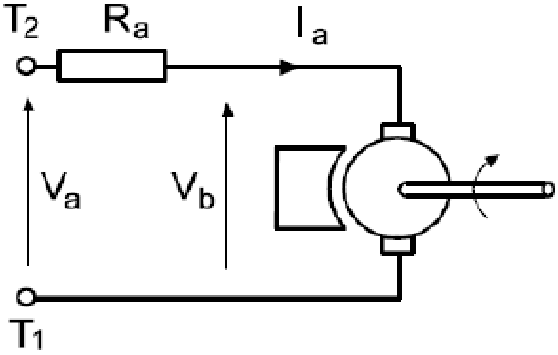


Figure 5. *Representation of a Motor in terms of an Ideal Motor.*

If the motor is stationary and a voltage Va is applied, a current Ia flows which causes the motor to rotate. As the motor rotates a back emf Vb is generated. As the motor speeds up, the back emf increases and Ia falls. In an ideal (loss free) motor, the armature current falls to substantially zero and Vb approximately equals Va. Thus if Va is varied slowly in either polarity, the motor speed is proportional to Va, and a plot of motor speed against Va would have the form of Figure 6.

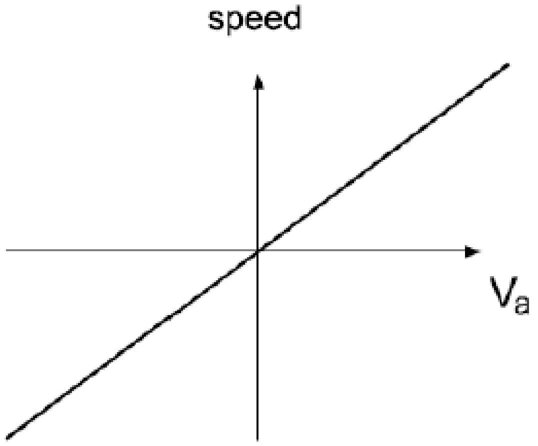


Figure 6. DC Motor characteristics.

In the 33-100 the armature voltage Va is provided by a **power amplifier**. A power amplifier is necessary, because although the voltages in the error channel may be of the same order as Va, the motor current may be up to 1 A, while the error channel operates with currents of less than 1 mA and could not drive the motor directly. The amplifier has two input sockets, enabling the motor rotation direction to be reversed for a given input.

The **tachogenerator** is a small permanent magnet machine and hence when rotated produces an emf proportional to speed which can be used as a measure of the rotation speed.

The magnetic brake consists of a permanent magnet which can be swung over an aluminum disc. When the disc is rotated eddy currents circulate in the area of the disc within the magnet gap, and these react with the magnet field to produce a torque which opposes rotation. This gives an adjustable torque speed relation of the form of Figure 7, and provides a very convenient load for the motor.

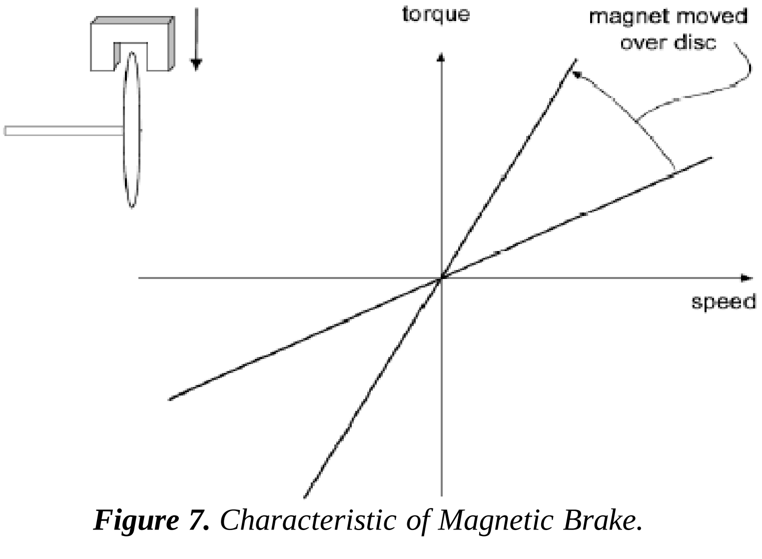


Figure 7. Characteristic of Magnetic Brake.

