ElCoM
ELECTRICAL COMPUTER MECHATRONICS

تقدم لجنة ElCoM الاكاديمية

دفتر لمادة:

الات كهربائية

من شرح:

محمد صلاح

جزيل الشكر للطالب:

ليث تفاحة

Introduction

By

Dr. Mohammad Salah

Mechatronics Engineering Department

The Hashemite University

Introduction

- An **Electric Machine** is a general term for **electric motors** and **electric generators** and other **electromagnetic machines**.
- They are electromechanical energy converters: an **electric** motor converts **electricity** to mechanical power while an **electric** generator converts mechanical power to **electricity**.
- Electric machines, in the form of generators, produce virtually all electric power on Earth, and in the form of electric motors consume approximately 60% of all electric power produced.

Scanned with CamScanner

Electrical Machines

- Motors → DC, AC
- Generators → DC, AC
- Transformers
  - 1 Phase
  - 3 Phase

Transformers ⇒ محولات ⇒ بيحول فيها طاقة كهربائية لطاقة كهربائية برضه

$V_1 I_1 = V_2 I_2$

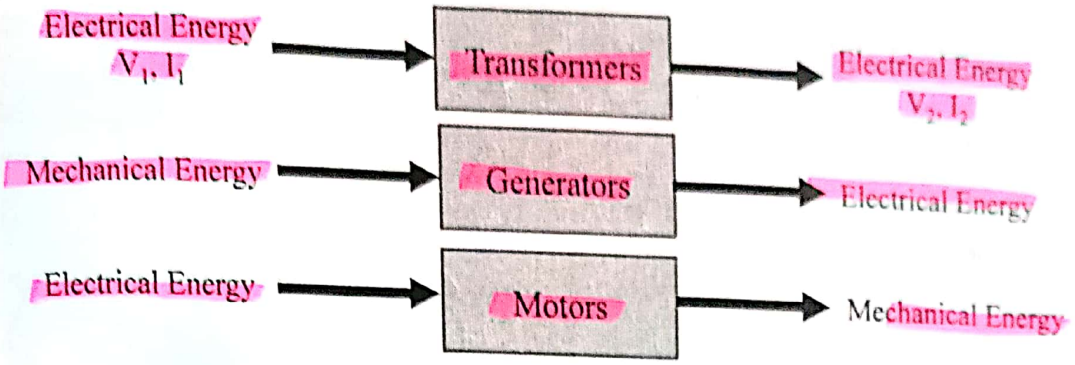
Generators ⇒ المولدات ⇒ بيحول فيها طاقة ميكانيكية لطاقة كهربائية

Motors ⇒ المحركات ⇒ بيحول فيها طاقة كهربائية لطاقة ميكانيكية

متفرع محركات الـ AC بتكون Asynchronous

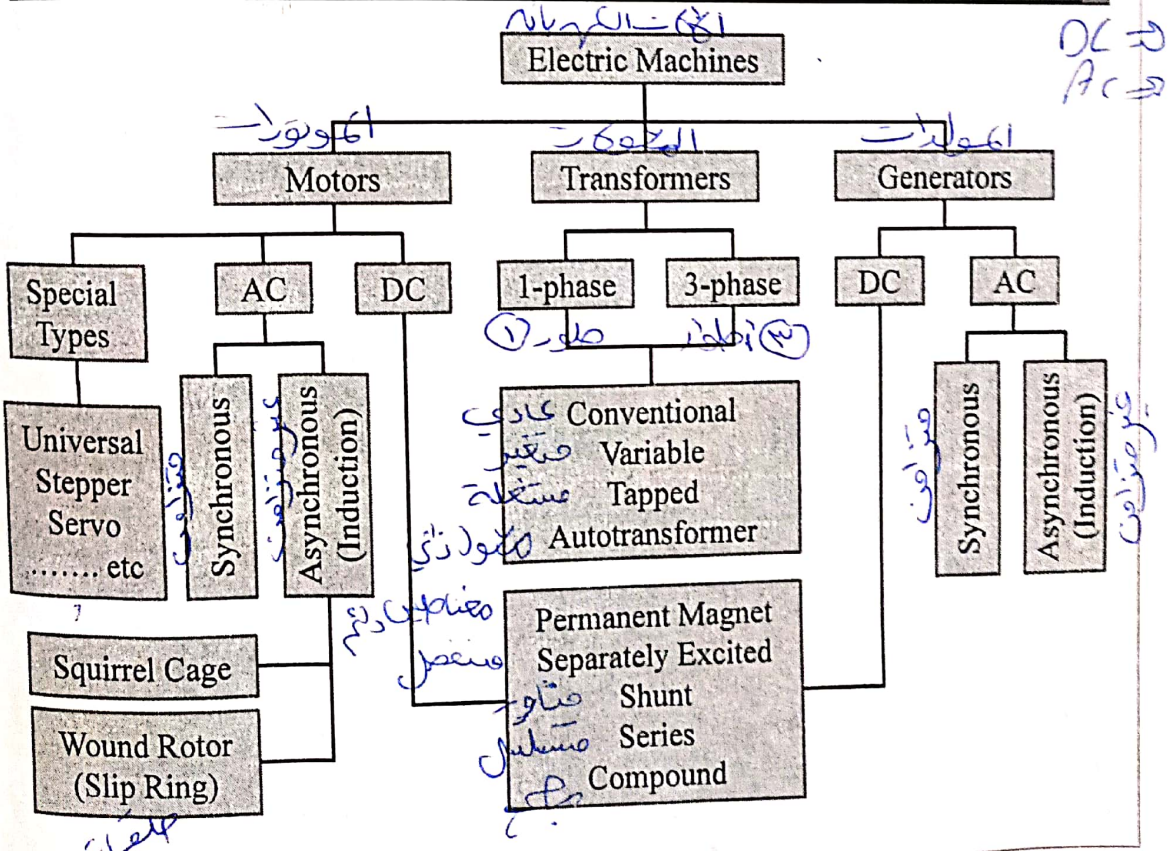
Scanned with CamScanner

Introduction



- The common variable in all machines is the magnetic field (Φ). Flux
- Without a magnetic field, machines CANNOT work.

* الأعمال الهندسية ضرورية لعمل الآلات الكهربائية.



Scanned with CamScanner

* تقاس السرعة بالراديان في حركات الدوران

* لما نتكلم على الآلات اي حاجة بها حركة
موتورات ومولدات
بتكون حركتها دائرية وبالعادة تكون هذه
الحركة دائرية وعشان نغير عنها منغير عنها
اما بسرعة أو عزم دوران

السرعة تقاس في أغلب المواصفات على اساس
(rpm) ⇒ revolution per minute

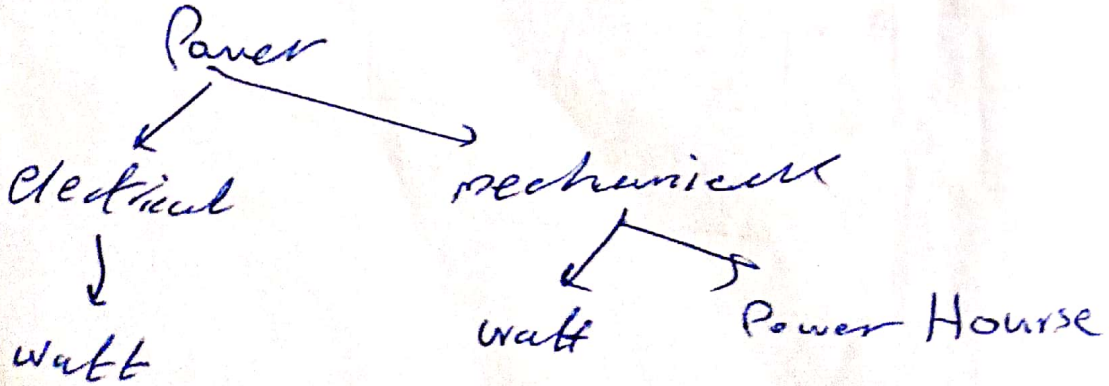
$$1\,[rpm] = \frac{\pi}{30}\,[r/s]$$

(نفس الشيء)

$$1\,r/s = \frac{30}{\pi}\,rpm$$

$$50\,r/s = X \quad rpm \quad \therefore \quad \frac{60 \times 30}{\pi} = X$$

$$X = \frac{1500}{\pi}\,rpm$$



Scanned with CamScanner

Introduction

- In rotary machines, speed is measured in radian per second [r/s] or revolution per minute [rpm] such that:

$$1\,[\text{rpm}] = 1\left[\frac{revolution}{minute}\right] = 1\left[\frac{2\pi\,[rad]}{60\,[sec]}\right] = \frac{\pi}{30}\,[\text{r/s}]$$

Example: Convert 50 [r/s] to [rpm]

$$1\,[\text{r/s}] = \frac{30}{\pi}\,[\text{rpm}] \Rightarrow 50\,[\text{r/s}] = 50 \times \frac{30}{\pi}\,[\text{rpm}]$$

$$= \frac{1500}{\pi}\,[\text{rpm}]$$

$$\cong 477.5\,[\text{rpm}]$$

Introduction

- In all motors and generators, electric power is measured in **Watts** [W].
- On the other hand, mechanical power is measured either in **Watts** [W] or **Hours Power** [hp] so that:

$$\mathbf{1\,[hp] = 746\,[W]}$$

Example: Convert 5 [kW] to [hp]

$$5\,[\text{kW}] = 5000\,[\text{W}] = 5000 \times \frac{1}{746}\,[\text{hp}]$$

$$\cong 6.7\,[\text{hp}]$$

Scanned with CamScanner

$P = T S$ → السرعة
↓ العزم
↙ القدرة

$P \Rightarrow [W]$
$T \rightarrow N.m$
$S \rightarrow r/s$

الذي أعبر عن الـ Power بوحدة الـ watt
كم العزم يكون بوحدة اسمه نيوتن
والسرعة بالـ r/s :

لو طلبي أحول الـ P بالـ HP بحسبها بعدين بجعل

(x) اذا كان عندي الـ S مأخوذة بوحدة الـ rpm
كم أحولها لـ r/s وإذا كانت الـ T مأخوذة بوحدة ثانية كم أحولها
N.m

DC machine electrical Power القدرة الكهربائية $P = I V$
W ↓ A ↓ V

AC machine electrical Power
1θ 1 Phase
3θ 3 Phase

Active Power = $\sqrt{3}\, I\, V \cos\theta$
↙ line current ↓ line voltage

Active Power = $I V \cos\theta$

OR

Active Power = $3\, I\, V \cos\theta$
↙ Phase current ↓ Phase voltage

Scanned with CamScanner

Intro

- It should be noted that the mechanical power can be computed from the torque and speed as:

Power [W] = Torque [N.m] × Speed [r/s]

- Moreover, electrical power can be computed as:

DC Machines ⇒ Power [W] = Current [A] × Voltage [V]

AC Machines – 1θ ⇒ Single Phase

Active Power [W] = Current [A] × Voltage [V] × cos(θ)

AC Machines – 3θ ⇒ 3 Three Phase

Active Power [W] = $\sqrt{3}$ × Line Current [A] × Line Voltage [V] × cos(θ)

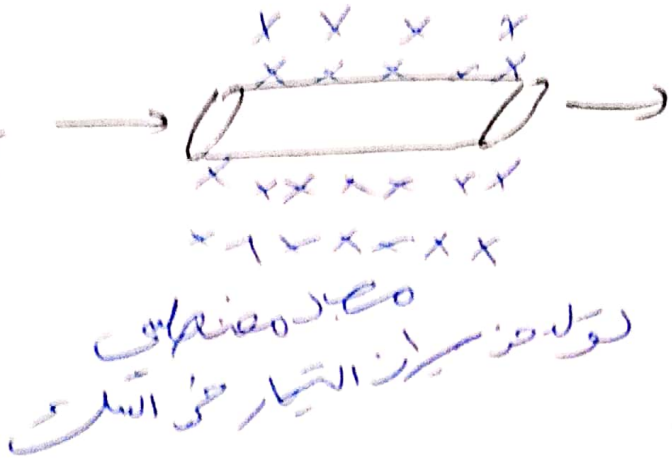
Active Power [W] = 3 × Phase Current [A] × Phase Voltage [V] × cos(θ)

Introduction – Magnetic Circuits

- As mentioned before, machines cannot work without magnetic fields. Hence, studying magnetic circuits is an important topic to understand the basic principles of electric machines operation and characteristics.
- Magnetic fields are the fundamental mechanism by which energy is converted from one form to another in motors, generators, and transformers.

Scanned with CamScanner

1) اذا كان عندي سلك سري بالتيار شنو يصير هذا التيار في هذا السلك رح يولد مجال مغناطيسي حول السلك وهذه واحدة من ظواهر الكهرومغناطيسية



2) اذا كان عندي مجال مغناطيسي يتغير مع الزمن ويؤثر بحلقة من الكهرباء سيؤدي ذلك الى احتثاث emf في طرفي هذا الملف (مبدأ عمل المولد)

3) اذا كان عندي تيار سري في سلك وهذا السلك موجود في مجال مغناطيسي سيؤدي مرور هذا التيار الى احتثاث قوة تؤدي الى تحريك السلك داخل هذا المجال (مبدأ عمل المولدات)

4) اذا كان في سلك يتحرك ضمن مجال مغناطيسي سيؤدي ذلك الى احتثاث emf في طرفي هذا السلك (مبدأ عمل المولدات)

Scanned with CamScanner

Introduction – Magnetic Circuits

- Four basic principles describe how magnetic fields are used in these devices:

1. A current-carrying wire produces a magnetic field in the area around it.
2. A time-changing magnetic field induces a voltage in a coil of wire if it passes through that coil. **(This is the basis of transformer action.)**
3. A current-carrying wire in the presence of a magnetic field has a force induced on it. **(This is the basis of motor action.)**
4. A moving wire in the presence of a magnetic field has a voltage induced in it. **(This is the basis of generator action.)**

Introduc gnetic Circuits

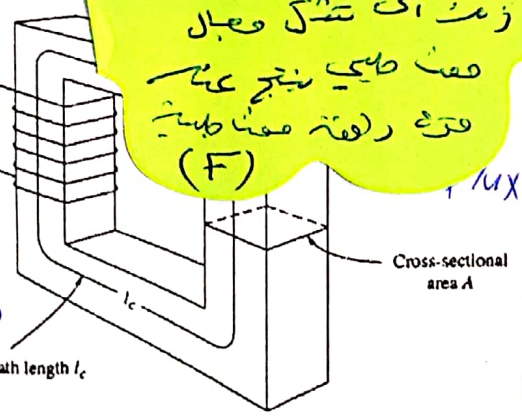


FIGURE 1–3
A simple magnetic core.

The total flux in the core due to the current i in the winding is

$$\phi = BA = \mu \frac{NiA}{l_c}$$

where ϕ is measured in **Webers** [Web] and B is measured in **Webers per square meters** [Web/m^2] known as **Tesla** [T]

Tesla = Web / m^2

Permeability

Scanned with CamScanner

F : Magnetomotive Force

ϕ : Flux تدفق المجال المغناطيسي

R : reluctance of circuit. ممانعة مغناطيسية

μ : Magnatic Permeability of material
النفاذية أو الحثية المغناطيسية

H : Magnatic Field Intensity
شدة المجال المغناطيسي

$$\phi = BA = \frac{\mu N i A}{L_c}$$

$$\Phi = \frac{F}{R}$$

$$B = \frac{\mu N i}{L_c}, \quad B = \mu H$$

$$H = \frac{Ni}{L_c} = \frac{F}{L_c}$$

$$F = Ni$$

$$R = \frac{L_c}{\mu A}$$

Scanned with CamScanner

Introduction – Magnetic Circuits

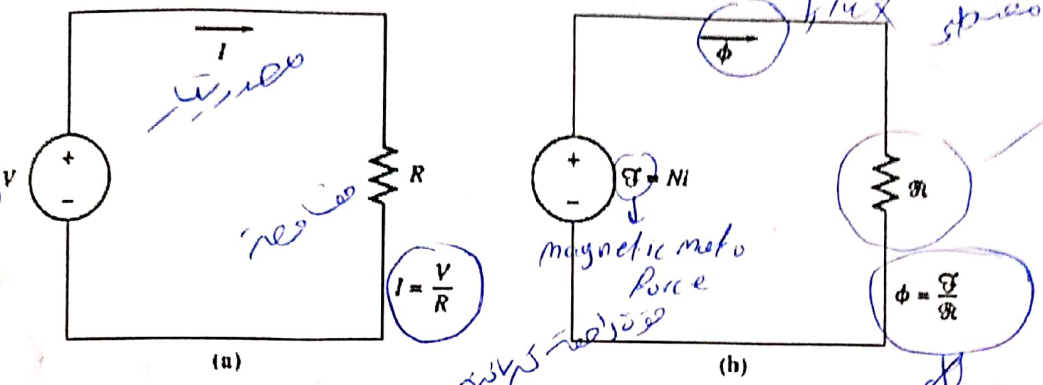
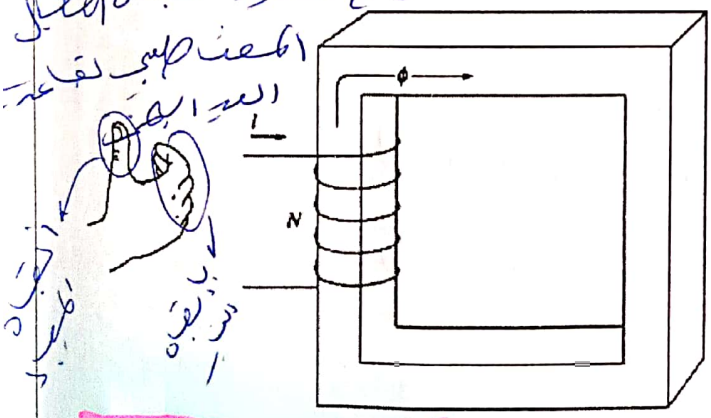


FIGURE 1–4
(a) A simple electric circuit. (b) The magnetic circuit analog to a transformer core.

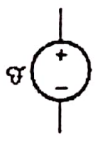
The magnetic circuit model of magnetic behavior is often used in the design of electric machines and transformers to simplify the otherwise quite complex design process.

Introduction – Magnetic Circuits



F = magnetomotive force of circuit
ϕ = flux of circuit
$\mathcal{R}$ = reluctance of circuit
μ = magnetic permeability of material
H = magnetic field intensity

FIGURE 1–5
Determining the polarity of a magnetomotive force source in a magnetic circuit.



