1 Experiment No. 7

2 Experiment Title

Torque and Speed Characteristics of a DC Motor

3 Objective

The objectives of this lab are as follows:

- To investigate the torque and speed characteristics of a DC motor.
- To understand the relationship between torque and speed for DC motors.
- To observe the effect of varying load on the motor's speed and torque.

4 Theory

Torque and Speed Characteristics of a DC Motor

The performance of a DC motor is primarily evaluated based on its torque and speed characteristics, which determine its suitability for specific tasks.
Different types of DC motors, such as shunt and compound motors, exhibit unique torque and speed characteristics:

- **DC Shunt Motor:** Known for its excellent speed regulation, this motor maintains a nearly constant speed regardless of load variations.
- **DC Compound Motor:** Combines the properties of both shunt and series motors, offering higher starting torque and adjustable speed regulation, depending on the type of compounding.

4.1 DC Shunt Motor

4.1.1 T/I_a Characteristics:

For a DC shunt motor, the torque (T) is directly proportional to the armature current (I_a). The torque equation is given by:

$$T = KI_a\Phi \tag{1}$$

Where:

- T is the developed torque,
- K is a constant depending on motor construction,
- I_a is the armature current,
- Φ is the flux per pole.

In a shunt motor, the field winding is connected in parallel with the armature winding. Since the supply voltage (V) is constant, the field current (I_f) remains nearly constant, and hence the flux (Φ) is constant. Therefore, the torque equation simplifies to:

$$T \propto I_a \tag{2}$$

This indicates that the torque varies linearly with the armature current. As a result, the torque characteristic of a DC shunt motor is represented by a straight line passing through the origin.

4.1.2 $Speed/I_a$ Characteristics:

The speed S of a DC shunt motor can be controlled by manipulating either the armature current I_a or the field flux Φ, as shown in the following formula:

$$S = \frac{V_T - I_a R_a}{K\Phi}$$

Where:

- S is the speed of the motor,
- V_T is the terminal voltage,
- I_a is the armature current,
- R_a is the armature resistance,
- K is a constant depending on motor construction,
- Φ is the flux per pole.

In a DC shunt motor, the field winding is connected in parallel with the armature winding, which ensures that the flux (Φ) remains constant under varying load conditions. As the load increases, the armature current (I_a) also increases, leading to a voltage drop across the armature resistance ($I_a R_a$). This reduces the back EMF, and consequently, the speed (S) decreases slightly.
Since the flux remains constant, the speed reduction is minimal, resulting in good speed regulation. The speed characteristic curve for a DC shunt motor shows a slight deviation from a flat horizontal line, indicating relatively small speed changes with varying load conditions.

4.2 DC Compound Motor

4.2.1 Cumulative Compound Motor

4.2.2 T/I_a Characteristics:

In a cumulative compound motor, the torque (T) is influenced by both the armature current (I_a) and the combined magnetic flux from the shunt and series field windings. The total flux (Φ) is the sum of the flux due to the shunt field (Φ_f) and the flux due to the series field (Φ_s). The torque can be expressed as:

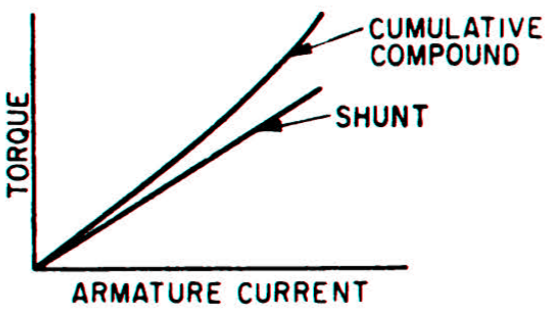
$$T = K I_a (\Phi_f + \Phi_s) \tag{3}$$

Where:

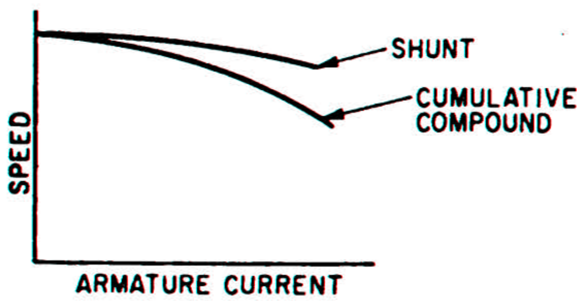
- T is the developed torque,

- K, K_1, and K_2 are motor-specific constants,
- I_a is the armature current,
- Φ_f is the flux from the shunt field,
- Φ_s is the flux from the series field.