The overall characteristics of a motor may be considered from two aspects, both of which can be related to the idealized representation of Figure 8. These aspects are**: Steady-state**, which are concerned with constant or very slowly changing operating conditions, and **transient**, corresponding with sudden changes, both are important in control system applications.

PROCEDURE:

PART I: Steady-State Characteristics

1. In this part, the motor is operated in a range of steady-state conditions.
2. Arrange the system as shown in Figure 8, where P3 enables a voltage in the range ±10 V to be applied to the power amplifier.

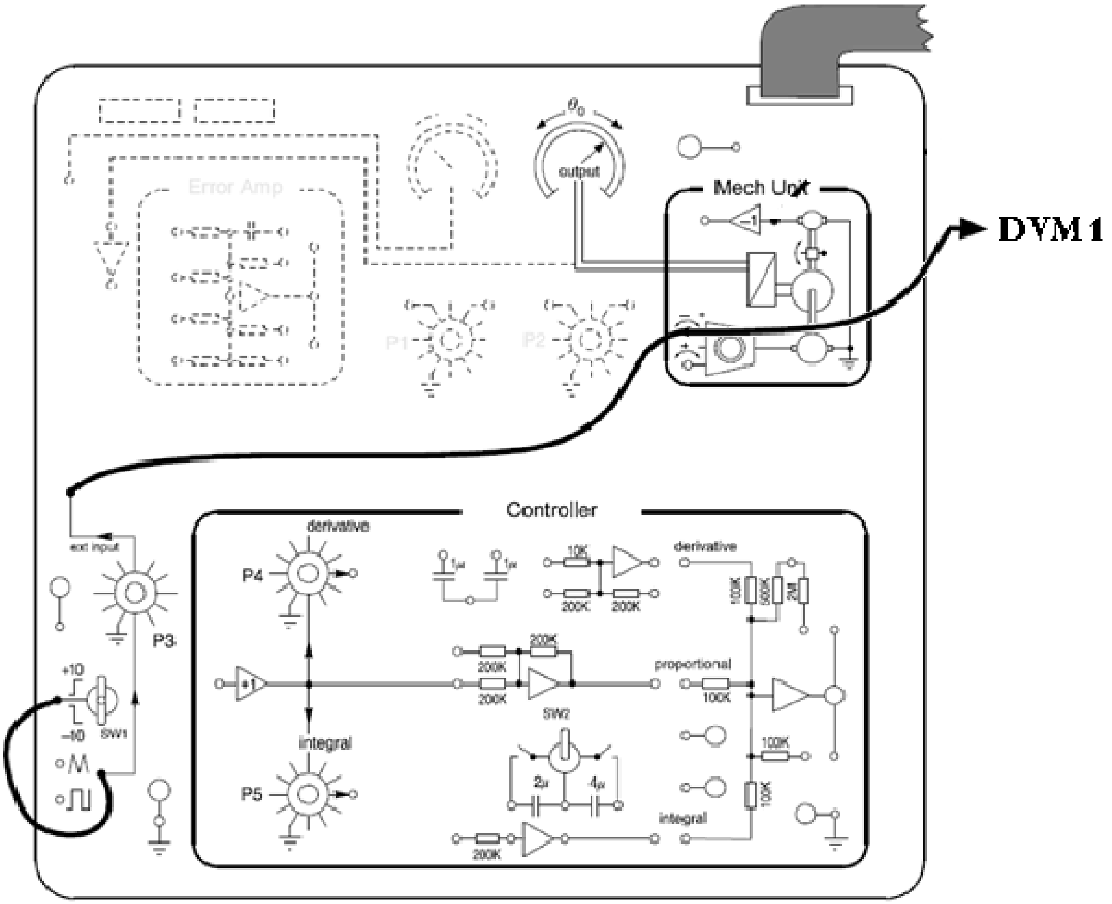


Figure 8. *Connections for PART I.*

3. Use the DVM on the 33-100 for voltage measurements. For each measurement set up the required steady state then switch between DVM and RPM.

