METU EE462 Utilization of Electric Energy

Emine Bostancı

Office: C-107

Content

Drive categories

Magnetic poles of an electric machine

DC machine drives

- Structure of DC machines
- Equivalent circuit diagram and basic dynamic equations

Classification of Electric Drives

According to the types of machines used:

DC machine drives

Universal machine drives

AC machine drives

- Induction machine drives
- Synchronous machine drives

Reluctance machine drives

Synchronous reluctance machine drives

Switched reluctance machine drives

According to the supply:

Single-phase drives

Three-phase drives

According to their operating quadrants:

Single quadrant drives

Four quadrant drives

According to their power:

Fractional hp drives

Integral hp drives

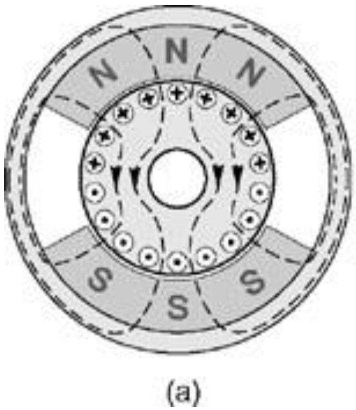
According to their speed-torque curve:

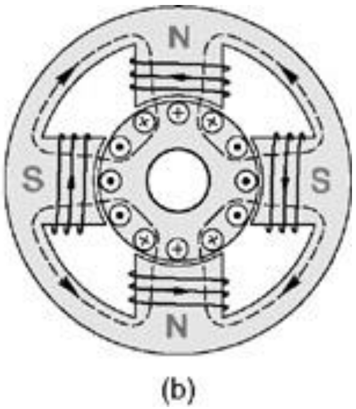
Adjustable speed (frequency) drives

Constant frequency drives

Constant power drives

Magnetic Poles in an Electric Machine

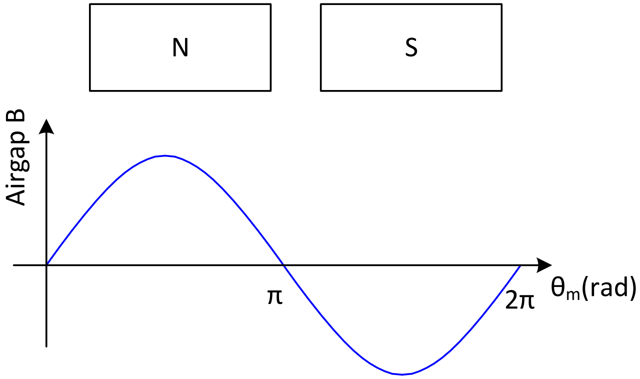




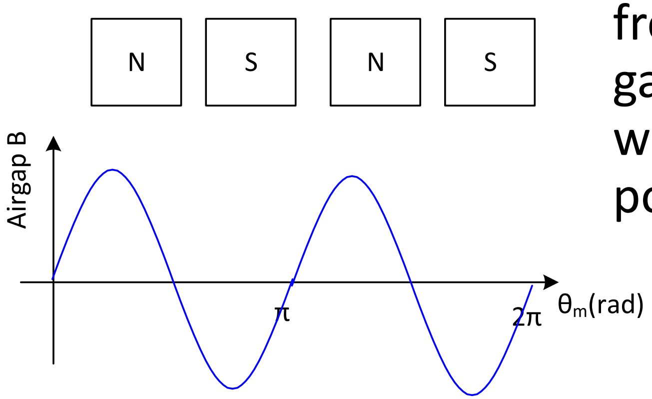
An electric machine has at least 2-poles (1 pole pair) and depending on speed characteristics and specifications of magnetic circuit there can be more pole-pairs.

a) 2-pole (or 1-pole-pair), b) 4-pole (or 2-pole-pairs)

As the number of pole pairs increase, frequency of the air-gap flux increases with the number of pole-pairs.



2-pole (or 1-pole-pair)



4-pole (or 2-pole-pairs)

Magnetic Poles in an Electric Machine

$$\omega_e = \frac{p}{2}\omega_m$$

Pole number

Mechanical speed

Electrical frequency

What can be the reason for increasing number of poles?