As the load increases, the armature current (I_a) also increases. This causes the series field flux (Φ_s) to increase, resulting in a more than linear increase in torque. This characteristic provides the motor with a "boost" in torque at higher loads, making cumulative compound motors well-suited for applications requiring high starting torque and improved load-handling capability. The torque characteristic curve of a cumulative compound motor shows a steeper rise compared to a shunt motor, especially at higher armature currents.



(a) Comparing torque of cumulative and shunt motor



(b) Comparing speed of cumulative and shunt motor

4.2.3 $Speed/I_a$ Characteristics:

The speed (S) of a cumulative compound motor is influenced by the terminal voltage, armature current, resistances, and the combined flux from the shunt and series fields. It can be expressed as:

$$S = \frac{V_T - I_a(R_a + R_s)}{K(\Phi_f + \Phi_s)} \tag{4}$$

Where:

- S is the speed of the motor,
- V_T is the terminal voltage,
- I_a is the armature current,
- R_a is the armature resistance,
- R_s is the series resistance,
- K is a motor-specific constant,
- Φ_f is the flux due to the shunt field,
- Φ_s is the flux due to the series field.

As the load on the motor increases, the armature current (I_a) also increases. This leads to a larger voltage drop across the combined resistance ($R_a + R_s$) and an increase in the series field flux (Φ_s). Since the speed is inversely proportional to the total flux, the increase in Φ_s causes the speed to decrease more rapidly compared to a shunt motor.
The speed characteristic curve of a cumulative compound motor is less flat than that of a shunt motor. This means the motor experiences a more significant reduction in speed as the load increases, due to the cumulative effect of the series field. This characteristic makes cumulative compound motors suitable for applications where a decrease in speed with increasing load is acceptable or even beneficial.

4.2.4 Differential Compound Motor

4.2.5 T/I_a Characteristics:

In a differential compound motor, the torque (T) is influenced by both the shunt field flux (Φ_f) and the series field flux (Φ_s). However, unlike in a cumulative compound motor, the series field flux opposes the shunt field flux. The torque can be expressed as:

$$T = KI_a(\Phi_f - \Phi_s) \tag{5}$$

Where:

- T is the developed torque,
- K, K_1, and K_2 are constants depending on motor construction,
- I_a is the armature current,
- Φ_f is the flux from the shunt field,
- Φ_s is the flux from the series field.

As the load increases, the armature current (I_a) also increases, leading to a rise in the opposing series flux (Φ_s). This reduces the net flux, which in turn decreases the torque at higher loads. This characteristic makes differential compound motors unsuitable for heavy-load applications, as the torque decreases with increasing load, which can lead to instability and inefficient operation under such conditions.

4.2.6 $Speed/I_a$ Characteristics:

The speed (S) of a differential compound motor is influenced by the terminal voltage, armature current, resistances, and the net flux resulting from the opposing shunt and series fields. The speed equation is given by:

$$S = \frac{V_T - I_a(R_a + R_s)}{K(\Phi_f - \Phi_s)} \tag{6}$$

In a differential compound motor, the series flux (Φ_s) opposes the shunt flux (Φ_f). As the load increases, the armature current (I_a) also increases, causing the opposing series flux (Φ_s) to grow. This reduces the total flux ($\Phi_f - \Phi_s$).
Since speed is inversely proportional to the net flux, the reduction in total flux causes the speed to increase as the load increases. This behavior is opposite to that of cumulative compound and shunt motors, where speed decreases with load.

The speed characteristic curve of a differential compound motor thus shows an increase in speed with increasing load. This characteristic makes differential compound motors suitable for applications where a slight increase in speed under load is advantageous.