4. By setting SW1 and varying P3, fill in the following table, then make a plot of motor speed against amplifier input.

Note:
Since the reduction to the output shaft is 32:1, the motor speed is calculated by multiplying the r/min reading by 32; eg, a reading of 31.25 = a motor speed of 1000 r/min.

Amplifier Input (Volts)	Output Shaft Speed (RPM)	Motor Speed (RPM)
+10		
+9		
+7.5		
+5		
+2.5		
+1		
0		
-1		
-2.5		
-5		
-7.5		
-9		
-10		

Brake Load
Considering the idealized motor shown in Figure 9(a), when the motor is unloaded the back emf Vb substantially equals the applied voltage Va, the armature current being very small. When the motor is loaded the speed falls, the back emf falls, and the armature current increases and the voltage drop in the armature resistance Vr (= IaRa) added to Vb matches Va, that is:

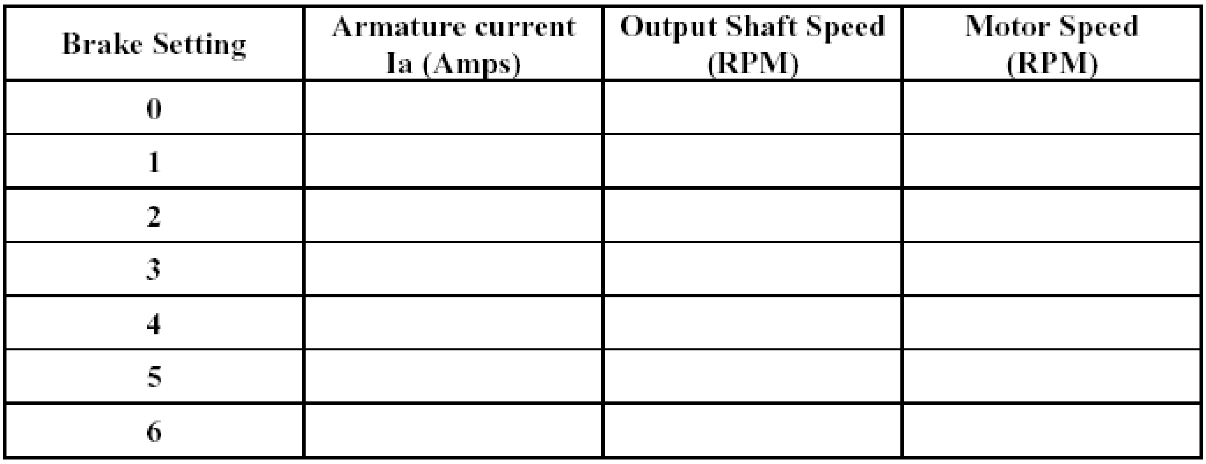
$$V_a = V_r + V_b$$

$$= I_a R_a + V_b$$

Hence, if the motor is loaded so that the speed falls, the armature current increases, the general characteristic being as the solid lines in Figure 9(b). If the armature resistance is low, which is the situation for a normal motor, the current increases greatly, as shown dotted, for a small change in speed. The proper operating range of the motor would be up to a load corresponding with a few percent drop in speed, perhaps to the point when the dotted current line crosses the speed line.

1. Adjust P3 to set the motor speed to 2000 r/min (62.5 r/min at output), with the brake fully upwards. Connect the DVM to the Armature Current (1volt/amp) output on the Mechanical Unit.

2. Set the brake to each of its six positions in turn and for each setting record the speed and armature current.



Brake Setting	Armature current Ia (Amps)	Output Shaft Speed (RPM)	Motor Speed (RPM)
0			
1			
2			
3			
4			
5			
6			

3. **Plot the speed and armature current against brake setting,** the plot should have the general form of Figure 9(c).