The reluctance of a magnetic circuit is the counterpart of electrical resistance, and its units are ampere-turns per weber

$$\phi = BA = \mu \mathrm{H}\, \mathrm{A}$$

$$\phi = \mu \left(\frac{Ni}{l_c}\right) \mathrm{A} = Ni \left(\frac{\mu A}{l_c}\right)$$

$$\phi = \mathcal{F} \left(\frac{\mu A}{l_c}\right) = \frac{\mathcal{F}}{\mathcal{R}}$$

Scanned with CamScanner

حسابات المجال المغناطيسي عادة Core رأي تتم
بإهمال تأثير المادة المغناطيسية والتي تعتبر
ونسبة الخطأ تقل عن 5%

وهذه الملاحظة عادة يكون السبب Permability
كونها متغيرة في حد ثابتة بالتالي تؤثر حساباتنا
وتكون ± 5%

المجال المغناطيسي المتولد الذي أعتمدنا عليه يمر في
أنبوب المجال ثابت يحتوي الـ Core المغناطيسي
وهذا الكلام غير صحيح والسبب هي في
يتراوح بين 2000 الى 6000
كمية من الـ Fraction هذا يتبع المجال المغناطيسي
يهرب من الـ Core

Core ← اي هدف صغير يكثف
خطوط المجال ويضاعف
كمية هذا الـ Core وهذا

سن وظيفة هي
سعة خطوط
المجال يخرج للوسط Surrounding
وهذا المجال الي بالمتسبة

Leakage flux

الدور كبير في
توضيح المكان
الكهربائي

Introduction – Magnetic Circuits

- Calculations of the flux in a core performed by using the magnetic circuit concepts are always approximations. At best, they are accurate to within about 5 percent of the real answer.
- Reasons for this inherent inaccuracy are:

1. The magnetic circuit concept assumes that all flux is confined within a magnetic core. Unfortunately, this is not quite true. The permeability of a ferromagnetic core is 2000 to 6000 times that of air, but a small fraction of the flux escapes from the core into the surrounding low-permeability air. This flux outside the core is called leakage flux, and it plays a very important role in electric machine design.

Introduction – Magnetic Circuits

2. The calculation of reluctance assumes a certain mean path length and cross sectional area for the core. These assumptions are not really very good, especially at corners.

3. In ferromagnetic materials, the permeability varies with the amount of flux already in the material. This nonlinear effect is described in detail. It adds yet another source of error to magnetic circuit analysis, since the reluctances used in magnetic circuit calculations depend on the permeability of the material.

4. If there are air gaps in the flux path in a core, the effective cross sectional area of the air gap will be larger than the cross-sectional area of the iron core on either side. The extra effective area is caused by the "fringing effect" of the magnetic field at the air gap.

Scanned with CamScanner

$B = \mu H$ →

- ↙ كثافة الفيض المغناطيسي (Density of Flux)
- ↓ النفاذية المغناطيسية (Permability)
- ↘ شدة المجال المغناطيسي (intensity)

Feromagnatic materials

حديد مغناطيسي حالة هذه المواد تزيد عن 6000 ضعف

↓

المواد المغناطيسية في الصنف بشكل عام

↓

تعني سهولة مرور المجال المغناطيسي بشكل عالي جداً

μ_0 ← حالة الـ Air

μ ← كان يفرض بأنها ثابتة وهي النفاذية المغناطيسية (القوة الدافعة) في الـ F لكل مادة

Scanned with CamScanner

Introduction – Magnetic Circuits

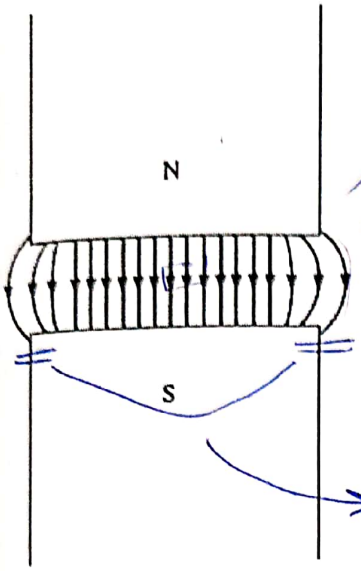


FIGURE 1–6
The fringing effect of a magnetic field at an air gap. Note the increased cross-sectional area of the air gap compared with the cross-sectional area of the metal.

Introduction –

Magnetic Behavior of Ferromagnetic Material.

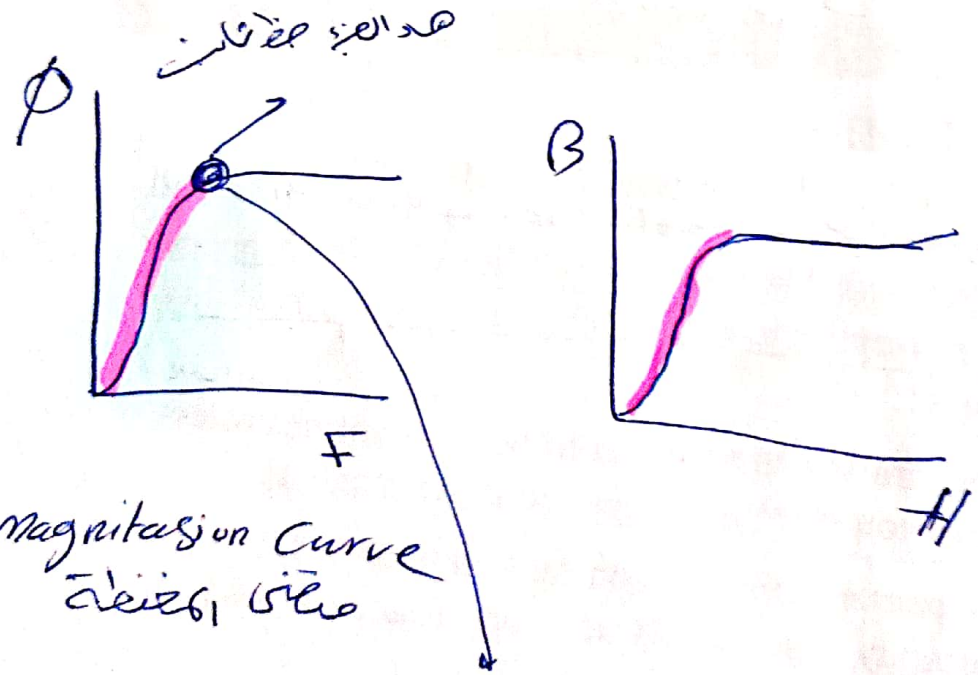
- It was explained that the permeability of ferromagnetic materials is very high, up to 6000 times the permeability of free space.
- The permeability was assumed to be constant regardless of the magnetomotive force applied to the material.
- Although permeability is constant in free space, this most certainly is not true for iron and other ferromagnetic materials.
- Recall

$$B = \mu H$$

Scanned with CamScanner

* كل ما زاد الـ H راح يزيد الـ B الى ان تصل الى نقطة معينة
يصير بعدها زيادة كبيرة بالـ H وزيادة طفيفة بالـ B
وهاد دليل انو احنا وصلنا مرحلة اشباع
وهاد يعني انو انا عندي عدد فجوة ثابتة والحيل
صار عندي يقل وعبا انو الحيل تقل يعني
الـ H تقل بالتالي

حاجة اكيدة لحتى اقدر اعالج بمنطقي
بتشغل وبناء عليه هذه العلاقة
انا بالعادة منشتغل عند الحد الاول
ومنصمم الاله عشان تشتغل احنا هاد الجزء



Magnitasion Curve
منحنى المغنطة

نقطة التحول وتسمى الـ Knee
وعندها منوصل حالة الاشباع

Scanned with CamScanner

Introduction –

Magnetic Behavior of Ferromagnetic Material

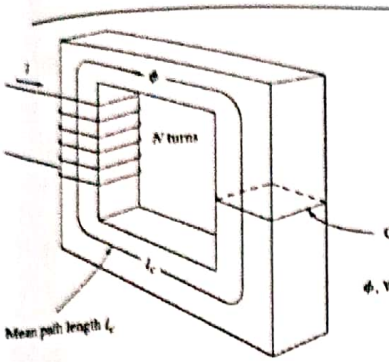


FIGURE 1–9
A simple magnetic core.

This type of plot is called a saturation curve or a magnetization curve. The region of this figure in which the curve flattens out is called the saturation region, and the core is said to be saturated. In contrast, the region where the flux changes very rapidly is called the unsaturated region of the curve, and the core is said to be unsaturated.

The transition region between the unsaturated region and the saturated region is sometimes called the knee of the curve.

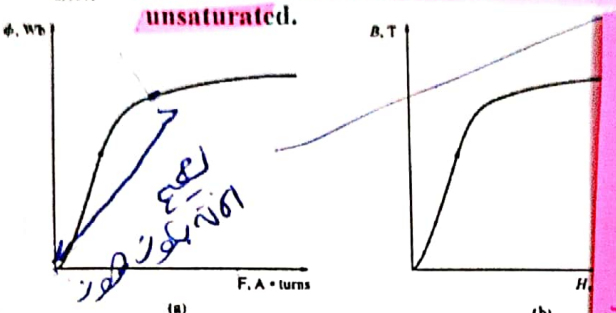


FIGURE 1–10
(a) Sketch of a dc magnetization curve for a ferromagnetic core. (b) The same curve expressed in terms of flux density and magnetizing intensity.

Introduction –

Magnetic Behavior of Ferromagnetic Material

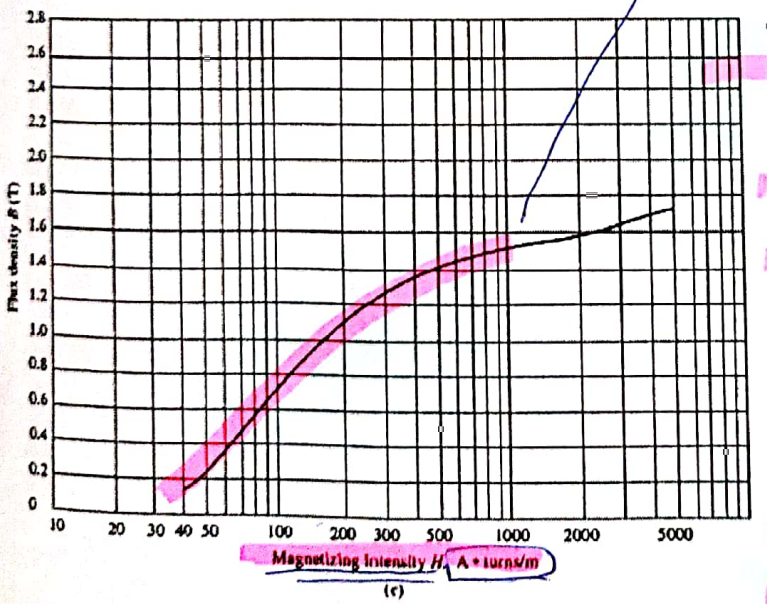


FIGURE 1–10
(c) A detailed magnetization curve for a typical piece of steel.

The advantage of using a ferromagnetic material for cores in electric machines and transformers is that one gets many times more flux for a given magnetomotive force with iron than with air. However, if the resulting flux has to be proportional, or nearly so, to the applied magnetomotive force, then the core must be operated in the unsaturated region of the magnetization curve.

Introduction –

Magnetic Behavior of Ferromagnetic Material

- Since real generators and motors depend on magnetic flux to produce voltage and torque, they are designed to produce as much flux as possible.
- As a result, most real machines operate near the knee of the magnetization curve, and the flux in their cores is not linearly related to the magnetomotive force producing it.
- This nonlinearity accounts for many of the strange behaviors of machines

Introduction – Linear DC Machine

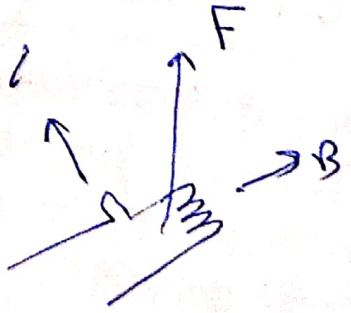
A linear dc machine is about the simplest and easiest-to-understand version of a dc machine, yet it operates according to the same principles and exhibits the same behavior as real generators and motors. It thus serves as a good starting point in the study of machines.

Scanned with CamScanner

بيوجد داخل الـ Rail مجال مغناطيسي ثابت (uniformed density magnetic field) موزع بشكل منتظم في كل مكان حولين

بتقرب دايرة الـ PC Machine بطارية مقاومة Switch وحولين بالهواي

بما أن الـ Rail عبارة عن سلك نحاسي ملفوف على شكل حلقة وبالتالي فيها تيار ثابت وبالتالي في أي جزء بتحرك عليه الـ Rail.



$$F = I L B \sin\theta$$

θ بين الـ B والـ L

Scanned with CamScanner

Introduction – Linear DC Machine

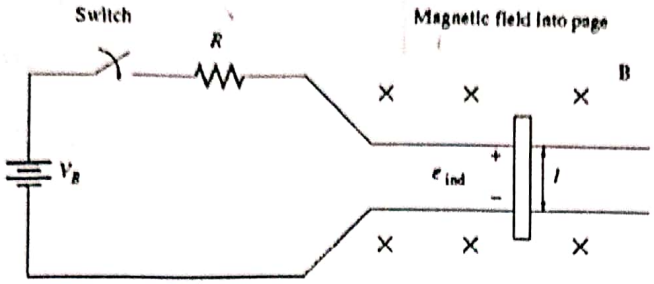


FIGURE 1–19
A linear dc machine. The magnetic field points into the page.

A linear dc machine consists of a battery and a resistance connected through a switch to a pair of smooth, frictionless rails. Along the bed of this "railroad track" is a constant uniform-density magnetic field directed into the page. A bar of conducting metal is lying across the tracks.

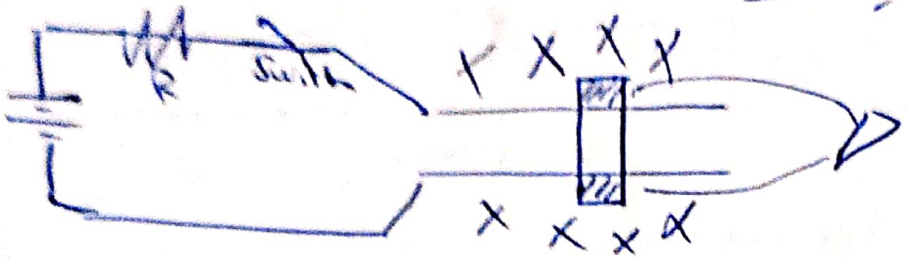
Introduction – Linear DC Machine

Linear DC machines' behavior can be determined from an application of four basic equations to the machine:

1. **The equation for the force on a wire in the presence of a magnetic field:**

$$\mathbf{F} = i(\mathbf{l} \times \mathbf{B}) \qquad (1\text{–}43)$$

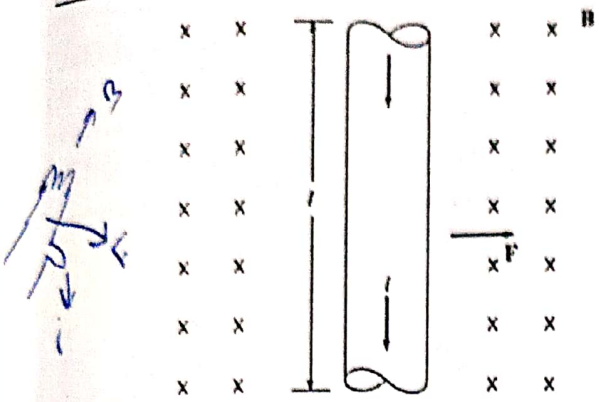
where **F** = force on wire
i = magnitude of current in wire
l = length of wire, with direction of **l** defined to be in the direction of current flow
B = magnetic flux density vector



$$e_{ind} = (V \times B) \cdot \ell$$
$$= (VB \sin\theta) \cdot \ell$$
$$= (VB \sin\theta)\, \ell \cos\theta$$

Scanned with CamScanner

Introduction – Linear DC Machine



$$F = iIB \sin\theta \qquad (1\text{–}44)$$

FIGURE 1-16
A current-carrying wire in the presence of a magnetic field.

where

i = magnitude of current in wire

l = length of wire, with direction of l defined to be in the direction of current flow

B = magnetic flux density vector

Introduction – Linear DC Machine

2. The equation for the voltage induced on a wire moving in a magnetic field:

$$e_{ind} = (\mathbf{v} \times \mathbf{B}) \cdot \mathbf{l} \qquad (1\text{–}45)$$

where e_{ind} = voltage induced in wire

v = velocity of the wire

B = magnetic flux density vector

l = length of conductor in the magnetic field

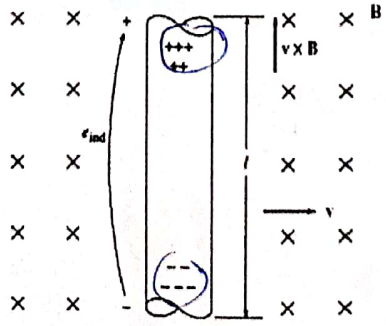


FIGURE 1-17
A conductor moving in the presence of a magnetic field.

Scanned with CamScanner

Introduction – Linear DC Machine

Example 1.5 Figure 1-18 shows a conductor moving with a velocity of 10 m/s to the right in a magnetic field. The flux density is 0.5 T, out of the page, and the wire is 1.0 m in length, oriented as shown. What are the magnitude and polarity of the resulting induced voltage?

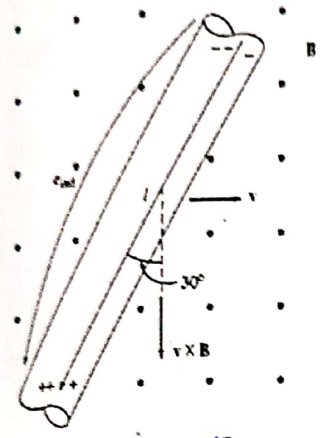


FIGURE 1–18
The conductor of Example 1–9.

$$e_{ind} = (\mathbf{v} \times \mathbf{B}) \cdot \mathbf{l} \qquad (1\text{–}45)$$
$$= (vB \sin 90°)\, l \cos 30°$$
$$= (10.0 \text{ m/s})(0.5 \text{ T})(1.0 \text{ m}) \cos 30°$$
$$= 4.33 \text{ V}$$

Introduction – Linear DC Machine

3. Kirchhoff's voltage law for this machine. From Figure 1–19 this law gives

$$V_B - iR - e_{ind} = 0$$

$$\boxed{V_B = e_{ind} + iR = 0} \qquad (1\text{–}46)$$

4. Newton's law for the bar across the tracks:

$$\boxed{F_{net} = ma} \qquad (1\text{–}7)$$

$$\Sigma F = Ma$$

Scanned with CamScanner

Introd... DC Machine

1. Closing the swit...
2. The current flow ...e bar given by $F_{ind} = iIB$
3. The bar accelerates due to the induced force as $a = F_{ind}/m = \Delta v/\Delta t$
4. The bar moves to the right, producing an induced voltage $e_{ind} = vBl$ as it speeds up
5. This induced voltage reduces the current flow $i = (V_B - e_{ind}\uparrow)/R$
6. The induced force is thus decreased $F_{ind} = i\downarrow lB$ until eventually $F_{ind} = 0$. At that point, $e_{ind} = V_B$, i = 0, and the bar moves at a constant no-load speed $v_{ss} = V_B/Bl$ where a = 0 (note that $F_{ind} = 0$)

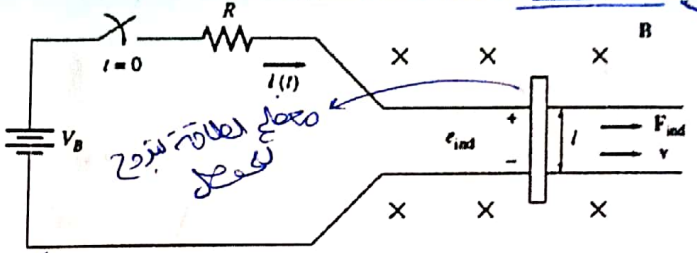


FIGURE 1–20
Starting a linear dc machine.