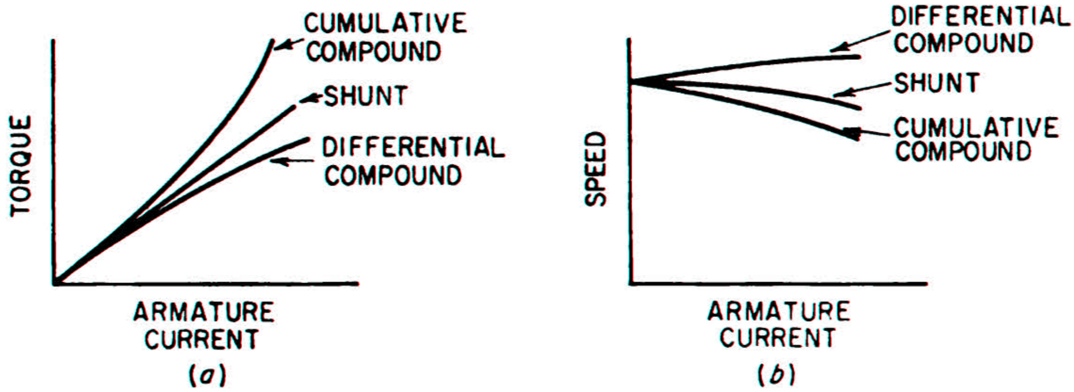
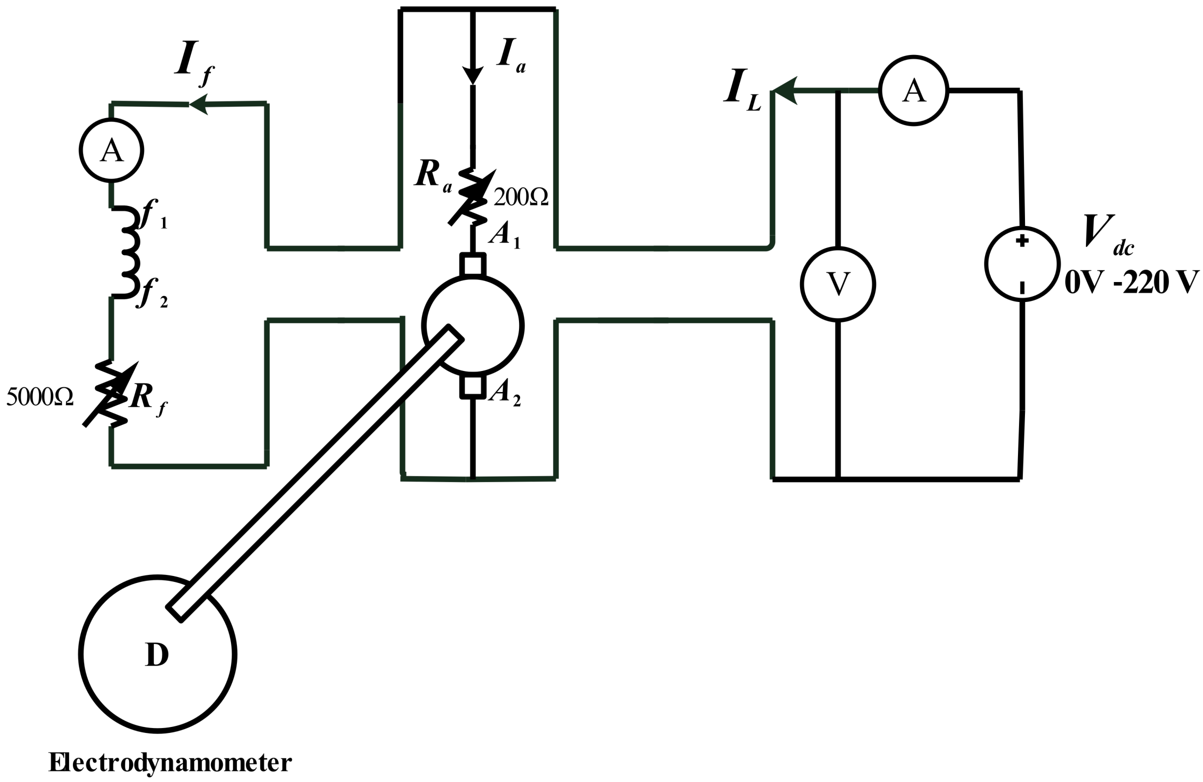