4. Comment on your results.

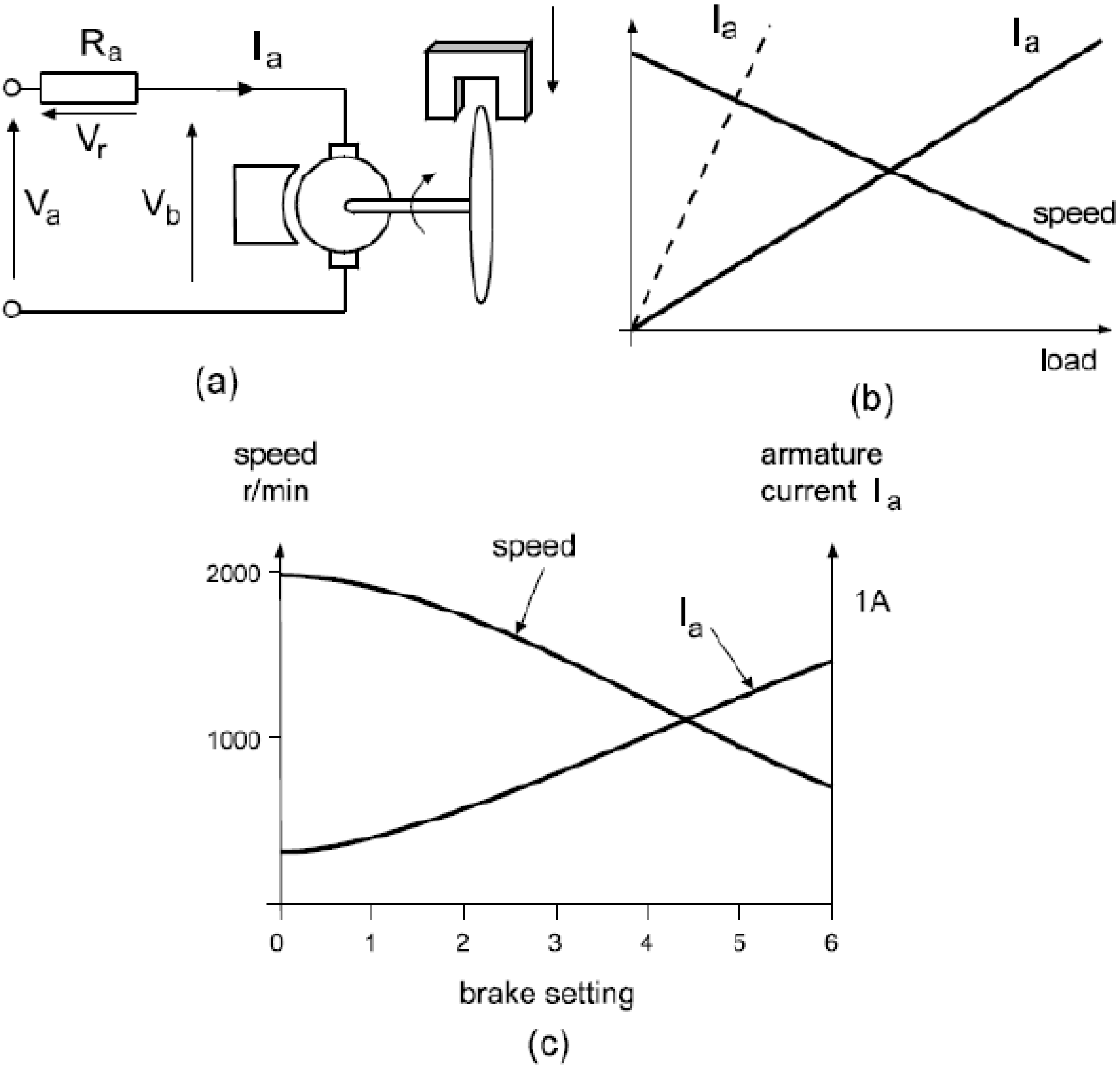


Figure 9. *Motor Characteristics Related to Load.*

PART II: Speed Control System

An important aspect of closed-loop control is speed control, which has many industrial applications, varying from heavy industrial, such as paper mills or steel rolling mills, to tape or video transport mechanisms.