Introduction – Linear DC Machine

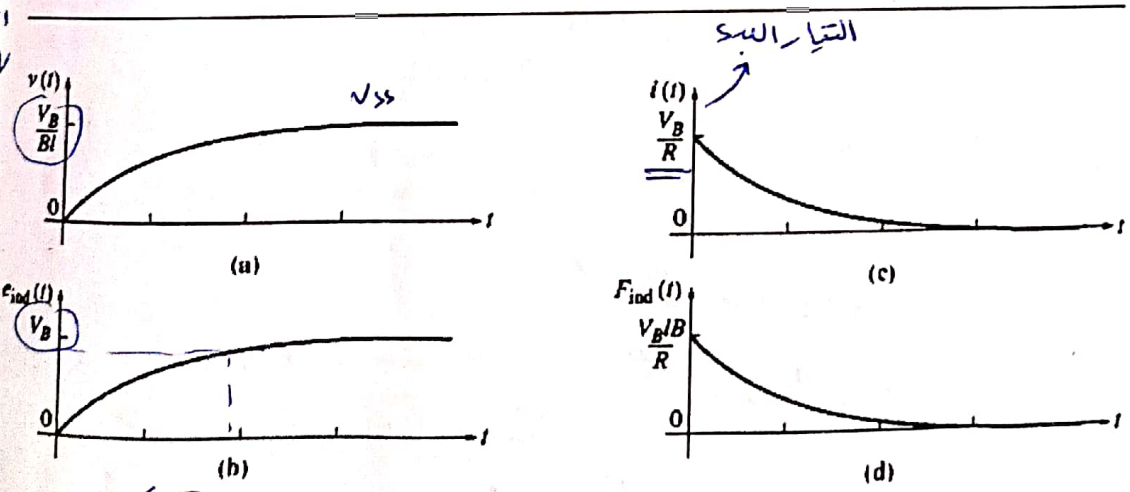


FIGURE 1–21
The linear dc machine on starting.
(a) Velocity v(t) as a function of time;
(b) induced voltage $e_{ind}(t)$; (c) current i(t);
(d) induced force $F_{ind}(t)$.

Response of DC machines working as a motor in Ideal conditions

Scanned with CamScanner

لما نكرر الـ Swith سوف نلاحظ هذا الكمال وبنفرض أنو
مقاومة هاد الكمال صفر ومنه التيار اكبر ما يمكن
صفر كمان بالعلاقة $i = \frac{V_B}{R}$ وهاي البداية
منه أنه بتساوي القيمة العظمى للتيار اللي بمشي
بسبب الدارة واللي بسمى الـ Starting current (تيار البدء)
وهي نفسها الـ Maximum value للتيار عند الاستقبال

لما يمر تيار بالكمال بنلاحظ عنه الظاهرة الأولى اللي
هي مرور تيار - داخل كمال موجود في مجال وهنا طلعي
سوف يؤدي لـ احتكاك قوة مغناطيسية على هذا الكمال
وهي القوة مقدارها F_{ind} وتساوي $F_{ind} = iLB$
كما بيلش عندي حركة حسب قانون نيوتن $\sum F = ma$ بنعوض
عندي تسارع وهاد التسارع رح يساوي $\frac{F}{m}$
والتسارع سببه التغير بالسرعة مع التغير بالزمن

$$F = ma \Rightarrow a = \frac{F}{m} \Rightarrow \frac{\Delta v}{\Delta t} = \frac{F}{m}$$

كون عندي تغير للتسارع يعني عندي زيادة بالسرعة كما أنجي
لحتى أحسب هذا التغير بالسرعة ΔV هو بعني السرعة النهائية
اللي التسارع هذا بعطيني
عندي q ← + ← تسارع ← سرعة تتشبت
q ← - ← تباطؤ
q هو عبارة عن التسارع
ΔV هو عبارة عن التغير بالسرعة يعني
هو

Introduction – Linear DC M

If a force F_{Load} is applied to the bar in the **OPPOSITE** direction
net force is $F_{net} = -F_{load}$ and the following events occur:

1. The bar decelerates due to the load force as $a = F_{net}/m = \Delta v/$
2. The effect of this net force will reduce $e_{ind} = v \downarrow Bl$ as ithe bar slows down
3. This induced voltage increases the current flow $i = (V_B - e_{ind}\downarrow)/R$
4. The induced force is thus increased $F = i \uparrow lB$ until $|F_{ind}| = |F_{Load}|$ at a lower speed v. Note that $F_{net} = F_{ind} - F_{Load}$ in this case.
5. An amount of electric power equal to $e_{ind}\, i$ is now being converted to mechanical power equal to $F_{ind}\, v$, and the machine is acting as a **motor**.

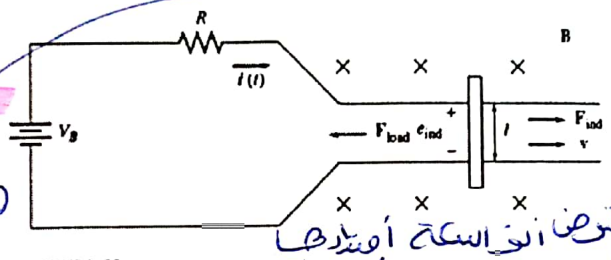
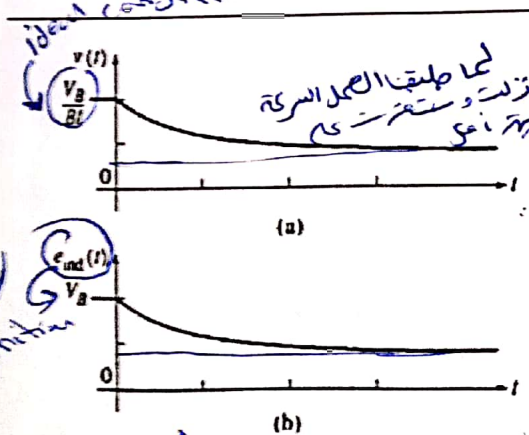


FIGURE 1–22
The linear dc machine as a motor.

Introduction – Linear DC Ma



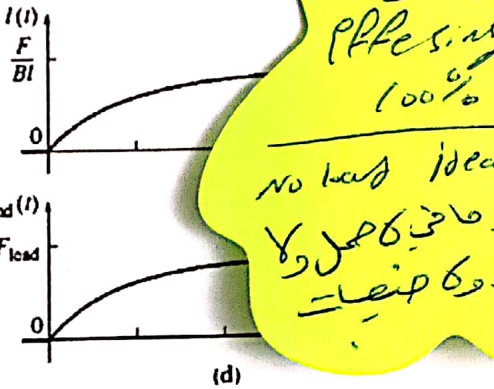


FIGURE 1–23
The linear dc machine operating at no-load conditions and then loaded as a motor.
(a) Velocity $v(t)$ as a function of time;
(b) induced voltage $e_{ind}(t)$; (c) current $i(t)$;
(d) induced force $F_{ind}(t)$.

Scanned with CamScanner

بهاي الحالة رح نلاحظ بالبداية قوة عكسية مقدارها F_{Ind}
طلبت وين راحت الـ F_{Ind} ؟؟ مش أختفت في حالة الاستقرار
الـ F_{Ind} أصبحت تساوي صفر نتيجة أنو التيار صار صفر وبهاي
هاد المعادل قاعد بتترك للعين نتيجة حالة الاستقرار وش أختلاف
و القوة المؤثرة عليه تساوي صفر فأكيد لما يجي للطيف مقدار
F_{Ind} رح تكون بس F_{Net}

⇐ بتؤثير عندي لو طبقنا هاي أو صار عندي Friction ؟؟
رح نلاحظ أنو θ مقدارها صارت سالبة يعني صارت عندي طاقة
بتاي السوكة رح تغير سلبة وبتناقص مالتالي e_{ind} رح تنزل
وبتزيد على ذلك أنو أصبح في عزم للعبر وصار عندي
مقدار للتيار و صار عندي F_{Ind} كانت صفر وبلشت تزيد رح
بتستمر هذه العملية (زيادة تيار ونقصان السرعة) اي أن نظام حالة
الاستقرار ⇐ $F_{Ind} = F_{load}$ لحتى يصير كأنه F_{Ind} لحيث F_{load}
كمان
وحالة الاستقرار رح تكون عندي سرعة أقل من سرعة
الاستقرار بال Ideal condition

$$F_{Net} = F_{Ind} - F_{load}$$

بما F_{Net} هو بكون بتاع
صفر و سرعة ثابتة
* يعني حالة الاستقرار وين تحدث عندي
بتاع صفر وسرعة ثابتة

بناءً على ذلك
مقدار في العشرة الكهربائية
رح تكون مساوية لـ (P_{ind})
في اي تحويل =
Mechanical Power

$$\text{Mechanical Power} = F_{ind} \, V$$

القدرة الميكانيكية = القوة بالسرعة *

Introduction – Linear DC Machine

If a force F_{app} is applied to the bar in the SAME direction of motion, hence the net force is $F_{net} = F_{app}$ and the following events occur:

1. The bar accelerates due to the load force as $a = F_{net}/m = \Delta v/\Delta t$ since $F_{net} > 0$
2. The effect of this net force will increase $e_{ind} = v \uparrow Bl$ as the bar speeds up
3. This induced voltage reverses the direction of the current flow $i = (V_B - e_{ind} \uparrow)/R$ since $(V_B < e_{ind})$
4. The induced force is thus reverses its direction due to the reversed current $-F_{ind} = -ilB$ until $|F_{ind}| = |F_{app}|$. Note that $F_{net} = F_{app} - F_{ind}$ in this case.
5. An amount of mechanical power equal to $F_{app}\, v$ is now being converted To electric power equal to $e_{ind}\, i$, and the machine is acting as a generator.

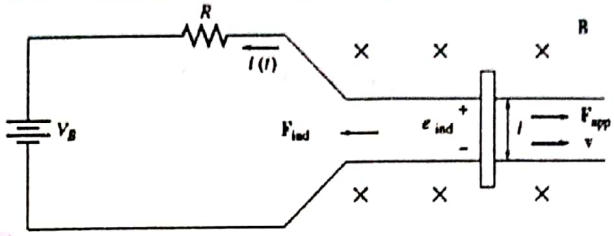


FIGURE 1–24
The linear dc machine as a generator.

Introduction – Linear DC Machine

Example 1.10 The linear dc machine shown in Figure 1-27a has a battery voltage of 120 V. An internal resistance of 0.3 n. and a magnetic flux density of 0.1 T. (a) What is this machine's maximum starting current? What is its steady-state velocity at no load? (b) Suppose that a 30-N force pointing to the right were applied to the bar. What would the steady-state speed be? How much power would the bar be producing or consuming? How much power would the battery be producing or consuming? Explain the difference between these two figures. Is this machine acting as a motor or as a generator? (c) Now suppose a 30-N force pointing to the left were applied to the bar. What would the new steady-state speed be? Is this machine a motor or a generator now? (d) Assume that a force pointing to the left is applied to the bar. Calculate speed of the bar as a function of the force for values from 0 N to 50 N in IO-N steps. Plot the velocity of the bar versus the applied force. (e) Assume that the bar is unloaded and that it suddenly nuns into a region where the magnetic field is weakened to 0.08 T. How fast will the bar go now?

Scanned with CamScanner

اذا طبقنا قوة في نفس اتجاه الحركة رح يصير عندي ال Fapp قوة
بالتالي رح تزداد السرعة وبتالي ال Emf بتزيد وبالتالي التيار
رح يقل سالبة يعني تغير اتجاهه بترتيب بكون انو التيار
(عكس)

في عندي تيار سري في موصل عمنا بحاد مغناطيس رح يصير عندي
Find = ي كمان التيار سالب والسالب قوة معاكسة رح تشرحها
العلاقة لحد ما توصل حالة الاستقرار بتكون فيها
$F_{app} = F_{in}$
في هاي الحالة ال F_{in} بقيمة البد الفي بالحالة الاولى كان عليها
قوة صار على التيار هاد يعني انو الآلة بتحاول تقاوم
التغير اللي صار بسبب التغير بتيار الحمل ي الحيث والمقاومة
بالنهاية ال F_{app} رح تأدي لزيادة السرعة لحد ما الآلة رح
تحل توازن بحيث تكون مجموع القوى ي الحمل صفر
بهاي الشارع صفر شاب ما في زيادة حركة بس بدها
تكون ي حالة أنو حركة الحمل اي واتجاه التيار بنعكس
ورح تحمل الآلة ي شغل Generator

← انا عندي القدرة الميكانيكية
اي هي $F_{app}.V$ حولناها
لقدرة كهربائية .

* ملاحظة *

- اما لو بعطيني قوة أو عزم حسب الحالة
يعني اذا اما لو أعطيتو كهربا وحاكى حتى تقاوم العزم
اللي بعطيني اياه صار لو في حزاز أقوى هو بعطي كل ما
كان في قوة اما لو اللي بولد عزم بالاتجاه المعاكس عشان
تقاوم الحركة وعشان يعطينا هذا العزم بتطلب انو سيحب تيار
من المصدر وبتالي بزيد حسب التيار عشان زيادة العمل الكهربائي

في حالة المولد لما بعض الآلة حركة الآلة بمرور الوقت في الحركة
للعضو (ثابت) والتيار يكون بالاتجاه العكسي بمرور
للعضو وفي هاي الحالة يكون عندي حركة دوران الآلة
أكبر من حركة دوران المحرك ويتاكب بعيرعندي توليد
عكسي له كلو كل ما زادت الحركة لنا حد معين
العزم الداخلي اعتمد يزداد واذا وصل الى قيمة أكبر
من قيمة العضو راح ينعكس التيار ويصير عندي عليه
Power supply لا Returning Power بعطي اخر انا بشحن البطارية
وتالي انا بشغل الآلة على أساس أنها مولد
Generator

DC Machines

By

Dr. Mohammad Salah

Mechatronics Engineering Department

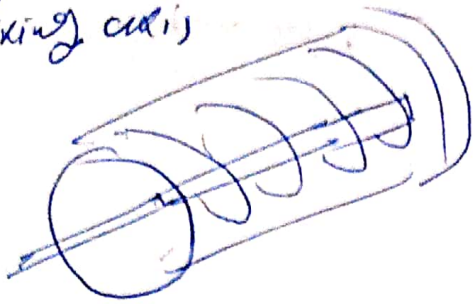
The Hashemite University

DC Machines – Definition

- DC machines are generators that convert mechanical energy to DC electric energy and motors that convert DC electric energy to mechanical energy.
- Most DC machines are like AC machines in that they have AC voltages and currents within them. DC machines have a DC output only because a mechanism exists that converts the internal AC voltages to DC voltages at their terminals.
- Since this mechanism is called a **commutator**, DC machinery is also known as **commutating machinery**.

Scanned with CamScanner

أبسط أشكال الموتورات الدوارة هو عبارة عن Loop تلف حولين
Fixing coils



الجزء الدوار في آلات الـ DC او أي
آلة تسمى الـ Rotor والجزء
الثابت تسمى Stator

هنا أنا حكيت انو كل آلة كهرومغناطيسية
لحتى تعمل واشتغل المغناطيس فيها بدو مغناطيس
اي في الـ (Stator) ويتم ذلك عن طريق انا

1 — ضرورتيا — في ملف — موجودة في الـ Stator

2 — تثبيت أقطاب مغناطيسية على الجزء الـ Stator في الداخل ليتفاعل المجال

بعدين نفرض أنو هاض السلك موجود في الـ Core ويتحرك بالحركة
والهدف من الـ Core هو تكثيف خطوط المجال وهذا الـ
Core مقابل وجه الأقطاب الموجودة في الـ Stator

عندي هيك آلة اشتغل عليها أشتق المعادلة = اي
بتشتغل الـ DC machine فاي :

1. انو يكون عندي خطوط المجال المغناطيسية صادرة من
السطح الداخلي للـ Rotor وبروح للـ Stator

2. شدة المجال المغناطيسي قيمتها ثابتة ما أقل
ولا أكثر لأقطاب لآخر

3. شكل على هاد الخط غير متغير والمجال متساوي وثابت

Scanned with CamScanner

DC Machines – Simple Rotating Loop

- The simplest possible rotating dc machine consists of a single loop of wire rotating about a fixed axis.
- The rotating part of this machine is called the **rotor**, and the stationary part is called the **stator**.
- The magnetic field for the machine is supplied by the magnetic north and south poles on the stator.
- Notice that the loop of rotor wire lies in a slot carved in a ferromagnetic core.
- The magnetic field is perpendicular to the rotor surface everywhere under the pole faces.
- The magnetic flux is uniformly distributed (constant) everywhere under the pole faces.

DC Machines – Simple Rotating Loop

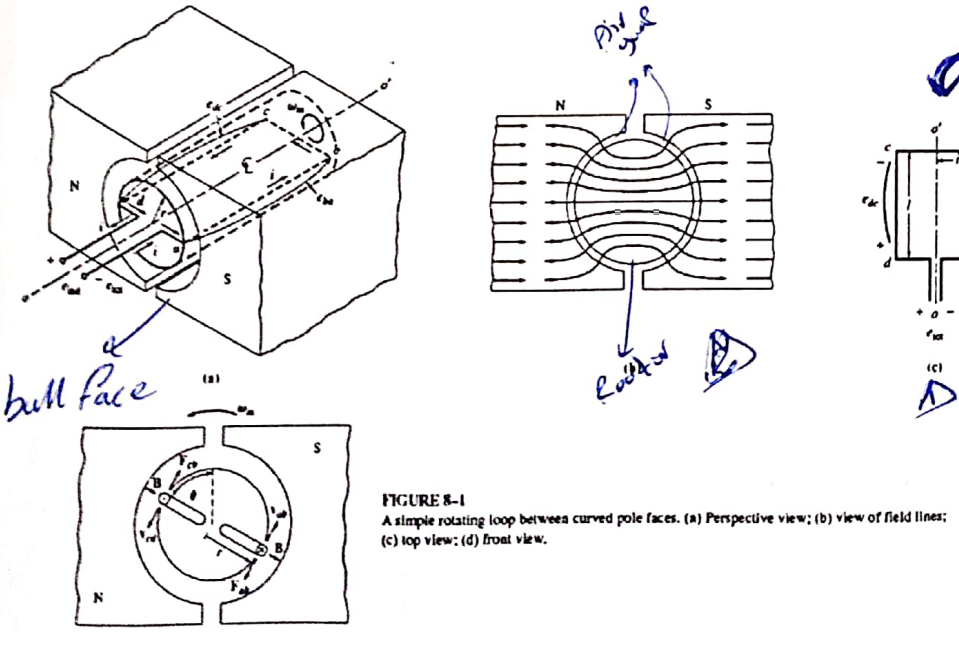


FIGURE 8–1
A simple rotating loop between curved pole faces. (a) Perspective view; (b) view of field lines; (c) top view; (d) front view.