Figure 2: Comparison of Torque and Speed characteristics

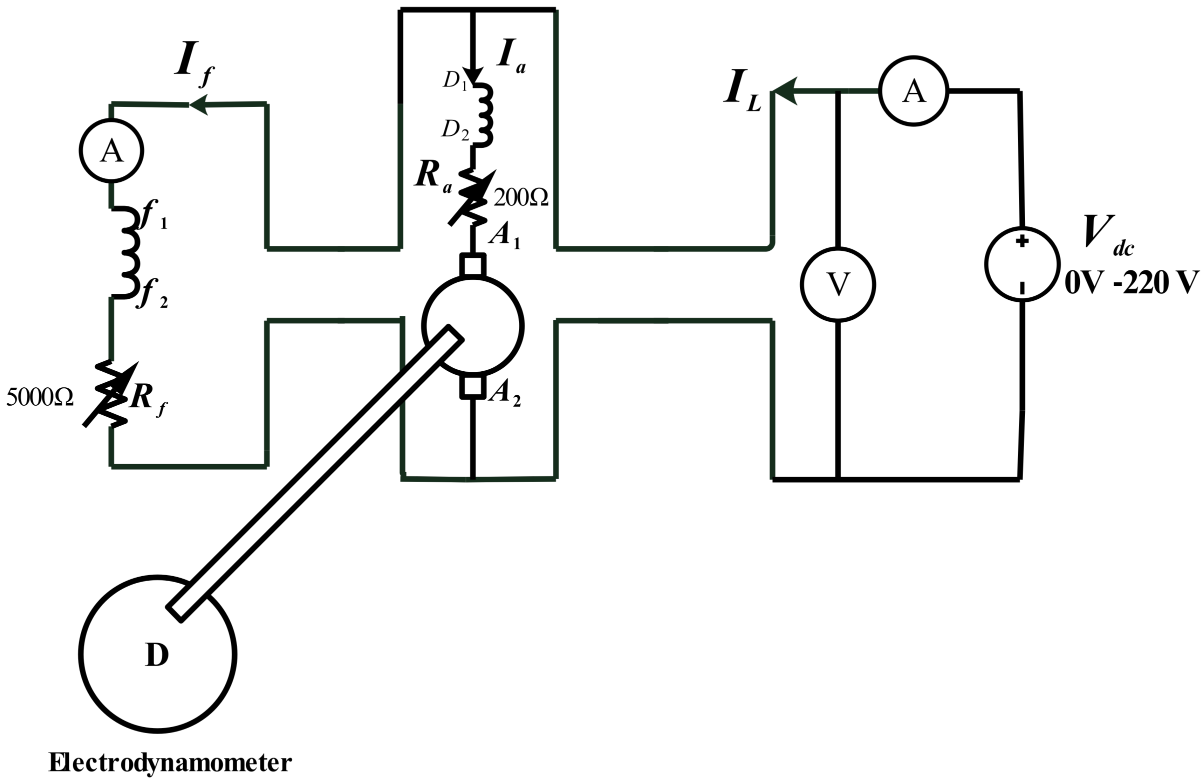
5 Required Apparatus

1. Electric Machine Trainer
   (a) DC Motor Starting Resistor
   (b) DC Power Supply (Rating: Voltage: 200V)
   (c) DC Ammeters (Rating: Current: 5A)
   (d) DC Voltmeter (Rating: Voltage: 500V)
   (e) DC Motor Field Resistor
   (f) Speed Meter (Rating: 1500 rpm max)
   (g) Torque Meter (Rating: 0.24 kg-m max)
2. DC Compound Motor (Ratings: Output: 360W, Voltage: 200V, Current: 2.5A, Speed: 1500 rpm; Field: 0.2A, Pole: 2P)
3. Dynamometer (Ratings: Output: 360W, Voltage: 100V, Current: 3A; Pole: 2P; Speed: 4000 rpm max, Type: Eddy Current)

6 Circuit Diagrram



(a) Circuit diagram for DC Shunt Motor



(b) Circuit diagram for DC Compound Motor

7 Data Table

Table 1: Readings of Armature current (I_a), Motor Speed (S) and Torque(T)