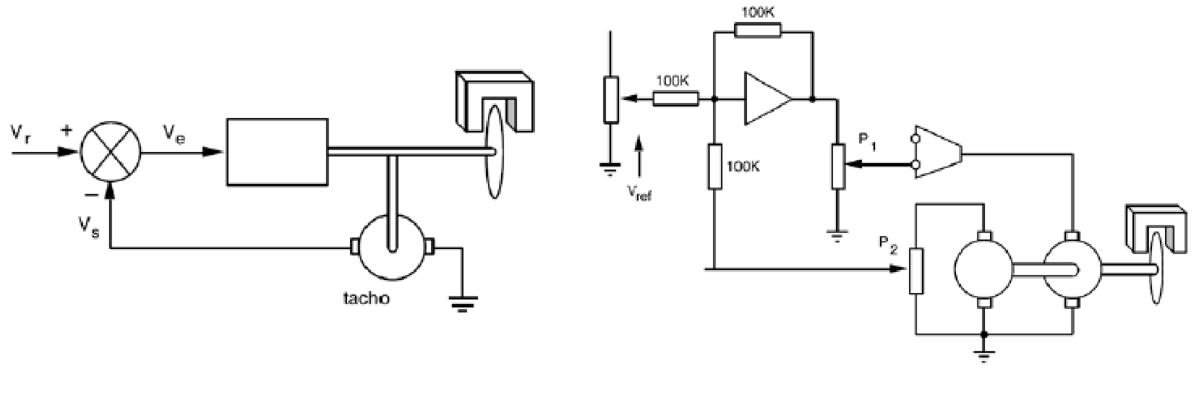
The essential principle of closed-loop speed control is similar to position control, except that the feedback signal is an output velocity signal Vs, normally from a tachogenerator, which is compared with a reference voltage Vr to give an error
Ve= Vr – Vs

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, 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.

The rotation direction can be reversed by reversing the reference voltage, though many industrial speed control systems are required to operate in one direction only.



(a) (b)

Figure 10. *Essential features of a Closed Loop Speed Control.*

1. Arrange the system as in Figure 11. Set P2 (tacho) to zero and set the amplifier feedback resistor to 100 k, this gives G = 1. Set P1 to 100. Set SW1 up to +10 and adjust P3 to run the motor at 1000 r/min (31.25 r/min at output).