Scanned with CamScanner

السؤال كامل

[illegible] ... [illegible]

[illegible]

اعمل اي بكون في ايجيت بسبب تغير الـ MF بقلبة
معينة وسبب الدورات اللي بعمل اي في ايجيت راح يجي في
اسبار وكمان في اسبار في ايجيت معين لو اتغلطت في

e_{ind} Total و بكون

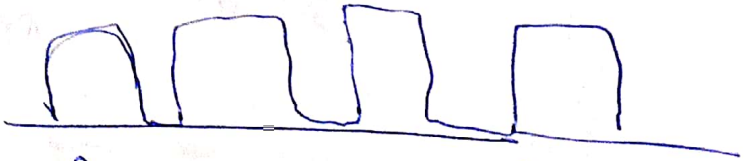
$$e_{ind}^{Total} = e_{ba} + e_{cb} + e_{dc} + e_{ad}$$

$e_{ind} = \int_0^{2VBL}$ under the pole faces
beyond the pole edges

$$e_{ba} = \int_0^{VBL} + e_{cb} + e_{dc} = \int_0^{VBL} + e_{ad}$$
$$= 0 \qquad = 0$$

$$= \int_0^{2VBL}$$

بكون عندي Commutator وظيفته بعمل تو هيد للإشارة
يا أما كلو موجب يا أما كلو سالب



Full wave Rectifire

Scanned with CamScanner

DC Machines – Simple Rotating Loop

- If the rotor of this machine is rotated, a voltage will be induced in the wire loop.
- To determine the total voltage e_{tot} on the loop, we need to examine each segment of the loop separately and sum all the resulting voltages. The voltage on each segment is given by

$$e_{ba} = (\mathbf{v} \times \mathbf{B}) \cdot \mathbf{l} = \begin{cases} vBl & \text{positive into page} \quad \text{under the pole face} \\ 0 & \text{beyond the pole edges} \end{cases} \quad (8\text{–}1)$$

$$e_{cb} = 0 \quad (8\text{–}2)$$

$$e_{dc} = (\mathbf{v} \times \mathbf{B}) \cdot \mathbf{l} = \begin{cases} vBl & \text{positive out of page} \quad \text{under the pole face} \\ 0 & \text{beyond the pole edges} \end{cases} \quad (8\text{–}3)$$

$$e_{ad} = 0 \quad (8\text{–}4)$$

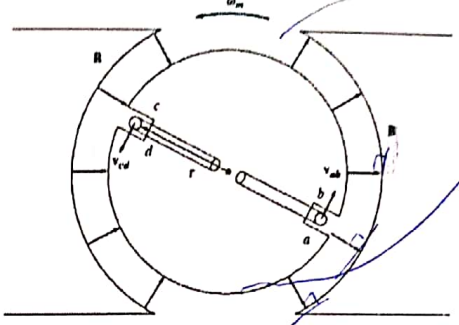


FIGURE 8–2
Derivation of an equation for the voltages induced in the loop.

DC Machines – Simple Rotating Loop

The total induced voltage on the loop e_{ind} is given by

$$e_{ind} = e_{ba} + e_{cb} + e_{dc} + e_{ad}$$

$$e_{ind} = \begin{cases} 2vBl & \text{under the pole faces} \\ 0 & \text{beyond the pole edges} \end{cases} \quad (8\text{–}5)$$

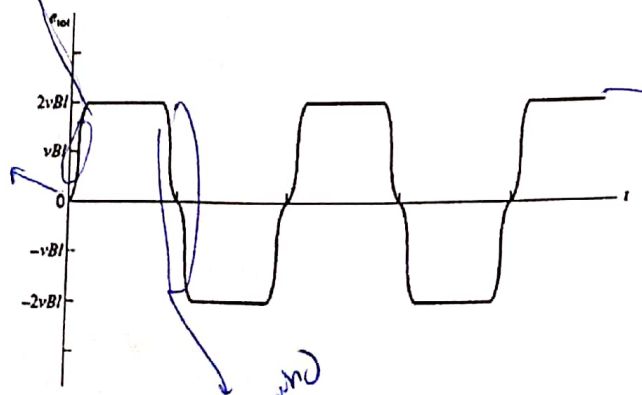


FIGURE 8–3
The output voltage of the loop.

Scanned with CamScanner

$$\frac{2\pi r \times L}{2} = \pi r L = A_p$$

$$v = r\omega$$

$$B = \frac{\phi}{A_p} \qquad A = \frac{A_p}{\pi r}$$

$$e_{ind} = \int_0^{2VBL}$$

$$2 \times r\omega * \frac{\phi}{A_p} * \frac{A_p}{\pi r}$$

$$= \frac{2r\omega\phi}{\pi r} = \boxed{\frac{2}{\pi}\omega\phi}$$

$$e_{ind} = \begin{cases} \frac{2}{\pi}\omega\phi & \text{under pole} \\ 0 & \text{beyond pole} \end{cases}$$

Scanned with CamScanner

DC Machines – Simple Rotating Loop

- Given $v = r\omega$, $\phi = A_p B$, and pole surface area of $A_p = \pi r l$, an alternative expression can be obtained.

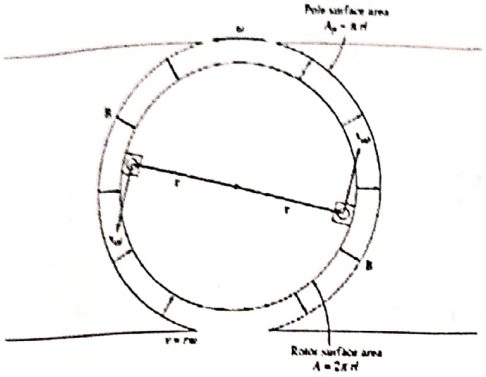


FIGURE 8–4
Derivation of an alternative form of the induced voltage equation.

$$e_{ind} = \begin{cases} 2r\omega Bl & \text{under the pole faces} \\ 0 & \text{beyond the pole edges} \end{cases}$$

$$e_{ind} = \begin{cases} \frac{2}{\pi} A_p B\omega & \text{under the pole faces} \\ 0 & \text{beyond the pole edges} \end{cases}$$

$$e_{ind} = \begin{cases} \frac{2}{\pi} \phi\omega & \text{under the pole faces} \\ 0 & \text{beyond the pole edges} \end{cases} \quad (8\text{–}6)$$

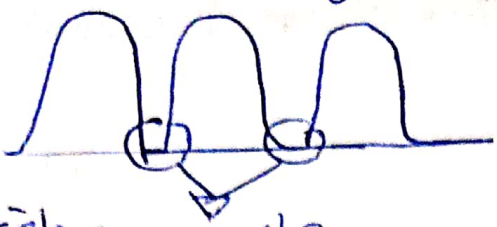
DC Machines – Simple Rotating Loop

- The voltage generated in the machine is equal to the product of the flux inside the machine and the speed of rotation of the machine, multiplied by a constant representing the mechanical construction of the machine.
- In general, the voltage in any real machine will depend on the same three factors:

1. The flux in the machine
2. The speed of rotation
3. A constant representing the construction of the machine

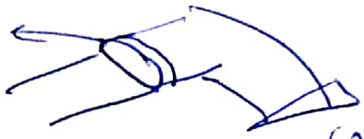
Scanned with CamScanner

مواصفات الـ voltage في حالة عمل المولد تكون على الشكل العكسي



هاي اسمها الموجة الشقالية
لأنه يكون فيها المولد وصول
لمرحلة ما فيها وصال معناطيسي
بين القطب الجنوبي والشمالي

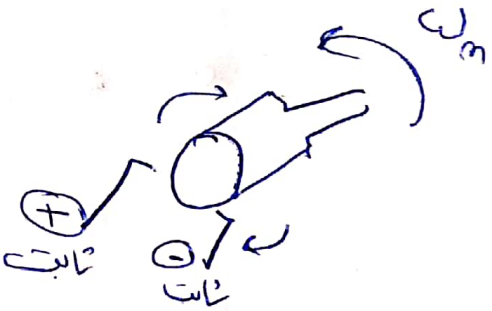
قبل ما نحكي عن طريقة الـ
الكلام عن طريقة اسمها
commutator اسمها الـ



مثل عدد الأسلاك اي جزء من الـ Simple
وهذا يسمى Rotating Loop

بكون فضة = بالعامل الثاني عن طريق الـ brushes

عبارة عن مادة موصلة
غالبة الكربون مضغوطة بزنبرك
على الملامس بحيث أنواعها
Brushes ثابتات ما بتركض
الفلزيين



ممزة الفتحة اي لا
اليمين دايما بالبداية طول واحد لليسار مقسم على طول
بس هو لفت فالسلك اي على اليمين مرة بكسن (+) وحركلو
(−) والعكس صح بس بالنهاية كلو في اشارات عن طريق
الـ commutator فاتت على اليمين (+) بشكل دائم واشارة على
اليسار (−) بشكل دائم

* لو تركت ω_s بأخذ مقادير وحتى الـ Polarity
بتظلت المحور بنفس وإذا كان عكس
الساعة

DC Machines – Simple Rotating Loop

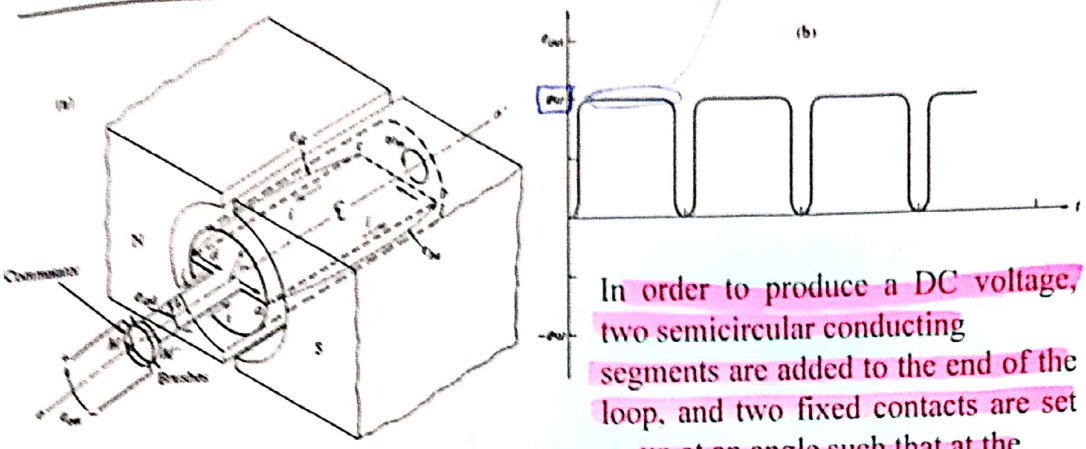


FIGURE 8–5
Producing a dc output from the machine with a commutator and brushes. (a) Perspective view; (b) the resulting output voltage.

In order to produce a DC voltage, two semicircular conducting segments are added to the end of the loop, and two fixed contacts are set up at an angle such that at the instant when the voltage in the loop is zero, the contacts short-circuit the two segments. This connection-switching process is known as **commutation**. The rotating semicircular segments are called **commutator segments**, and the fixed contacts are called **brushes**.

DC Machines – Simple Rotating Loop

Let's suppose that a battery is connected to the machine and see how the torque is developed inside it.

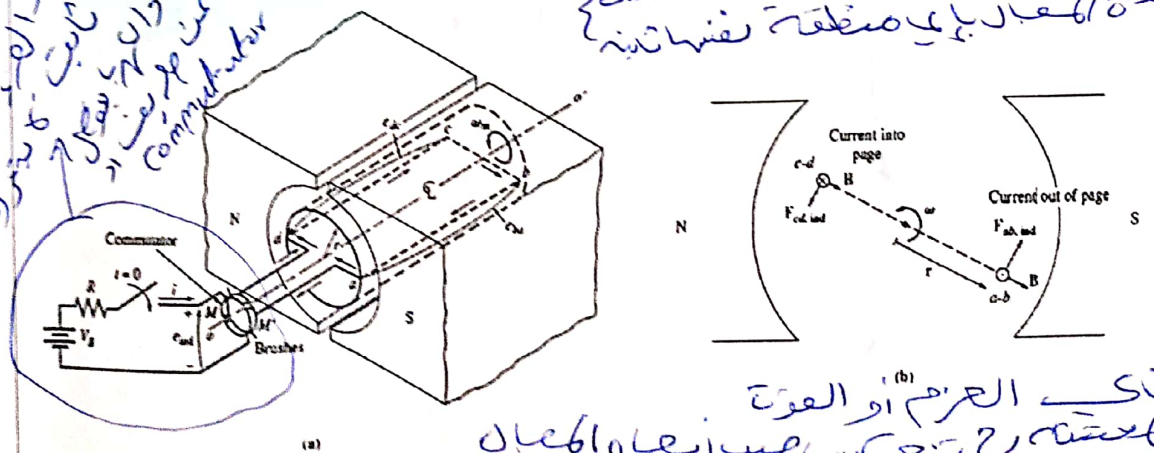


FIGURE 8–6
Derivation of an equation for the induced torque in the loop. Note that the iron core is not shown in part b for clarity.

Scanned with CamScanner

$$\tau_{ind} = \tau_{ab} + \tau_{bc} + \tau_{cd} + \tau_{da}$$

$$F_{ab} = i(l \times B) = ilB$$

$$\tau_{ab} = rF\sin\theta = r(ilB)\sin 90 = rilB$$

$$\tau_{bc} = 0 \Rightarrow \sin\theta = 0$$

$$\tau_{cd} = rF\sin\theta = r(ilB)\sin 90 = rilB$$

$$\tau_{da} = 0 \Rightarrow \sin\theta = 0$$

$$\Rightarrow \tau_{ind} = rilB + 0 + rilB + 0 = 2rilB$$

by using $A_p = \pi r^2$ & $AB = \phi$

$$T_{ind} = \begin{cases} \frac{2}{\pi}\phi i, & \text{under the pole faces} \\ 0, & \text{beyond the pole edges} \end{cases}$$

التيار الحثي
الطول الفعال
الجزء السفلي

Scanned with CamScanner

DC Machines – Simple Rotating Loop

$$F_{ab} = i(l \times B)$$
$$= ilB \quad \text{tangent to direction of motion} \qquad (8\text{–}7)$$

The torque on the rotor caused by this force is

$$\tau_{ab} = rF \sin\theta$$
$$= r(ilB) \sin 90°$$
$$= rilB \quad \text{CCW} \qquad (8\text{–}8)$$

$$F_{bc} = i(l \times B)$$
$$= 0 \quad \text{since l is parallel to B} \qquad (8\text{–}9)$$

Therefore,

$$\tau_{bc} = 0 \qquad (8\text{–}10)$$

$$F_{cd} = i(l \times B)$$
$$= ilB \quad \text{tangent to direction of motion} \qquad (8\text{–}11)$$

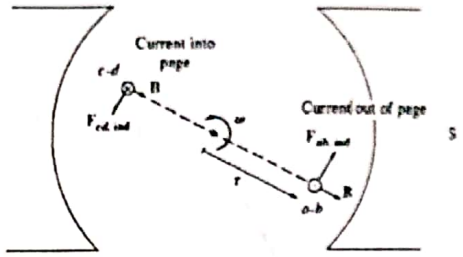
The torque on the rotor caused by this force is

$$\tau_{cd} = rF \sin\theta$$
$$= r(ilB) \sin 90°$$
$$= rilB \quad \text{CCW} \qquad (8\text{–}12)$$

$$F_{da} = i(l \times B)$$
$$= 0 \quad \text{since l is parallel to B} \qquad (8\text{–}13)$$

Therefore,

$$\tau_{da} = 0 \qquad (8\text{–}14)$$



DC Machines – Simple Rotating Loop

The resulting total induced torque on the loop is given by

$$\tau_{ind} = \tau_{ab} + \tau_{bc} + \tau_{cd} + \tau_{da}$$

$$\tau_{ind} = \begin{cases} 2rilB & \text{under the pole faces} \\ 0 & \text{beyond the pole edges} \end{cases} \qquad (8\text{–}15)$$

By using the facts that $A_p \approx \pi rl$ and $\phi = A_p B$, the torque expression can be reduced to

$$\tau_{ind} = \begin{cases} \frac{2}{\pi}\phi i & \text{under the pole faces} \\ 0 & \text{beyond the pole edges} \end{cases} \qquad (8\text{–}16)$$

Scanned with CamScanner

$\frac{e}{x}$ ⇒ تمثيلي 1/100 P

أما إذا كان عندي

نوع أكثر من واحد حسب الثابت

ثابت نحو K

⇐ العزم المحرك المتولد من الآلة بحالة تشغيلها كمولد

تيار ثابت مضروب بالـ ϕ ومضروب بالسرعة الزاوية

في اللفوف المحيطة بالجزء المتحرك حيث الـ Rod

بالتالي كل ما يكون عندي ϕ زائد زائد،

بيوفر بكمية عندي Ring & Ring.

Scanned with CamScanner

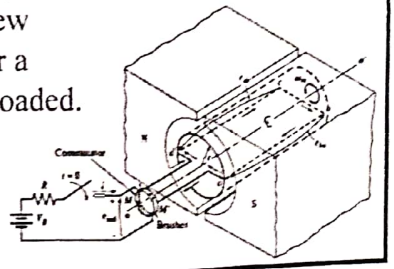
DC Machines – Simple Rotating Loop

- The torque produced in the machine is the product of the flux in the machine and the current in the machine, times some quantity representing the mechanical construction of the machine (the percentage of the rotor covered by pole faces).
- In general, the torque in any real machine will depend on the same three factors:

1. The flux in the machine
2. The current in the machine
3. A constant representing the construction of the machine

DC Machines – Simple Rotating Loop

Example 8.1 Given the system shown in Figure 8-6. The physical dimensions and characteristics of this machine are r = 0.5m, R = 0.3Ω, V_B = 120V, l = 1.0m, B = 0.25T. (a) What happens when the switch is closed? (b) What is the machine's maximum starting current? What is its steady-state angular velocity at no load? (c) Suppose a load is attached to the loop, and the resulting load torque is 10 N· m. What would the new steady-state speed be? How much power is supplied to the shaft of the machine? How much power is being supplied by the battery? Is this machine a motor or a generator? (d) Suppose the machine is again unloaded, and a torque of 7.5 N • m is applied to the shaft in the direction of rotation. What is the new steady-state speed? Is this machine now a motor or a generator? (e) Suppose the machine is running unloaded. What would the final steady-state speed of the rotor be if the flux density were reduced to 0.20 T?