SI No.	Armature Current, $I_a(A)$	Speed , S (r.p.m)	Torque $T(KgM)$
1	0.363	1500	0.7
2	0.405	1495	0.93
3	0.429	1493	0.115
4	0.449	1488	0.13
5	0.462	1485	0.142
6	0.474	1482	0.155
7	0.505	1481	0.181
8	0.51	1480	0.191
9	0.536	1470	0.220
10	0.537	1469	0.224
11	0.554	1477	0.235
12	0.572	1463	0.247

(a) Readings for DC Shunt Motor

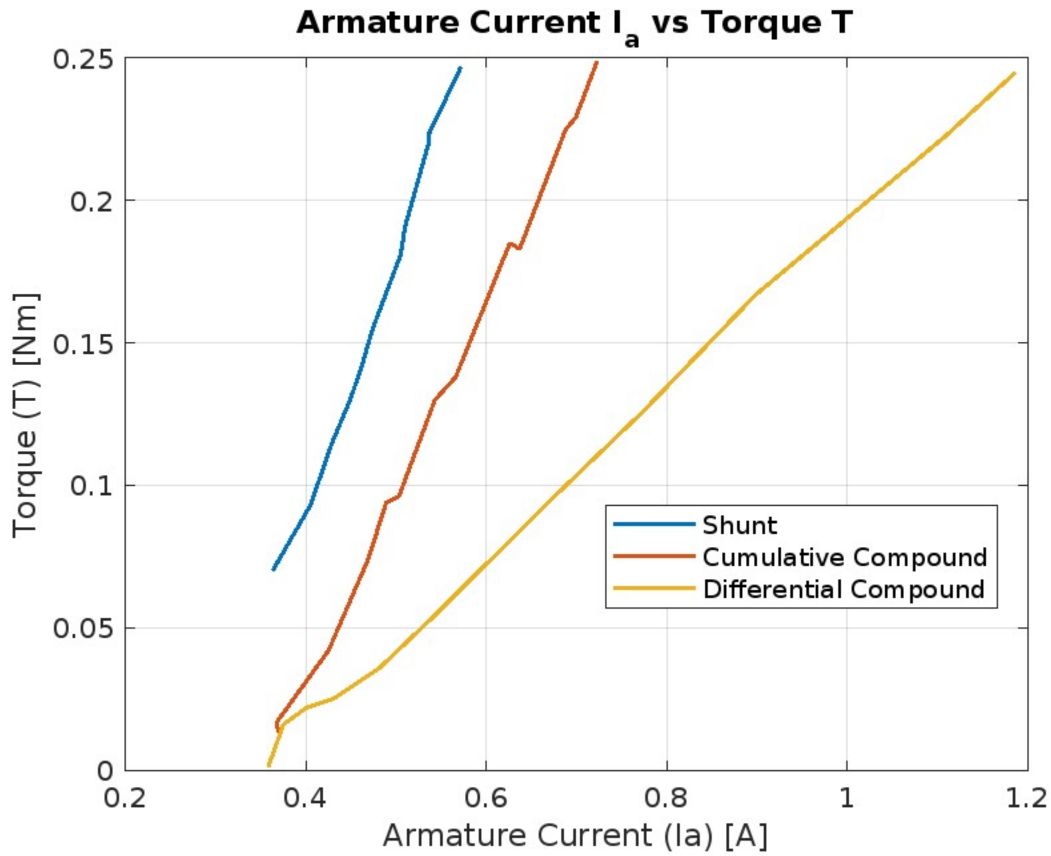
SI No.	Armature Current, $I_a(A)$	Speed , S (r.p.m)	Torque $T(KgM)$
1	0.369	1500	0.013
2	0.368	1497	0.017
3	0.425	1487	0.042
4	0.469	1477	0.074
5	0.489	1474	0.094
6	0.503	1467	0.096
7	0.543	1460	0.130
8	0.566	1455	0.138
9	0.626	1440	0.185
10	0.637	1433	0.183
11	0.688	1422	0.225
12	0.699	1417	0.229
13	0.723	1412	0.249