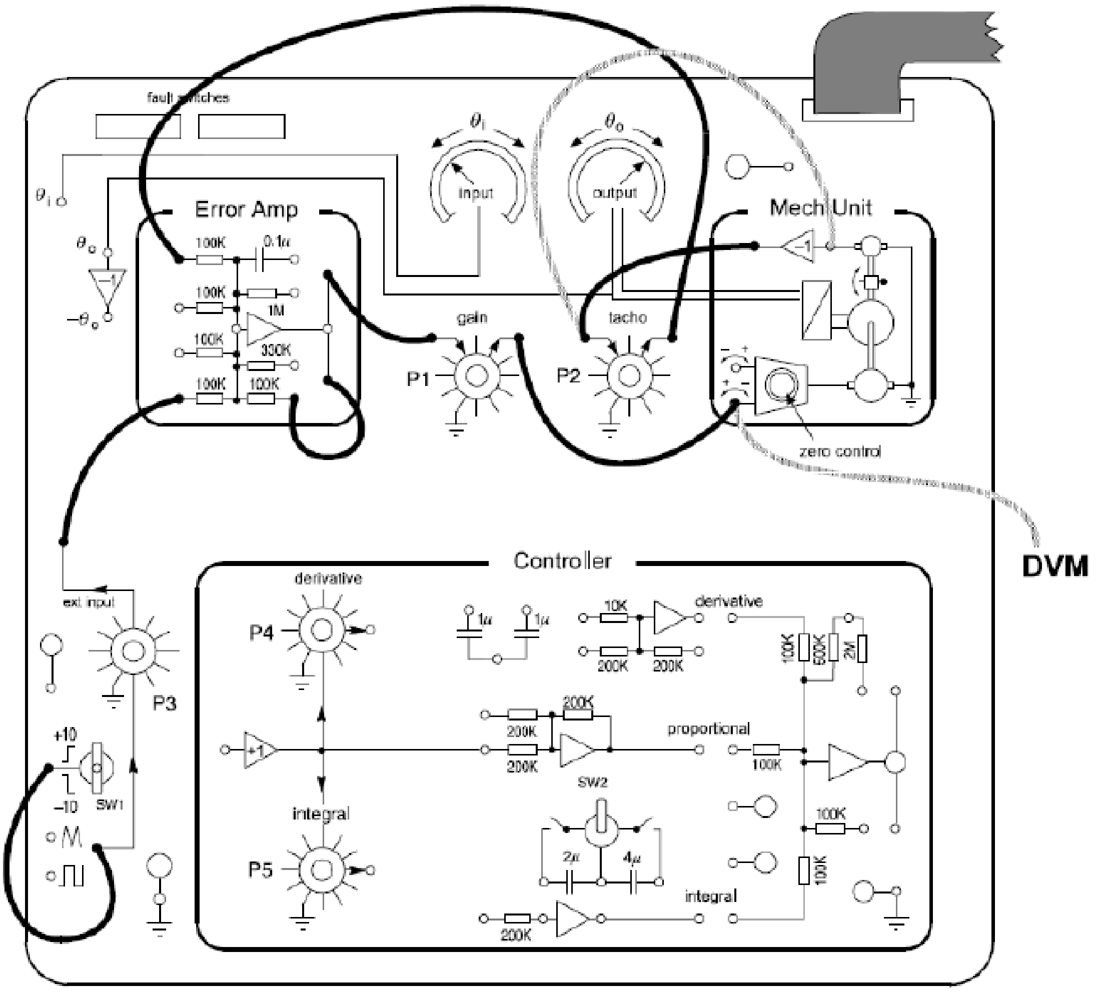


Figure 11. *Connections for PART V.*

2. Turn up P2 slightly, if the speed decreases the loop feedback is negative as required. If the speed increases use the other tachogenerator polarity.

Note that if the system has negative feedback and both the tachogenerator polarity and the power amplifier input are reversed, the system still has negative feedback, but the motor runs in the opposite direction.

3. Set P2 to zero and **fill in the following table then plot the speed against brake setting to full brake load.** The general characteristic should be as in Figure 12.

Brake Setting	Armature current Ia (Amps)	Output Shaft Speed (RPM)	Motor Speed (RPM)
0			
1			
2			
3			
4			
5			
6			

4. Set P2 to 100 and readjust P3 to give 1000 r/min with the brake off.
5. **Fill in the following table, then plot the speed characteristic and error (Power Amplifier input).**

Brake Setting	Ia (Amps)	Output Shaft Speed (RPM)	Motor Speed (RPM)	PA Input (Volts)
0				
1				
2				
3				
4				
5				
6				