Scanned with CamScanner

DC Machines – Simple Rotating Loop

(a) When the switch in Figure 8–6 is closed, a current will flow in the loop. Since the loop is initially stationary, $e_{ind} = 0$. Therefore, the current will be given by

$$i = \frac{V_B - e_{ind}}{R} = \frac{V_B}{R}$$

This current flows through the rotor loop, producing a torque

$$\tau_{ind} = \frac{2}{\pi}\phi i \quad \text{CCW}$$

This induced torque produces an angular acceleration in a counterclockwise direction, so the rotor of the machine begins to turn. But as the rotor begins to turn, an induced voltage is produced in the motor, given by

$$e_{ind} = \frac{2}{\pi}\phi\omega$$

so the current i falls. As the current falls, $\tau_{ind} = (2/\pi)\phi i \downarrow$ decreases, and the machine winds up in steady state with $\tau_{ind} = 0$, and the battery voltage $V_B = e_{ind}$.

This is the same sort of starting behavior seen earlier in the linear dc machine.

Electrical Machines (110405323) Dr. Mohammad Salah 16

DC Machines – Simple Rotating Loop

(b) At *starting conditions*, the machine's current is

$$i = \frac{V_B}{R} = \frac{120\ \text{V}}{0.3\ \Omega} = 400\ \text{A}$$

At *no-load steady-state conditions*, the induced torque τ_{ind} must be zero. But $\tau_{ind} = 0$ implies that current i must equal zero, since $\tau_{ind} = (2/\pi)\phi i$, and the flux is nonzero. The fact that $i = 0$ A means that the battery voltage $V_B = e_{ind}$. Therefore, the speed of the rotor is

$$V_B = e_{ind} = \frac{2}{\pi}\phi\omega$$

$$\omega = \frac{V_B}{(2/\pi)\phi} = \frac{V_B}{2rlB}$$

$$= \frac{120\ \text{V}}{2(0.5\ \text{m})(1.0\ \text{m})(0.25\ \text{T})} = 480\ \text{rad/s}$$

Scanned with CamScanner

DC Machines – Simple Rotating Loop

(c) If a load torque of 10 N • m is applied to the shaft of the machine, it will begin to slow down. But as ω decreases, $e_{ind} = (2/\pi)\phi\omega\downarrow$ decreases and the rotor current increases $[i = (V_B - e_{ind}\downarrow)/R]$. As the rotor current increases, $|\tau_{ind}|$ increases too, until $|\tau_{ind}| = |\tau_{load}|$ at a lower speed ω.

At steady state, $|\tau_{load}| = |\tau_{ind}| = (2/\pi)\phi i$. Therefore,

By Kirchhoff's voltage law, $e_{ind} = V_B - iR$, so

$$e_{ind} = 120\text{ V} - (40\text{ A})(0.3\ \Omega) = 108\text{ V}$$

Finally, the speed of the shaft is

$$\omega = \frac{e_{ind}}{(2/\pi)\phi} = \frac{e_{ind}}{2rlB}$$

$$= \frac{108\text{ V}}{(2)(0.5\text{ m})(1.0\text{ m})(0.25\text{ T})} = 432\text{ rad/s}$$

The power supplied to the shaft is

$$P = \tau\omega$$

$$= (10\text{ N} \cdot \text{m})(432\text{ rad/s}) = 4320\text{ W}$$

The power out of the battery is

$$P = V_B i = (120\text{ V})(40\text{ A}) = 4800\text{ W}$$

This machine is operating as a *motor*, converting electric power to mechanical power.

DC Machines – Simple Rotating Loop

(d) If a torque is applied in the direction of motion, the rotor accelerates. As the speed increases, the internal voltage e_{ind} increases and exceeds V_B, so the current flows out of the top of the bar and into the battery. This machine is now a *generator*. This current causes an induced torque opposite to the direction of motion. The induced torque opposes the external applied torque, and eventually $|\tau_{load}| = |\tau_{ind}|$ at a higher speed ω.

The current in the rotor will be

$$i = \frac{\tau_{ind}}{(2/\pi)\phi} = \frac{\tau_{ind}}{2rlB}$$

$$= \frac{7.5\text{ N} \cdot \text{m}}{(2)(0.5\text{ m})(1.0\text{ m})(0.25\text{ T})} = 30\text{ A}$$

The induced voltage e_{ind} is

$$e_{ind} = V_B + iR$$

$$= 120\text{ V} + (30\text{ A})(0.3\ \Omega)$$

$$= 129\text{ V}$$

Finally, the speed of the shaft is

$$\omega = \frac{e_{ind}}{(2/\pi)\phi} = \frac{e_{ind}}{2rlB}$$

$$= \frac{129\text{ V}}{(2)(0.5\text{ m})(1.0\text{ m})(0.25\text{ T})} = 516\text{ rad/s}$$

Scanned with CamScanner

DC Machines – Simple Rotating Loop

(e) Since the machine is initially unloaded at the original conditions, the speed $\omega = 480$ rad/s. If the flux decreases, there is a transient. However, after the transient is over, the machine must again have zero torque, since there is still no load on its shaft. If $\tau_{ind} = 0$, then the current in the rotor must be zero, and $V_B = e_{ind}$. The shaft speed is thus

$$\omega = \frac{e_{ind}}{(2/\pi)\phi} = \frac{e_{ind}}{2rlB}$$

$$= \frac{120 \text{ V}}{(2)(0.5 \text{ m})(1.0 \text{ m})(0.20 \text{ T})} = 600 \text{ rad/s}$$

Notice that when the flux in the machine is decreased, its speed increases. This is the same behavior seen in the linear machine and the same way that real dc motors behave.

DC Machines – Operation

- **DC Motor, How it works?**
  https://www.youtube.com/watch?v=LAtPHANEfQo&t=1s

Scanned with CamScanner

Commutator هو المسؤول عن تحويل الـ Ac إلى Dc ← للعمل الـ Rectifire

Armature هو الجزء الدوار في الموتور بال DC machine يعني هو نفسه motor بس في DC machine بيكون ثابت!!

$L\frac{di}{dt}$ ← Inductive kick

الهبوط الصغير في الجهد Voltage Drop

حسب قوانين العوكيت $\frac{di}{dt}$ بالزمن تغير بالتيار وضروب بالمحاثة فهاي الهبوط لا تكون اكا اذا كان في تغير في التيار

تأثير الأرمتشر ← هو تأثير المجال المغناطيسي الناتج عن مرور تيار في الأرمتشر عن توزيع مجال فيت الأقطاب الرئيسية

الفرق ← التوزيع المجال المغناطيسي بتكون منتظمة بكل مكان وفيت المجال عند الأقطاب قوية

① هبوط الجهد تكون مفقودة مع السطح

⊗ ⊙ الدوائر هي عبارة عن أسلاك فيها الموخا تقبل التيارات والموخ تشكل المجال المغناطيسي

DC Machines – Commutation Problems

- **Commutation** is the process of converting the AC voltages and currents in the rotor of a DC machine to DC voltages and currents at its terminals.
- It is the most critical part of the design and operation of any DC machine.
- The commutation process is not as simple in practice as it seems in theory, because two major effects occur in the real world to disturb it:

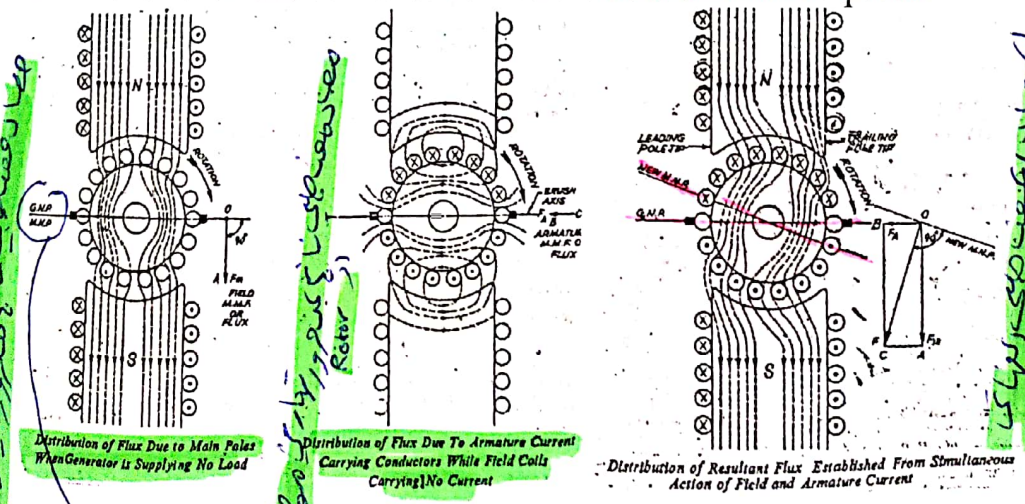
1. **Armature reaction**
2. $L\frac{di}{dt}$ **voltages**

Inductive Kick

DC Machines – Commutation Problems

Armature Reaction

It is the effect of the magnetic field set up by the armature current on the distribution of the flux under main poles



Scanned with CamScanner

الشوه الحب صيرتة الانتقاد بأرك الى تأثيرى اكهب الـ Magnetic
لى تتلاقى الفحمات مع الـ Commutator وتغير مكان الـ
Neutral Plane هاد الى متفوق عن الاعتماد او اكمتاكل الى
تكون تحت عنوت د فعل الـ Armature

* Neutral Plane Shifts:

Shift يصير
بنفس الاتجاه اذا كان
يشتغل كـ Generator

Shift يصير
بالاتجاه اكعاكس اذا كان
يشتغل كـ موتور

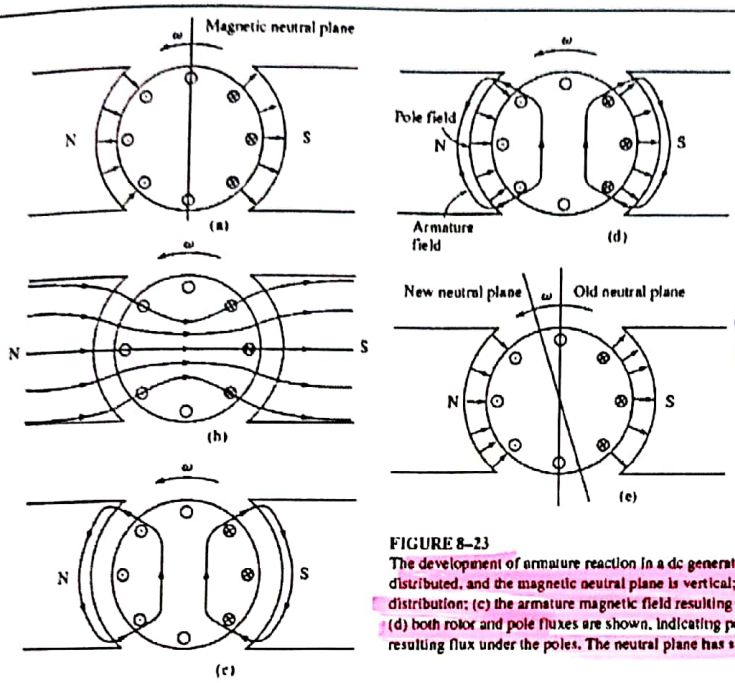
هذه الازاحة بتعتمد على هذه التيار بالتالي بتعتمد على الحمل
على الآلة
يطلع وينزل بناءً على الأحمال
كهربائي تحمل كهربائية وبأثر عليها
وكانيكي صب التركة والسورعة

تأثير تيار الهواء

الموضوع هاد عبارة عن انتقال تيار من نقطة لـ أخرى
من خلال الهواء وكيف من الأحيان بعاجبو حراية كالية عبر الـ
ممكن تأثر على عدد وبات الفحمات والأماكن على الـ Commutator

Scanned with CamScanner

DC Machines – Commutation Problems



Armature Reaction causes two serious problems:

1. **Neutral Plane Shift**
2. **Flux weakening**

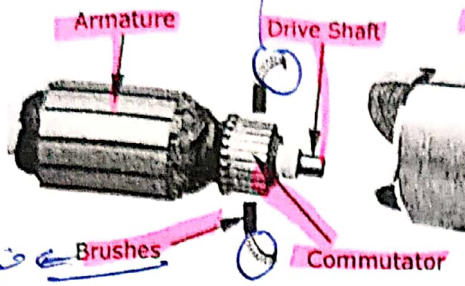
FIGURE 8–23
The development of armature reaction in a dc generator. (a) Initially the pole flux is uniformly distributed, and the magnetic neutral plane is vertical; (b) the effect of the air gap on the pole flux distribution; (c) the armature magnetic field resulting when a load is connected to the machine; (d) both rotor and pole fluxes are shown, indicating points where they add and subtract; (e) the resulting flux under the poles. The neutral plane has shifted in the direction of motion.

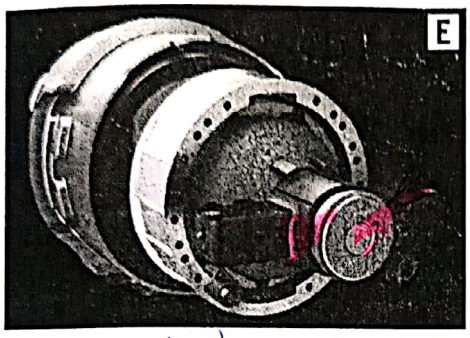
DC Machines – Commutation Problems

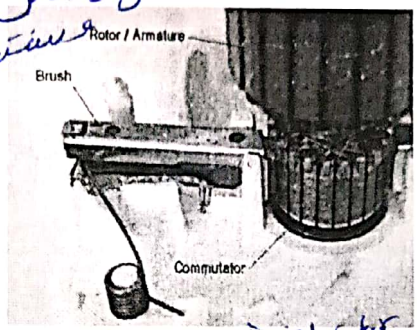
- **Magnetic neutral plane** is defined as the plane within the machine where the velocity of the rotor wires is exactly parallel to the magnetic flux lines, so that e_{ind} in the conductors in the plane is exactly zero.
- In general, the neutral-plane shifts in the direction of motion for a generator and opposite to the direction of motion for a motor.
- Furthermore, the amount of the shift depends on the amount of rotor current and hence on the load of the machine.
- The end result is **arcing and sparking at the brushes** and this is a very serious problem

Scanned with CamScanner

DC Machines – Commutation Problems







DC Machines – Commutation Problems

- **Arcing and sparking at the brushes** lead to:
  - (1) drastically reduced brush life
  - (2) pitting (making holes) of the commutator segments
  - (3) greatly increased maintenance costs
- Notice that this problem cannot be fixed even by placing the brushes over the full-load neutral plane, because then they would spark at no load.

Scanned with CamScanner

Flashover ⟹ extra نجد
السرعة بكون كبيرة على جزء لنوعي
segments الى أخرج ال

الرهاد هنب الفحمات بكون متأين نتيجة السرعة الى
يصير عند الفحمات

هو كمتا أعلاه، أنف السرعة هو انتقال الترونات لحاملين
الرهاد نحو عبد الهواء.

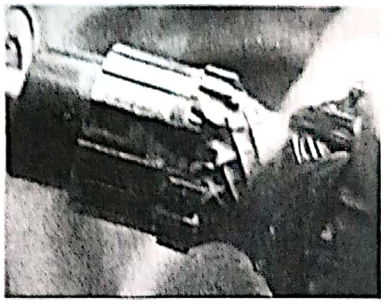
كما يصير عندي الصهد لقطعتين نحاسيتين هنب بعض
يصير عندي شرار على صدأ نتيجة مرور تيار
فندث ال Flashover

بالموتورات ⟸ تزيد السرعة والمرجع يزداد العمل (فوكوت عندي عمل ميكانيكي
لن يزداد لكن المقصود هو زيادة سرعة التيار) ترتب على زيادة
أنو ممكن يصير عندي حرق أصابع الكهربائي لمعنا لي.

Scanned with CamScanner

DC Machines – Commutation Problems

- In extreme cases, the neutral-plane shift can even lead to flashover in the commutator segments near the brushes.
- The air near the brushes in a machine is normally ionized as a result of the sparking on the brushes.
- **Flashover** occurs when the voltage of adjacent commutator segments gets large enough to sustain an arc in the ionized air above them.
- If flashover occurs, the resulting arc can even melt the commutator's surface.



DC Machines – Commutation Problems

- The effect of flux weakening is simply to reduce the voltage supplied by the generator for any given load.
- In motors, this effect increases the speed and then probably the load, resulting in more flux weakening.
- It is possible for some motors to reach a runaway condition.
- as a result of flux weakening, where the speed of the motor just keeps increasing until the machine is disconnected from the power line or until it destroys itself.

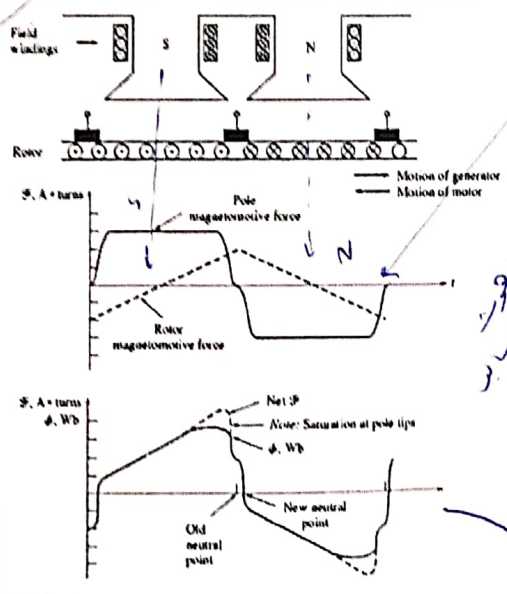


FIGURE 8–25
The flux and magnetomotive force under the pole faces in a dc machine. At those points where the magnetomotive forces subtract, the flux closely follows the net magnetomotive force in the iron; but at those points where the magnetomotive forces add, saturation limits the total flux present. Note also that the neutral point of the rotor has shifted.