(b) Readings for DC Cumulative Compound

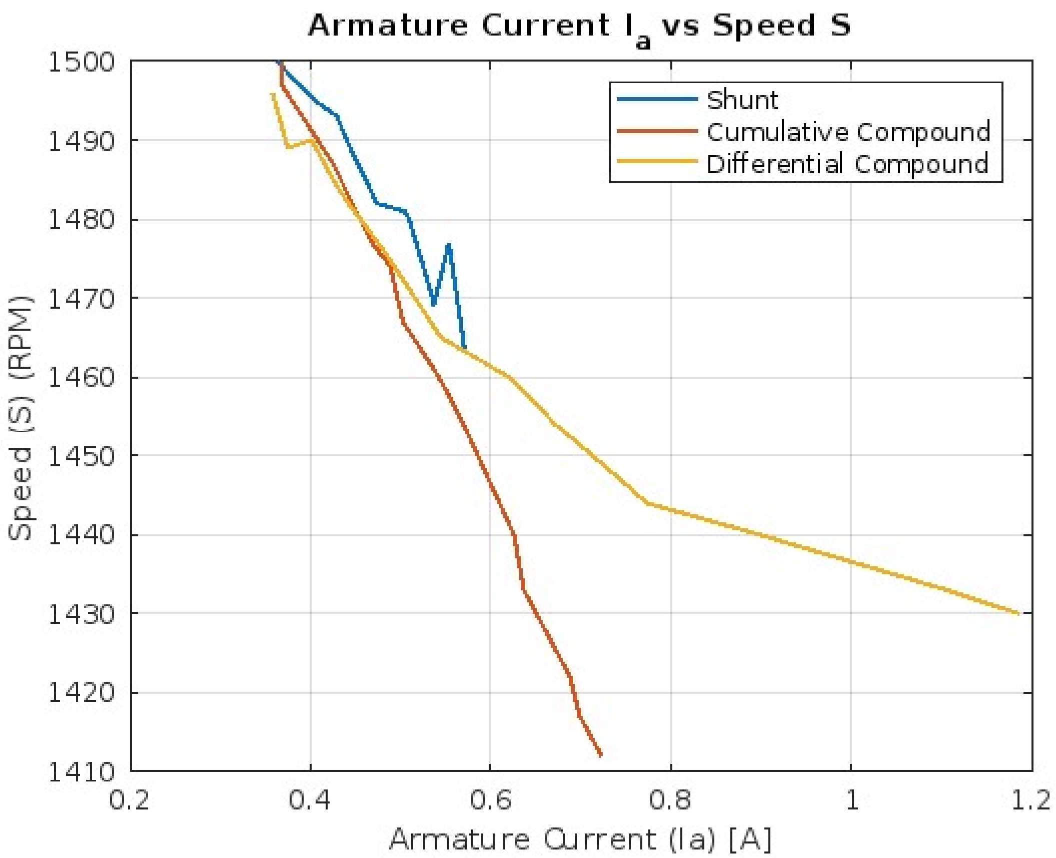
SI No.	Armature Current, $I_a(A)$	Speed , S (r.p.m)	Torque $T(KgM)$
1	0.358	1496	0.001
2	0.375	1489	0.016
3	0.401	1490	0.022
4	0.43	1484	0.025
5	0.482	1476	0.036
6	0.545	1465	0.055
7	0.621	1460	0.079
8	0.672	1454	0.095
9	0.774	1444	0.126
10	0.899	1440	0.167
11	1.107	1433	0.222
12	1.187	1430	0.245

(c) Readings for DC Differential Compound

8 Graph



(a) I_a vs. Torque (T) Graph



(b) I_a vs. Speed(S) Graph

9 Discussion

The experiment was conducted to investigate the Torque and Speed Characteristics of a DC Motor. The relationship between torque and speed can be described by the following equations:

$$T = KI_a\Phi \tag{7}$$

$$S = \frac{V_T - I_a R_a}{K\Phi}$$

To start the motor, it was carefully ensured that the starting resistance was kept at its maximum value, and the field resistance was also kept at its maximum. Then, the voltage of the supply was increased to 100V. After that, the starting resistance was decreased. The supply voltage was further increased to 200V, and the field resistance was then decreased to speed up the motor to 1500 rpm, the rated speed of the motor.

There were three knobs to adjust the torque value of the electrodynamometer. Initially, the torque was set to zero by adjusting the knob. Data was then recorded for the armature current, torque value, and speed at different torque levels for the DC shunt and compound motors.