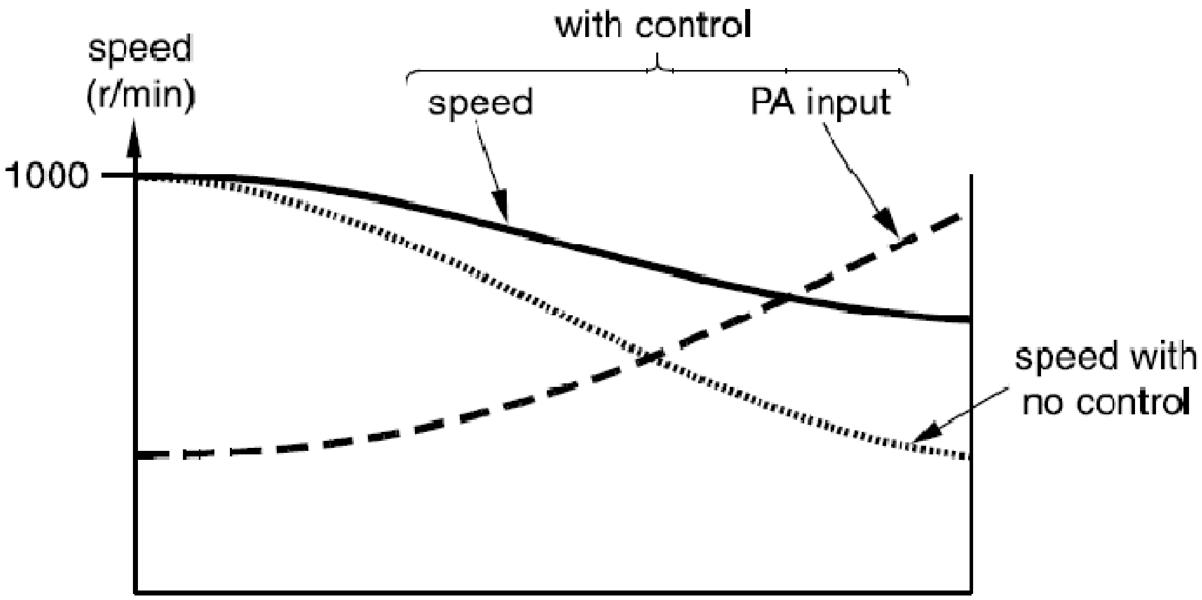


Figure 12. *Speed Regulation with and without Closed-Loop Control.*

PART III: Position Control System

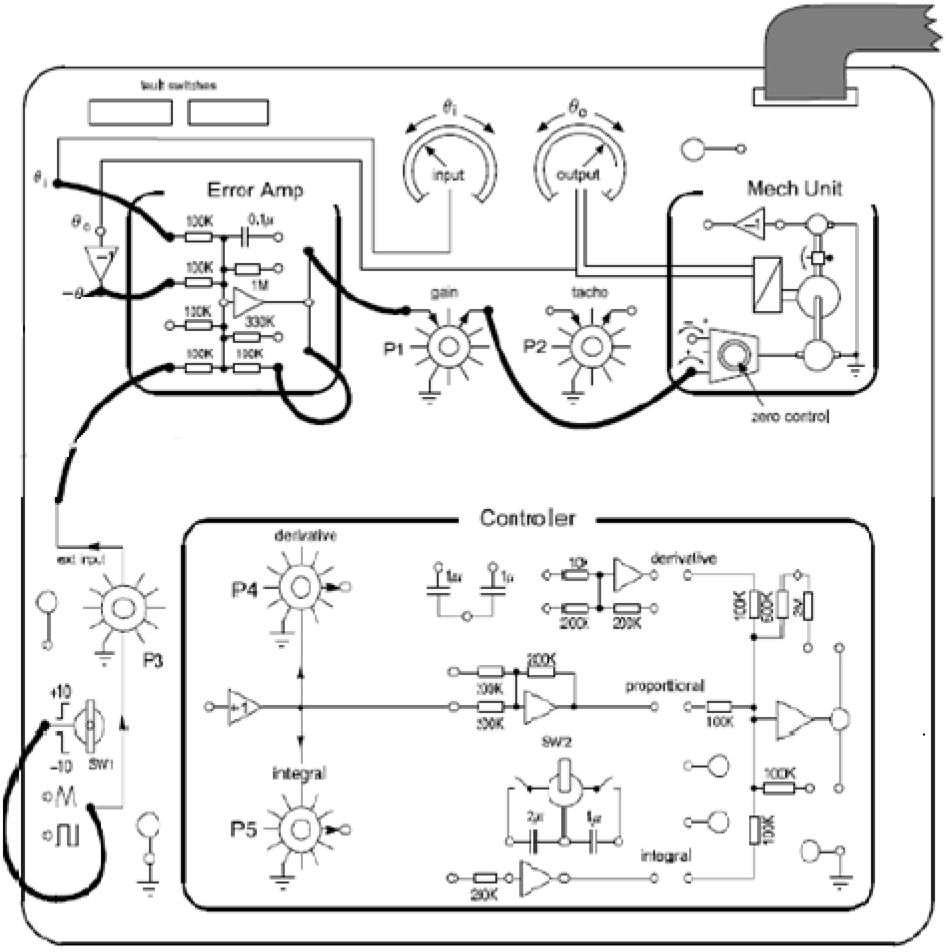


Figure 13. *Connection for PART III.*

1. Arrange the system with the solid connections of Figure 13, with the error amplifier feedback resistor 100 k, giving G = 1.
2. Set the desired angle θi at a certain position.
3. Set P1 to zero, and then turn up P1 until the motor just rotates; notice the response.
4. Disconnect the position feedback signal θo, and notice the response.

- **What is the P1 percentage value that makes the system just rotates?**
- **What is the relationship between the Time to reach steady state (Ta) and the overshoot value?**
- **Draw both open-loop and closed-loop position responses versus time.**