Scanned with CamScanner

كيف ان brushes بها تعمل Shorted out segments ؟

الـ Commutator عبارة عن segments (أجزاء نحاسية) والفحمة تتلامس مع هذه الأجزاء عندما تدور brush تكون ملامسة لـ Two segments وبهذا يتم توزيع الـ AC الكهربي وبهذا تتلاشى الـ Drop voltage الذي هو (Inductive Kick) $L\frac{di}{dt}$

وكوننا هذا يسمى (Inductive Kick) الذي هو عبارة عن شحنة متبقية للتيار

Scanned with CamScanner

DC Machines – Commutation Problems

- $L\frac{di}{dt}$ **voltage** that occurs in commutator segments being shorted out by the brushes, sometimes called **inductive kick**
- This voltage is relatively high and naturally causes sparking at the brushes of the machine, resulting in the same arcing problems that the neutral-plane shift causes.

DC Machines – Commutation Problems

Three approaches have been developed to partially or completely correct the problems of armature reaction and $L\frac{di}{dt}$ voltages:

(1) Brush shifting

(2) Commutating poles or interpoles

(3) Compensating windings

Scanned with CamScanner

Shifting brushes

اي هو حركة
الفرش
Neutral
Plane
تتردد وبين ما
يعيد عندها
يعيد

حركنا سابقا ان الفرش اي يعيد بين القاعدة وبين
الـ Segments اي هو يكون عندي عليه وصلت بـ
الملف = في تلك المنطقة بالتالي اذا قلنا ان
زاوية الصفر اتصلت بـ هذا الملف مع هذا
يكون تغلبت على الفرش وهي عملية باسمها تسمى
Commutating Poles or Interpoles
تقع وضعها Midway بالمنطقة المحايدة بين اقطاب
الـ N & S

هذه الـ Poles يعني فيها تيار يولد مجال
عكسي بالغرض انه اتصال الأوتاد
في الملف وبالغرض
بالتالي مروح عندي
الفرش

DC Machines – Commutation Problems

- **Shifting brushes** may stop the sparking but it actually aggravated the flux-weakening effect of the armature reaction in the machine. In addition, the neutral plane moves with every change in load, and the shift direction reverses when the machine goes from motor operation to generator operation.
- By about 1910, the brush-shifting approach to controlling sparking was already obsolete. Today, brush-shifting is only used in very small machines that always run as motors.

DC Machines – Commutation Problems

- If the voltage in the wires undergoing commutation can be made zero, then there will be no sparking at the brushes.
- To accomplish this, small poles, called **commutating poles or interpoles**, are placed midway between the main poles.

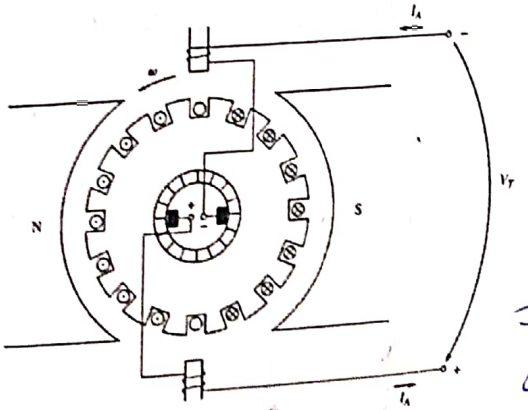


FIGURE 8–28
A dc machine with interpoles.

Scanned with CamScanner

مشكل ضعف المجال المغناطيسي لما يكون عندي أحمال
عالية بسبب ممكن تعمل مع وجود Armature Reaction
و Magnetic field weakening بالمحركات عندي
الات كبيرة وأحمال كبيرة وفي عندي Duty cycle

يعني شغل واطئ
شغل واطئ

هاد الشي بعمل تيارات
بدو عليه كبيرة كتير
ممكن تسبب الـ Armature reaction
و weak magnetic field

لتتغلب على
هاي
المشكلة منستخدم
شي أسمو
Compensating winding
ملفات التعويض

بنحكي عن هاي بالمحاضرة اللي جاية انه عطاب اي بتكون
موازية لموصلات الـ Rotor
بتكون في slots فيها
ملفات التعويض
بتولد مجال مغناطيسي بتعوض
النقص اللي صار أو بتعمل
Cancel للمجال المغناطيسي اللي صاير من الـ Rotor فبتعطي
المجال اللي مقابلته اما شيء هو الصح بس انه عطاب وبتمم
توصيلهم مع التوازي بحيث كل ما زاد الحمل بزداد التيار فبزيد المجال

Scanned with CamScanner

DC Machines – Commutation Problems

- These commutating poles are located directly over the conductors being commutated. By providing a flux from the commutating poles, the voltage in the coils undergoing commutation can be exactly canceled. If the cancellation is exact, then there will be no sparking at the brushes.
- The use of commutating poles or interpoles is very common, because they correct the sparking problems of dc machines at a fairly low cost.
- They are almost always found in any dc machine of 1 hp or larger.
- It is important to realize, though, that they do nothing for the flux distribution under the pole faces, so the flux-weakening problem is still present.

DC Machines – Commutation Problems

- For very heavy, severe duty cycle motors, the flux-weakening problem can be very serious.
- To completely cancel armature reaction and thus eliminate both neutral-plane shift and flux weakening, **compensating windings** are placed in slots carved in the faces of the poles parallel to the rotor conductors, to cancel the distorting effect of armature reaction.
- These windings are connected in series with the rotor windings, so that whenever the load changes in the rotor, the current in the compensating windings changes, too.

Scanned with CamScanner

DC Machines – Commutation Problems

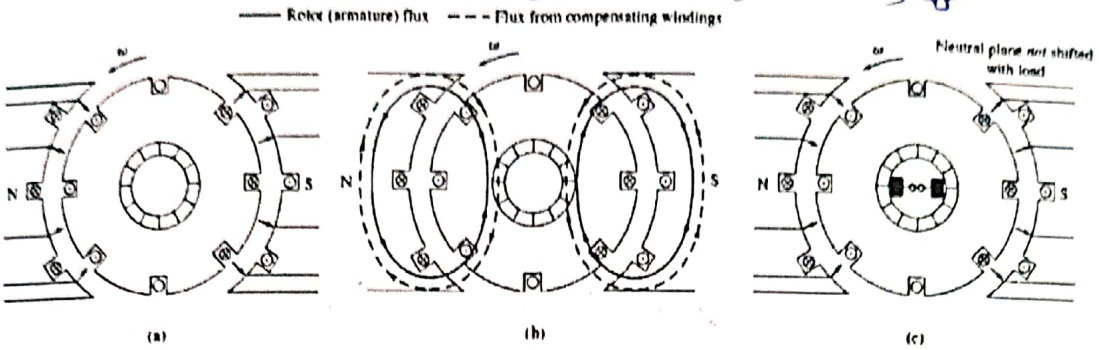


FIGURE 8–30
The effect of compensating windings in a dc machine. (a) The pole flux in the machine; (b) the fluxes from the armature and compensating windings. Notice that they are equal and opposite; (c) the net flux in the machine, which is just the original pole flux.

DC Machines – Commutation Problems

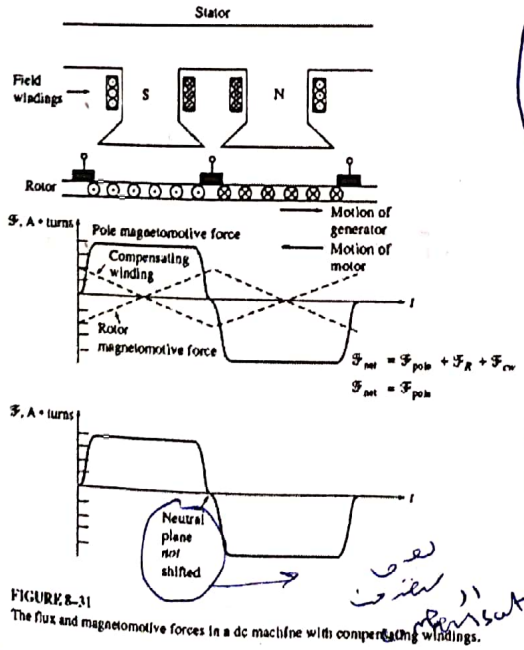


FIGURE 8–31
The flux and magnetomotive forces in a dc machine with compensating windings.

The major disadvantage of compensating windings is that they are expensive, since they must be machined into the faces of the poles. Any motor that uses them must also have interpoles, since compensating windings do not cancel $L\frac{di}{dt}$ effects. Because of the expense of having both compensating windings and interpoles on such a machine, these windings are used only where the extremely severe nature of a motor's duty demands them.

Scanned with CamScanner

ناتج في جميع الآلات ٥ وصف وكيف وصفات من عملية التشغيل

5 أقسام الفقد الضياعات

1 I^2R losses ← Electrical or Copper losses ← ناتجة عن مرور تيار في المقاومات الداخلية للعناصر

(ضياعات نحاسية)

كلما زاد الحمل زاد الضياعات هاي بسبب حرارة والنحاس مناقل الحرارة الكهربي بتتبع أنه استخدامه لتوصيل التيار والنحاس بعمل حرارة عشان هيك اسمه Copper (الحرارة ناتجة من مرور التيار)

Thermal losses / Electrical losses / Copper losses

3 Brush losses (الفحمات صغيرة مع الـ Commutator نقطة التواصل بتتسبب التيار والعينة هاي عليها مقاومة بيصير عليها Drop voltage وجود الـ Drop هوا Brush losses)

4 Core losses ضياعات المادة المصنوعة من الـ Ferromagnetic الحلقة داخل المحرك ومرور التيار داخلها بعمل ضياعات

5 ضياعات ميكانيكية (احتكاك أو أي شي آخر)

الضياعات الثابتة المتغيرة ← بتتغير حسب تغير قيمة الحمل

DC Machines – Power Flow and Losses

- In all DC machines, there is always some loss associated with the operation.
- The losses that occur in DC machines can be divided into five basic categories:

1. Electrical or copper losses (I^2R losses)
2. Brush losses
3. Core losses
4. Mechanical losses
5. Stray load losses

الضياعات الشاردة

DC Machines – Power Flow and Losses

- **Electrical or copper losses** are the losses that occur in the armature and field windings of the machine.
- The copper losses for the armature and field windings are given by

Armature loss:	$P_A = I_A^2 R_A$	(8–52)
Field loss:	$P_F = I_F^2 R_F$	(8–53)

where P_A = armature loss
P_F = field circuit loss
I_A = armature current
I_F = field current
R_A = armature resistance
R_F = field resistance

Scanned with CamScanner

DC Machines – Power Flow and Losses

- **Brush losses** is the power lost across the contact potential at the brushes of the machine. It is give n by the equation

$$P_{BD} = V_{BD} I_A \quad (8\text{–}54)$$

where P_{BD} = brush drop loss
V_{BD} = brush voltage drop
I_A = armature current

- The reason that the brush losses are calculated in this manner is that the voltage drop across a set of brushes is approximately constant over a large range of armature currents. Unless otherwise specified. the brush voltage drop is usually assumed to be about 2 V.

DC Machines – Power Flow and Losses

- **Core losses** are the hysteresis losses and eddy current losses occurring in the metal of the motor.
- These losses vary as the square of the flux density (B^2) and for the rotor, as the 1.5th power of the speed of rotation ($n^{1.5}$).
- **Mechanical losses** are associated with mechanical effects and there are two basic types:
  1. **Friction losses** are losses caused by the friction of the bearings in the machine.
  2. **Windage losses** are caused by the friction between the moving parts of the machine and the air inside the motor's casing.
- These losses vary as the cube of the speed (n^3).

Scanned with CamScanner

⇐ تناسب قيمة الـ core loss تقريباً مع (B^2) ⇐ Flux density

⇐ تتناسب طردياً مع سرعة دوران المحرك

للعقدة 1.5

⇐ تتناسب الصفات الميكانيكية تتناسب طردياً مع مكعب السرعة لدوران المحرك

Scanned with CamScanner

DC Machines – Power Flow and Losses

- **Stray losses (or miscellaneous losses)** are losses that cannot be placed in one of the previous categories. No matter how carefully losses are accounted for, some always escape inclusion in one of the above categories.
- All such losses are lumped into stray losses. For most machines, stray losses are taken by convention to be 1% of full load input power.

1% of Input Power
Full load

DC Machines – Power Flow and Losses

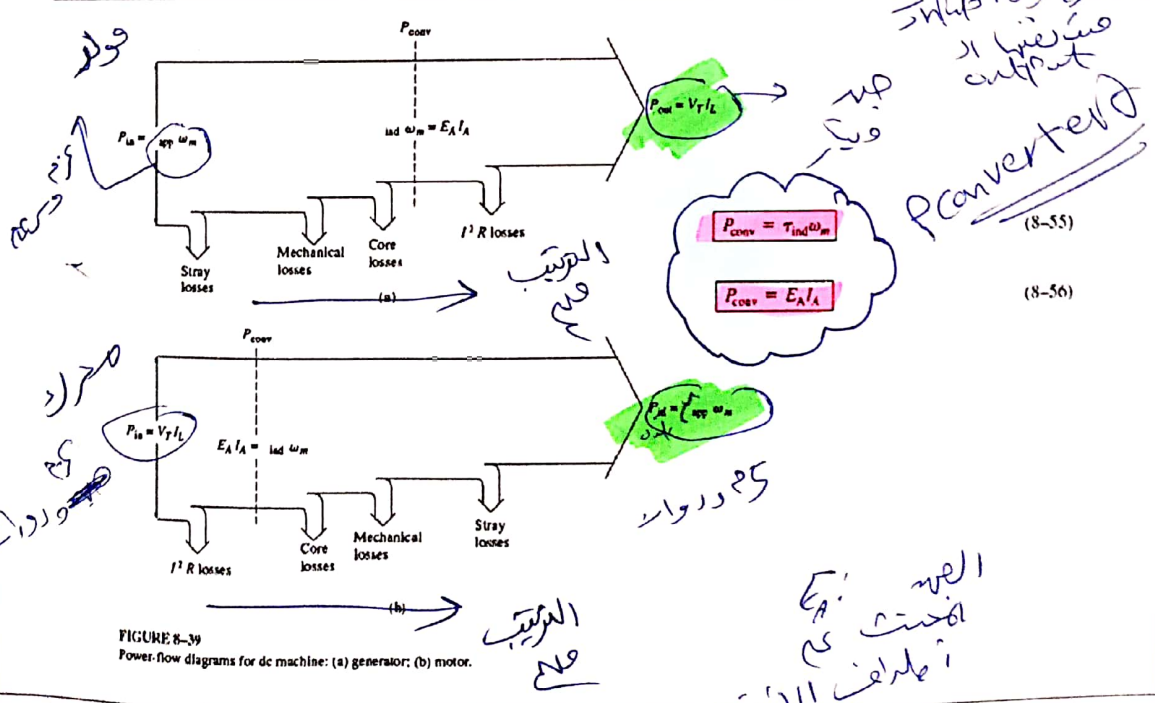


FIGURE 8–39
Power-flow diagrams for dc machine: (a) generator; (b) motor.

Scanned with CamScanner

DC Machines – Power Flow and Losses

The efficiency of a DC machine is defined by the equation

$$\eta = \frac{P_{out}}{P_{in}} \times 100\%$$

$$\eta = \frac{P_{in} - Ploss}{P_{in}} \times 100\%$$

$$\eta = \frac{P_{out}}{P_{out} + Ploss} \times 100\%$$

DC Machines – Simple Rotating Loop

Example 9.8 A 50 hp, 250 V, 1200 rpm shunt dc motor has a rated armature current of 170 A and a rated field current of 5 A. When its rotor is blocked, an armature voltage of 10.2 V (exclusive of brushes) produces 170 A of current flow and a field voltage of 250 V produces a field current flow of 5 A. The brush voltage drop is assumed to be 2 V. At no load with the terminal voltage equal to 240 V. the armature current is equal to 13.2 A. the field current is 4.8 A. and the motor's speed is 1150 rpm.

(a) How much power is output from this motor at rated conditions?
(b) What is the motor's efficiency?

Scanned with CamScanner

⇐ لما تنزل الجملة أطراف الأوتار السرية ع نقل

Scanned with CamScanner

DC Machines – Simple Rotating Loop

The armature resistance of this machine is approximately

$$R_A = \frac{10.2\ \text{V}}{170\ \text{A}} = 0.06\ \Omega$$

and the field resistance is

$$R_F = \frac{250\ \text{V}}{5\ \text{A}} = 50\ \Omega$$

Therefore, at full load the armature I^2R losses are

$$P_A = (170\ \text{A})^2(0.06\ \Omega) = 1734\ \text{W}$$

and the field circuit I^2R losses are

$$P_F = (5\ \text{A})^2(50\ \Omega) = 1250\ \text{W}$$

The brush losses at full load are given by

$$P_{\text{brush}} = V_{BD}I_A = (2\ \text{V})(170\ \text{A}) = 340\ \text{W}$$

DC Machines – Simple Rotating Loop

The rotational losses at full load are essentially equivalent to the rotational losses at no load, since the no-load and full-load speeds of the motor do not differ too greatly. These losses may be ascertained by determining the input power to the armature circuit at no load and assuming that the armature copper and brush drop losses are negligible, meaning that the no-load armature input power is equal to the rotational losses:

$$P_{\text{rot}} = P_{\text{core}} + P_{\text{mech}} = (240\ \text{V})(13.2\ \text{A}) = 3168\ \text{W}$$

(a) The input power of this motor at the rated load is given by

$$P_{\text{in}} = V_T I_L = (250\ \text{V})(175\ \text{A}) = 43{,}750\ \text{W}$$

Its output power is given by

$$\begin{aligned} P_{\text{out}} &= P_{\text{in}} - P_{\text{brush}} - P_{\text{cu}} - P_{\text{core}} - P_{\text{mech}} - P_{\text{stray}} \\ &= 43{,}750\ \text{W} - 340\ \text{W} - 1734\ \text{W} - 1250\ \text{W} - 3168\ \text{W} - (0.01)(43{,}750\ \text{W}) \\ &= 36{,}820\ \text{W} \end{aligned}$$

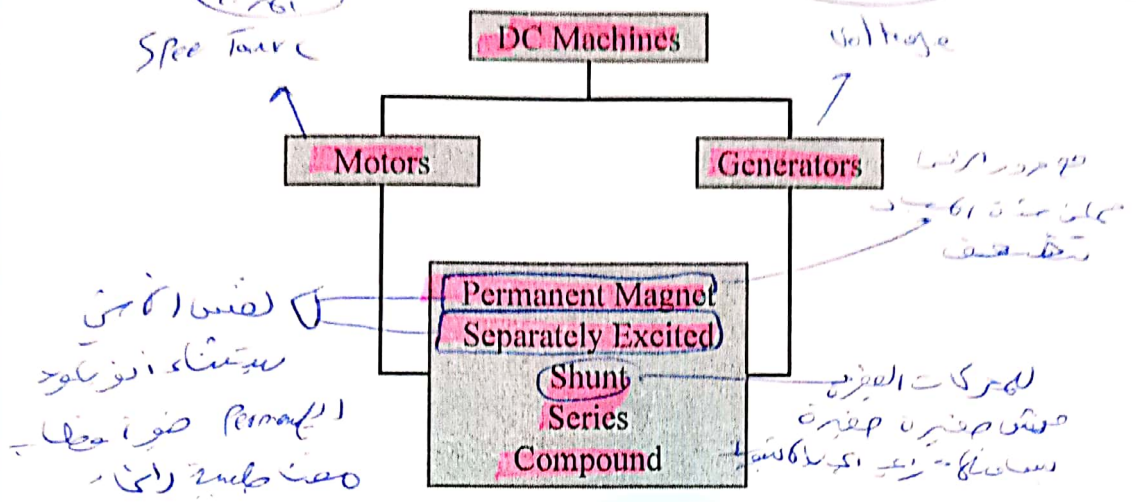
where the stray losses are taken to be 1 percent of the input power.

(b) The efficiency of this motor at full load is

$$\eta = \frac{P_{\text{out}}}{P_{\text{in}}} \times 100\% = \frac{36{,}820\ \text{W}}{43{,}750\ \text{W}} \times 100\% = 84.2\%$$

Scanned with CamScanner

DC Machines – Types



These various types of DC machines differ in their output (voltage-current) characteristics if they are generators or (speed-torque) characteristics if they are motors, and therefore in the applications to which they are suited.

DC Machines – Types

- In a **separately excited machine**, the field flux is derived from a separate power source.
- In a **shunt machine**, the field flux is derived by connecting the field circuit directly across the terminals of the armature.
- In a **series machine**, the field flux is produced by connecting the field circuit in series with the armature.
- In a **cumulatively compounded machine**, both a shunt and a series field are present, and their effects are additive.
- In a **differentially compounded machine**, both a shunt and a series field are present, but their effects are subtractive.

Scanned with CamScanner

في حالة المضخة ذات (compound) النوعين

Short Shunt ← توازي مع المجموع قبل التوازي

long Shunt ← توازي مع المجموع قبل التوازي

Shunt ← المكلف مربوط على التوازي مع المقاومة

series ← المكلف مربوط على التوازي مع المقاومة

Compound ← طريقة يكون فيها ملف توالي ومتوازي واحد توالي واحد توازي

Cummulatively ← اذا كان المجال المغناطيسي الناشئ التوالي والتوازي بنفس الاتجاه

differentially ← اذا كان التوالي = التوازي والتوازي = يعكس الاتجاه

DC Machines – Types

YouTube

- **Types of DC Motors - Classification of DC Motors**
  https://www.youtube.com/watch?v=uth3248pzqM

DC Machines – Generators

- DC generators are compared by their voltages, power ratings, efficiencies, and voltage regulations.
- Voltage regulation (VR) is defined by the equation

$$VR = \frac{V_{nl} - V_{fl}}{V_{fl}} \times 100\%$$

- V_{nl} is the no-load terminal voltage of the generator and V_{fl} is the full- load terminal voltage of the generator
- It is a rough measure of the shape of the generator's voltage-current characteristic. A positive voltage regulation means a drooping characteristic, and a negative voltage regulation means a rising characteristic.

Scanned with CamScanner

Voltage regulation (Rough mesure)

مقياس تقديري بحكلفات شكل الفولتج والكرنت الخاص بالمولد كيف يكون شكلو

$$V_R = \frac{V_{nl} - V_{fl}}{V_{fl}}$$

Drop Characteristics

Rising Characteristics

العمود بزداد بالحمل

العمود ينقص بالحمل

V_{nl} ⟹ هو فولتج المولد في حالة لا حمل No load

V_{fl} ⟹ هو فولتج المولد في حالة الحمل full load

nl : no load

fl : full load

في التشغيل للمولد يجب أن يبقى عمل كهربائي ممكن يكون مقاومة أو مقاومة أو مكثف أو معدة متنوعة كانوا بدك مولد يعطي كهرباء negative Regulation ممكن يكون مولج بالتالي يعطي مردود كبير ويعرف يكون مولج

Rising characteristic ⟸ tve Regulation

واذا عمل هاي الأربعة بتنزل الكرنت والعكس Drop characteristic ⟸ tve Regulation

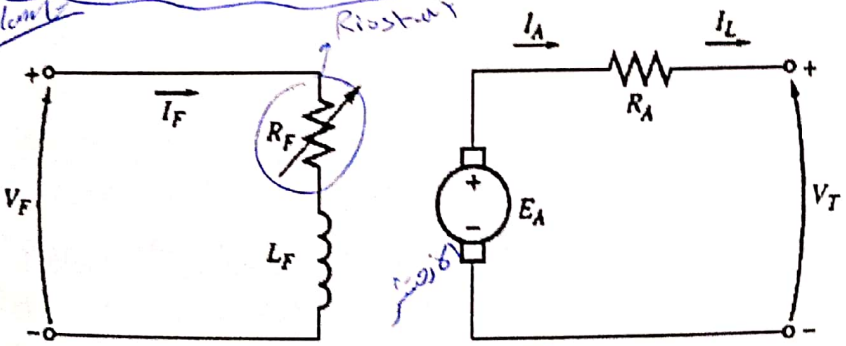
Scanned with CamScanner

DC Machines – Generators

- All generators are driven by a source of mechanical power, which is usually called the **prime mover** of the generator.
- A prime mover for a DC generator may be a steam turbine, a diesel engine, or even an electric motor.
- Since the speed of the prime mover affects the output voltage of a generator, and since prime movers can vary widely in their speed characteristics, it is customary to compare the voltage regulation and output characteristics of different generators, assuming constant speed prime movers.
- DC generators are quite rare in modern power systems. Even DC power systems such as those in automobiles now use AC generators plus rectifiers to produce DC power.

DC Machines – Generators

Separately Excited DC Generators



$I_L = I_A$

$V_T = E_A - I_A R_A$

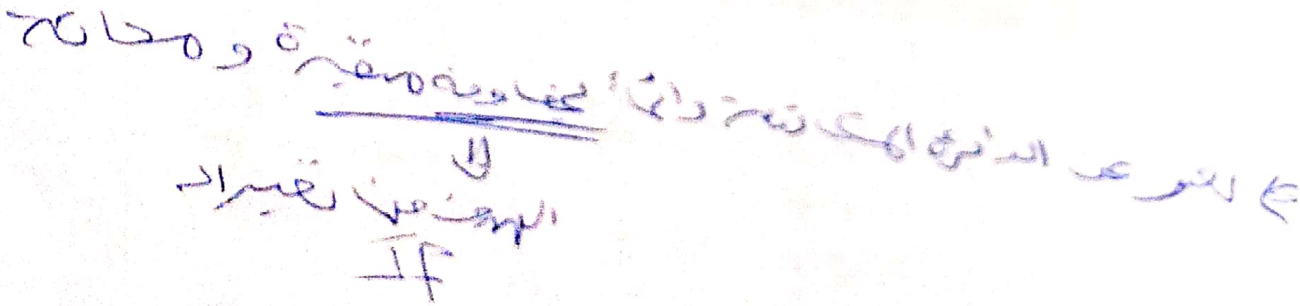
$I_F = \frac{V_F}{R_F}$

FIGURE 9–44
A separately excited dc generator.

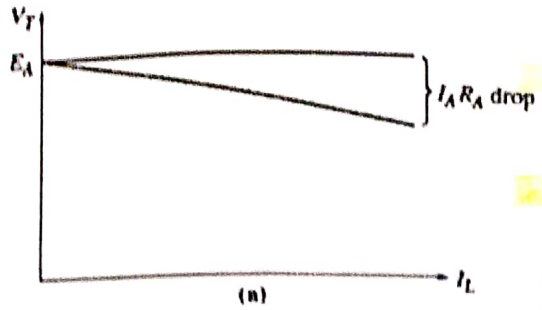
For a constant speed $V_T = E_A - I_A R_A$ (9–41)

Prm Moving Mesh

يفيد بشكل كبير بالتالي الخوارزمية تتعقد
الفيزيا ح تتغير وبتالي حد ح يعرف
حل الـ Characteristic بفرض أنو السرعة ثابتة



Scanned with CamScanner



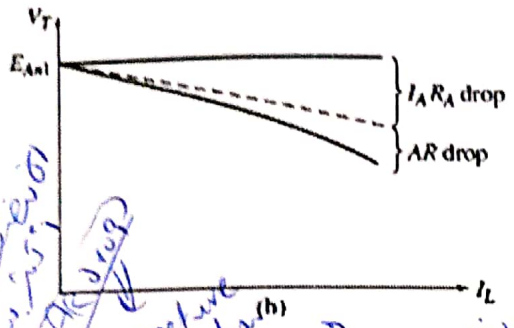


FIGURE 9–45
The terminal characteristic of a separately excited dc generator (a) with and (b) without compensating windings.

When the load supplied by the generator is increased, I_L (and therefore I_A) increases. As the armature current increases, the $I_A R_A$ drop increases, so the terminal voltage of the generator falls. This terminal characteristic is not always entirely accurate. In generators without compensating windings, an increase in I_A causes an increase in armature reaction, and armature reaction causes flux weakening. This flux Weakening causes a decrease in $E_A = K\phi \downarrow \omega$ which further decreases the terminal voltage of the generator.

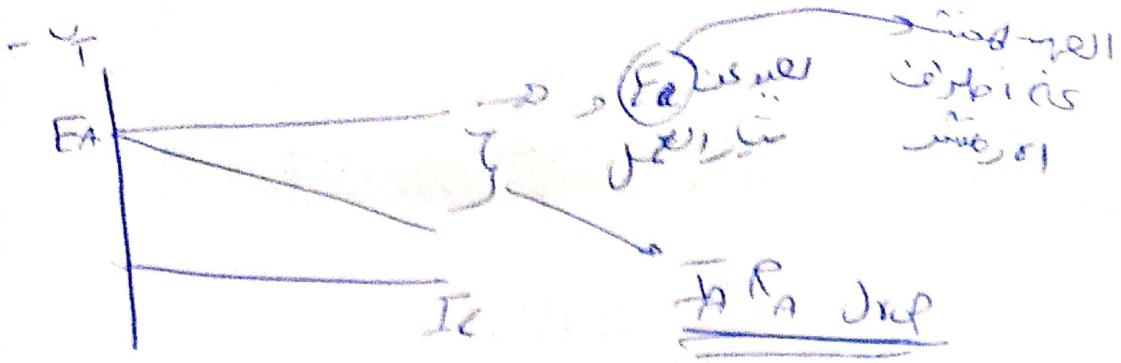
DC Machines – Generators

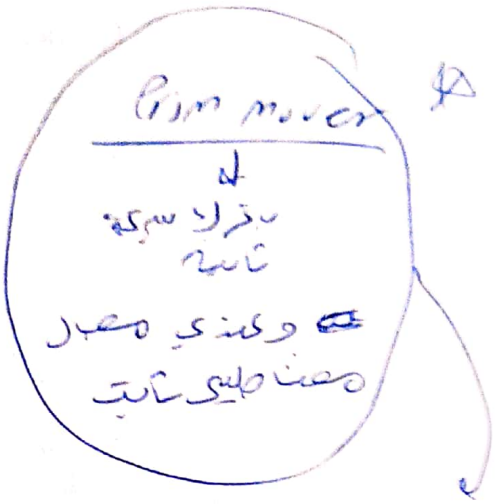
- Since the internal generated voltage E_A is given by the equation $E_A = K\phi\downarrow\omega$, there are two possible ways to control the voltage of this generator:

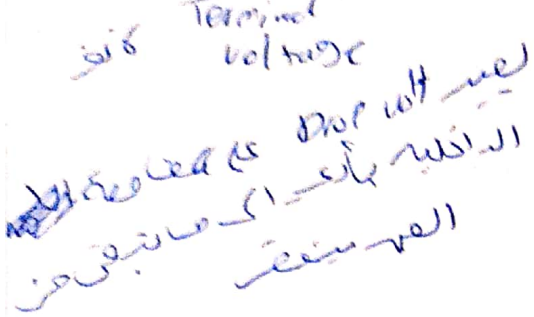
1. **Change the speed:** If ω increases, then $E_A = K\phi\omega\uparrow$ increases, so $V_T = E_A\uparrow - I_A R_A$ increases too.
2. **Change the filed current:** If R_F is decreased, then the field current increases ($I_F = V_F/R_F\downarrow$). Therefore, the flux ϕ in the machine increases. As the flux rises, $E_A = K\phi\uparrow\omega$ must rise too, so $V_T = E_A\uparrow - I_A R_A$ increases.

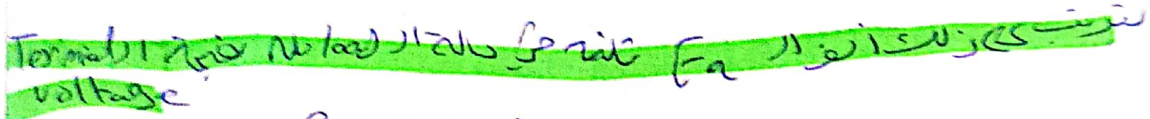
- In many applications, the speed ran ge of the prime mover is quite limited, so the terminal voltage is most commonly controlled by changing the field current.

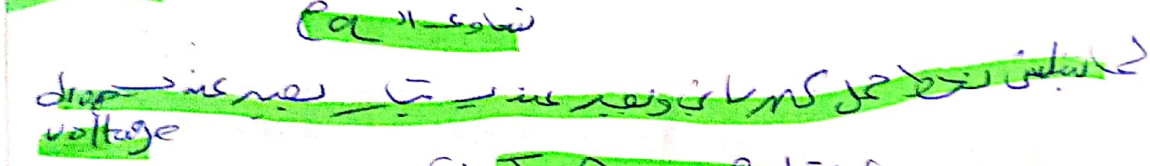
Scanned with CamScanner

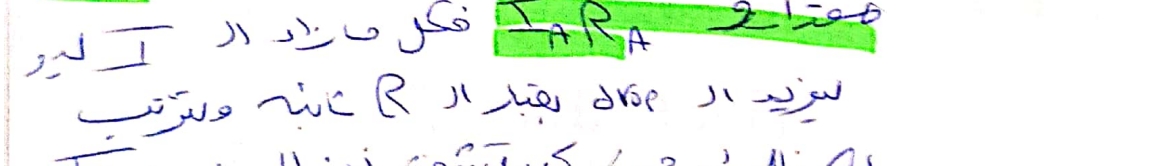

EA
Ia
Ia RA Drop

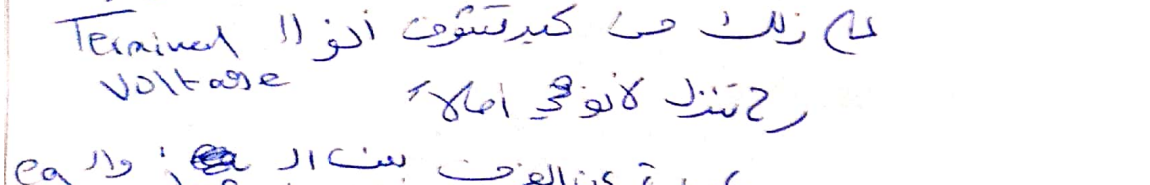

Prim mover
بنزل سرعة ثابتة
وكمان مصدر صناعي ثابت

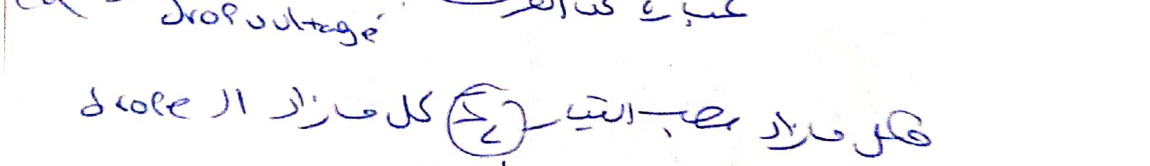


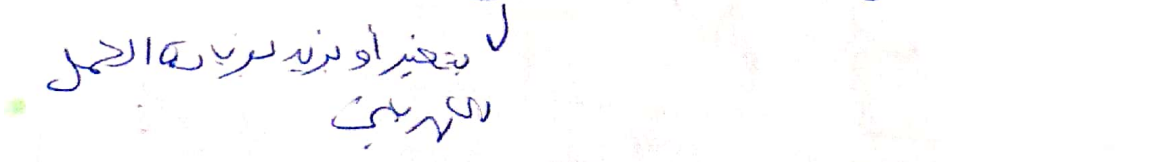


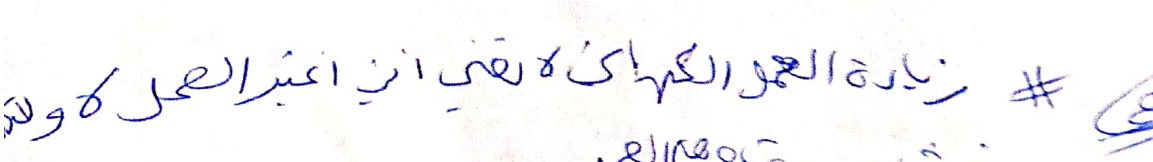


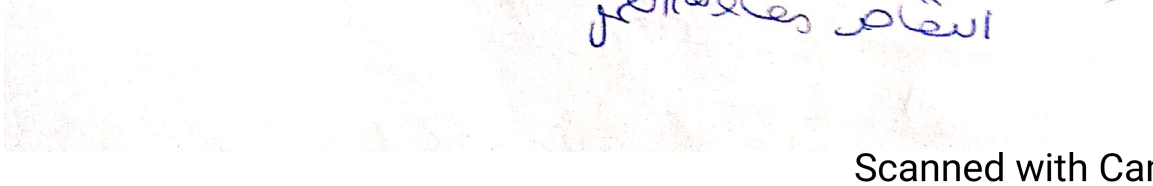












DC Machines – Generators

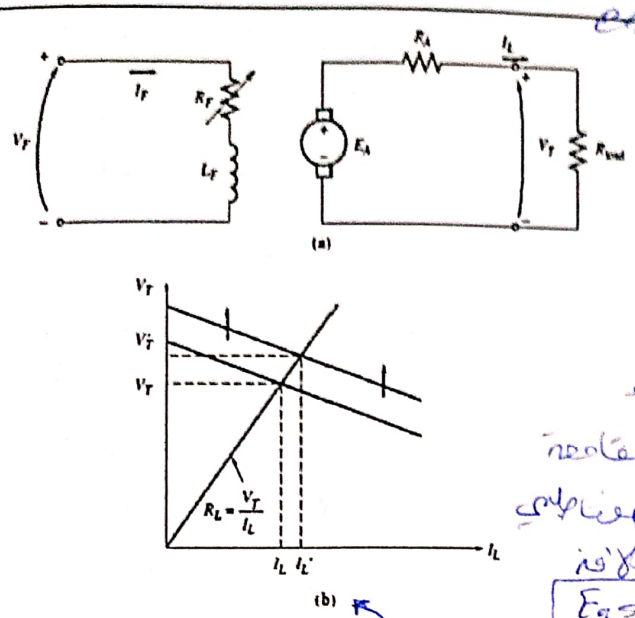


FIGURE 9–46
(a) A separately excited dc generator with a resistive load. (b) The effect of a decrease in field resistance on the output voltage of the generator.

DC Machines – Generators

- Because the internal generated voltage of a generator is a nonlinear function of its magnetomotive force, it is not possible to calculate simply the value of E_A to be expected from a given field current.
- The magnetization curve of the generator must be used to accurately calculate its output voltage for a given input voltage.
- In addition, if a machine has armature reaction, its flux will be reduced with each increase in load, causing E_A to decrease.
- The only way to accurately determine the output voltage in a machine with armature reaction is to use graphical analysis.

Scanned with CamScanner

أحد أنواع مضاعفات باور مطلوبة بكونها ذات خاصية
بالتي السلوك يكون Nonlenier

Minimization curve ⇐ يربط بين
كل قيمتين

الكيرف تاع Demand
يستخدم لحساب القيمة
الأدنى
Output voltage

Scanned with CamScanner

DC Machines – Generators

- The total magnetomotive force in a separately excited generator is the field circuit magnetomotive force less the magnetomotive force due to armature reaction (AR):

$$\mathcal{F}_{net} = N_F I_F - \mathcal{F}_{AR}$$

- As with DC motors, it is customary to define an **equivalent field current** that would produce the same output voltage as the combination of all the magnetomotive forces in the machine.
- The resulting voltage E_{A0} can then be determined by locating that equivalent field current on the magnetization curve.

DC Machines – Generators

- The equivalent field current of a separately excited DC generator is given by

$$I_F^* = I_F - \frac{\mathcal{F}_{AR}}{N_F}$$

- Also, the difference between the speed of the magnetization curve and the real speed of the generator must be taken into account:

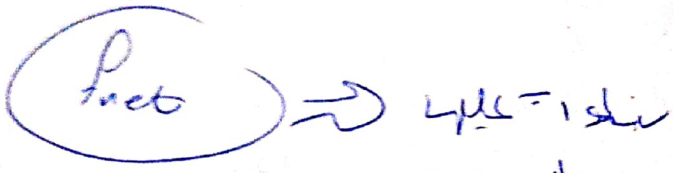
$$\frac{E_A}{E_{A0}} = \frac{n}{n_0}$$

Scanned with CamScanner

في أغلب الأحيان يلزمنا الحالة Magnetization curve لما يحدث عندي Armature Reaction

نقطة مهمة # المولدات والمحركات

بيكون عندي Magnetization curve بالسؤال يعني مصدر أضافي أطلع منه المعلومات



بناءا عليه بطلع عندي Find

يعتمد على

Prime mover ١ سرعة دوران

٢ شدة المجال المغناطيسي المتولدة

F بال

DC Machines – Generators

Example 9.9 A separately excited dc generator is rated at 172kW, 430V, 400A, and 1800 r/min. It is shown in Figure 9-47 and its magnetization curve is shown in Figure 9-48. This machine has the following characteristics: R_A=0.05 Ω, R_F=20Ω, R_{adj}=0 to 300Ω, V_F = 430V, N_F = 1000 turns per pole (a) If the variable resistor R_{adj} in this generator's field circuit is adjusted to 63Ω and the generator's prime mover is driving it at 1600 r/min, what is this generator's no-load terminal voltage? (b) What would its voltage be if a 360-A load were connected to its terminals? Assume that the generator has compensating windings. (c) What would its voltage be if a 360-A load were connected to its terminals but the generator does not have compensating windings? Assume that its armature reaction at this load is 450 A·turns. (d) What adjustment could be made to the generator to restore its terminal voltage to the value found in part a? (e) How much field current would be needed to restore the terminal voltage to its no-load value? (Assume that the machine has compensating windings.) What is the required value for the resistor R_{adj} to accomplish this?

Scanned with CamScanner

DC Machines – Generators

(d) The voltage at the terminals of the generator has fallen, so to restore it to its original value, the voltage of the generator must be increased. This requires an increase in E_A, which implies that R_{adj} must be decreased to increase the field current of the generator.

(e) For the terminal voltage to go back up to 382 V, the required value of E_A is

$$E_A = V_T + I_A R_A = 382\text{ V} + (360\text{ A})(0.05\ \Omega) = 400\text{ V}$$

To get a voltage E_A of 400 V at n_m = 1600 r/min, the equivalent voltage at 1800 r/min would be

$$\frac{E_A}{E_{A0}} = \frac{n}{n_0} \qquad (9\text{–}13)$$

$$E_{A0} = \frac{1800\text{ r/min}}{1600\text{ r/min}} 400\text{ V} = 450\text{ V}$$

From the magnetization curve, this voltage would require a field current of I_F = 6.15 A. The field circuit resistance would have to be

$$R_F + R_{adj} = \frac{V_F}{I_F}$$

$$20\ \Omega + R_{adj} = \frac{430\text{ V}}{6.15\text{ A}} = 69.9\ \Omega$$

$$R_{adj} = 49.9\ \Omega \sim 50\ \Omega$$

DC Machines – Motors

- Today, induction motors with solid-state drive packages are the preferred choice over DC motors for most speed control applications. However, there are still some applications where dc motors are preferred.
- DC motors are often compared by their speed regulations.
- The **speed regulation** (SR) of a motor is defined by

$$SR = \frac{\omega_{nl} - \omega_{fl}}{\omega_{fl}} \times 100\%$$

$$SR = \frac{n_{nl} - n_{fl}}{n_{fl}} \times 100\%$$

Scanned with CamScanner

DC Machines – Motors

- It is a rough measure of the shape of a motor's speed–torque characteristic. A positive speed regulation means that a motor's speed drops with increasing load, and a negative speed regulation means a motor's speed increases with increasing load.
- The magnitude of the speed regulation tells approximately how steep the slope of the torque- speed curve is.
- It is a rough measure of the shape of a motor's torque-speed characteristic. A positive speed regulation means that a motor's speed drops with increasing load, and a negative speed regulation means a motor's speed increases with increasing load.

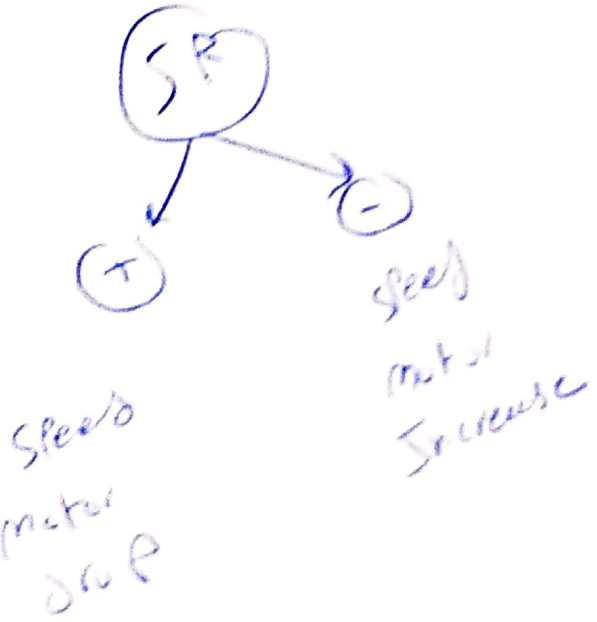
DC Machines – Motors

- The magnitude of the speed regulation tells approximately how steep the slope of the torque- speed curve is.
- It should be noted that in order to get the maximum possible power per pound of weight out of a machine, most motors and generators are designed to operate near the saturation point on the magnetization curve (at the knee of the curve).
- This implies that a fairly large increase in field current is often necessary to get a small increase in E_A when operation is near full load.

Scanned with CamScanner

در اغلب اکسترکلک‌های از Speed Regulation
تکنولوژی‌های مختلفی استفاده می‌شود که در
اینجا

سنجش سرعت توربین از طریق اندازه‌گیری
اختلاف فاز میان فرکانس ژنراتور از طریق اندازه



Scanned with CamScanner

DC Machines – Motors

Separately Excited and Shunt DC Motors

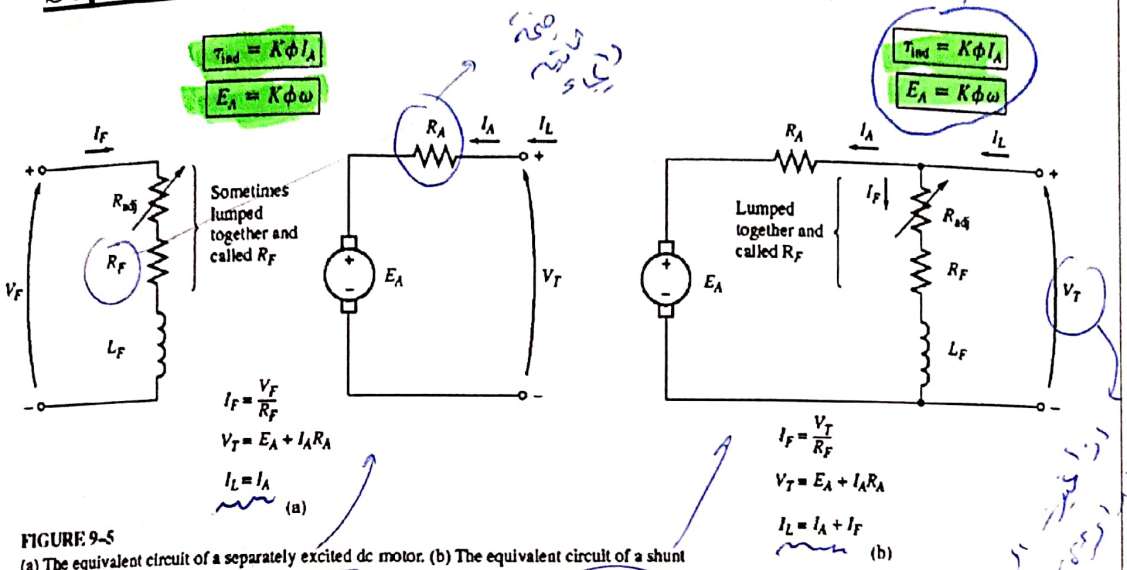


FIGURE 9–5
(a) The equivalent circuit of a separately excited dc motor. (b) The equivalent circuit of a shunt dc motor.

DC Machines – Motors

- The output characteristic of a separately excited and shunt DC motors can be derived from the induced voltage and torque equations of the motor plus Kirchhoff's voltage law as

$$V_T = E_A + I_A R_A$$

$$V_T = K\phi\omega + I_A R_A$$

$$V_T = K\phi\omega + \frac{\tau_{ind}}{K\phi} R_A \quad \text{where} \quad \tau_{ind} = I_A K\phi$$

$$\Rightarrow \omega = \frac{V_T}{K\phi} - \frac{R_A}{(K\phi)^2}\tau_{ind}$$

Scanned with CamScanner

فوتوز ← الأوب مع إنتاج
جينيرتيف ←

ودليل هذا الوب مع
انتقاء النبات

العامل يكون داخل بار AP

المولد يكون خارج بار AP

Scanned with CamScanner

DC Machines – Motors

It is important to realize that, in order for the speed of the motor to vary linearly with torque, the other terms in this expression must be constant as the load changes.

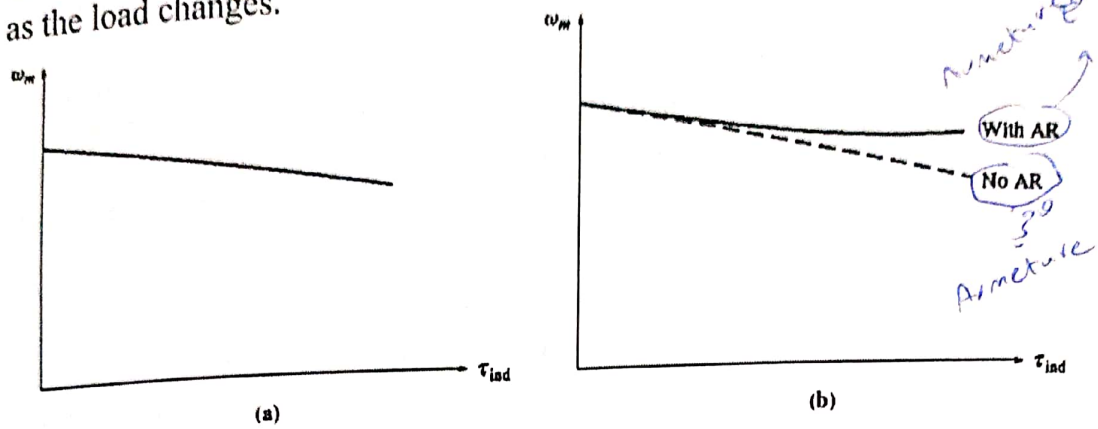


FIGURE 9–6
(a) Torque–speed characteristic of a shunt or separately excited dc motor with compensating windings to eliminate armature reaction. (b) Torque–speed characteristic of the motor with armature reaction present.

DC Machines – Motors

Example 9.1 A 50-hp, 250-V, 1200 r/min dc shunt motor with compensating windings has an armature resistance (including the brushes, compensating windings, and interpoles) of 0.06 Ω. Its field circuit has a total resistance $R_{adj}+R_F$ of 50 Ω, which produces a no-load speed of 1200 r/min. There are 1200 turns per pole on the shunt field winding (see Figure 9-7).

(a) Find the speed of this motor when its input current is 100 A.

(b) Find the speed of this motor when its input current is 200 A.

(c) Find the speed of this motor when its input current is 300 A.

(d) Plot the to torque-speed characteristic of this motor.

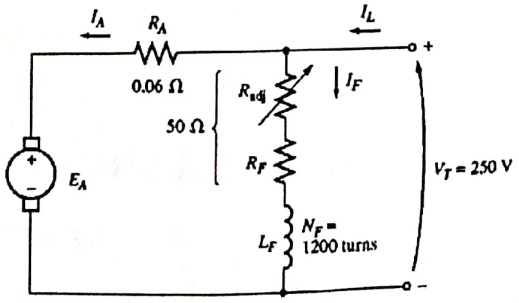


FIGURE 9–7
The shunt motor in Example 9–1.

Scanned with CamScanner

DC Machines – Motors

(b) At 200 A of load in Example 9–1, the motor's speed was $n = 1144$ r/min. In this example, the motor's speed is 1227 r/min. *Notice that the speed of the motor with armature reaction is higher than the speed of the motor with no armature reaction.* This relative increase in speed is due to the flux weakening in the machine with armature reaction.

(c)

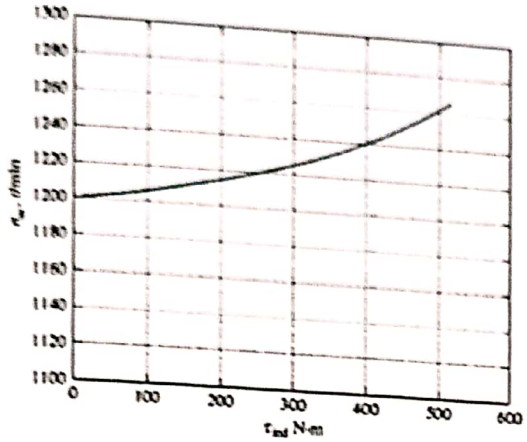


FIGURE 9–10
The torque–speed characteristic of the motor with armature reaction in Example 9–2.

DC Machines – Motors

There are two common ways in which the speed of a separately excited and shunt DC motors can be controlled:

1. Adjusting the field resistance R_F (and thus the field flux)
2. Adjusting the terminal voltage applied to the armature.
3. Inserting a resistor in series with the armature circuit (the less common method of speed control).

Scanned with CamScanner

DC Machines – Motors

Changing the Field Resistor Control Method

1. Increasing R_F causes I_F ($= V_F/R_F \uparrow$) to decrease.
2. Decreasing I_F decreases ϕ.
3. Decreasing ϕ lowers E_A ($= K\phi\downarrow\omega$).
4. Decreasing E_A increases I_A ($= (V_T - E_A\downarrow)/R_A$)
5. Increasing I_A increases τ_{ind} ($= K\phi\downarrow I_A\Uparrow$), with the change in I_A dominant over the change in flux.
6. Increasing τ_{ind} makes $\tau_{ind} > \tau_{load}$, and the speed ω increases.
7. Increasing ω increases E_A ($= K\phi\omega\uparrow$) again.
8. Increasing E_A decreases I_A
9. Decreasing I_A decreases τ_{ind} until $\tau_{ind} = \tau_{load}$ at a higher speed ω

DC Machines – Motors

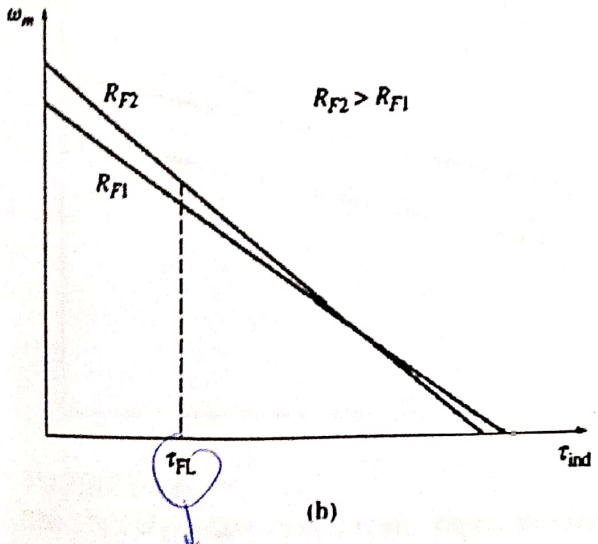


FIGURE 9–12
The effect of field resistance speed control on a shunt motor's torque–speed characteristic:
(b) over the entire range from no-load to stall conditions.

Scanned with CamScanner

زيادة قيمة R_F تقلل من قيمة التيار I_F

المقاومة الكلية $R_F + R_{adj}$

$$I_F = \frac{V_F}{R_{FF}}$$

لذا نقصد الـ R_F كمثال في الحمل

بالتالي ان R_{in} في البنزل و يقل $\rightarrow$ في تزيد ان I_A بالتالي

المقدار $\frac{V}{I}$ يكون معتمد على انتقال مار ϕ

بالتالي ان R_{in} في يزيد بالتالي $R_{in} < R_{load}$ يكون

بالتالي السرعة في تزيد في يشد ان I_A يزيد و يقل

I_A و نقل ان R_{in} لحتى نقل اي حدة الاستقرار

عند أعلى سرعة $R_{in} = R_{load}$

Scanned with CamScanner