- To couple a higher electrical frequency to a relatively slow rotating mechanical system.
- Decrease the stator back iron (stator yoke) thickness by diving total stator flux.

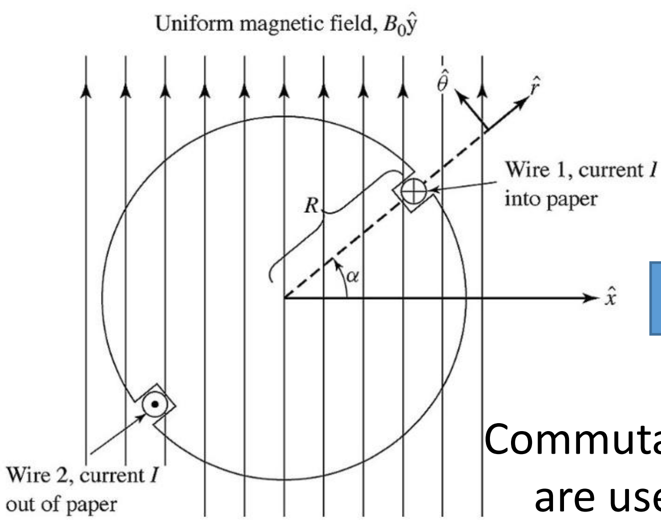
What are the limiting factors of the pole number?

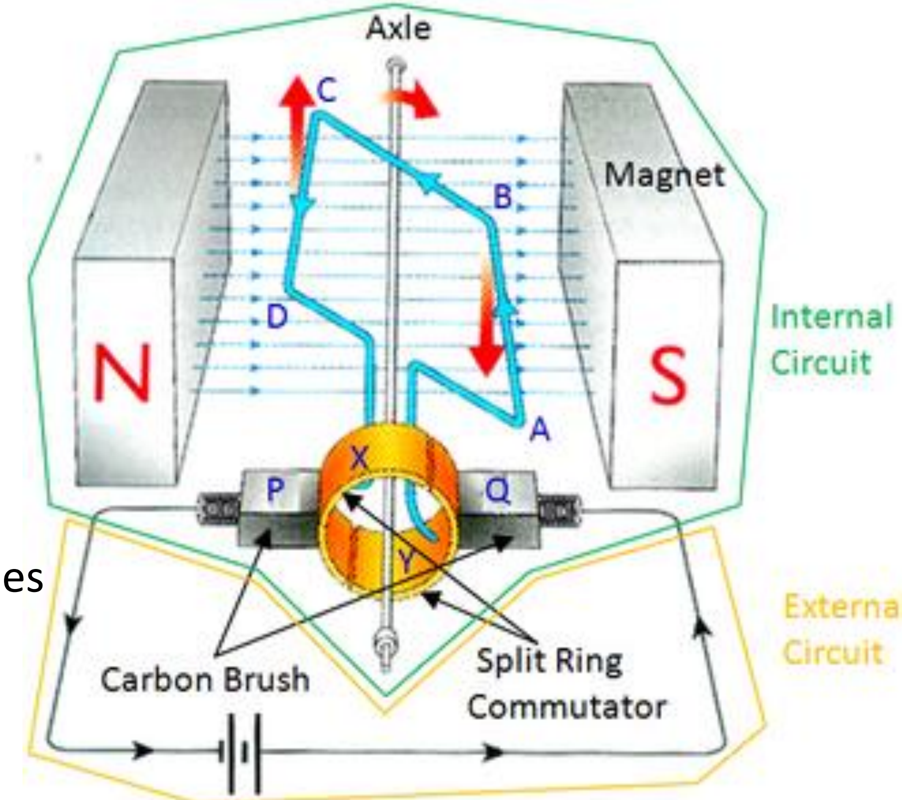
- Losses will increase with the electrical frequency of the electric machine.
- Our controllers have a maximum switching frequency and processing time. For example, at high speeds, stator frequency can be quite high and our processing times should be much higher than that frequency to be able to regulate the system.

Structure of DC Machines

Uniform magnetic field can be created by

- Permanent magnets: PM excited DC machine
- Coils placed in stator: Electrically excited DC machine

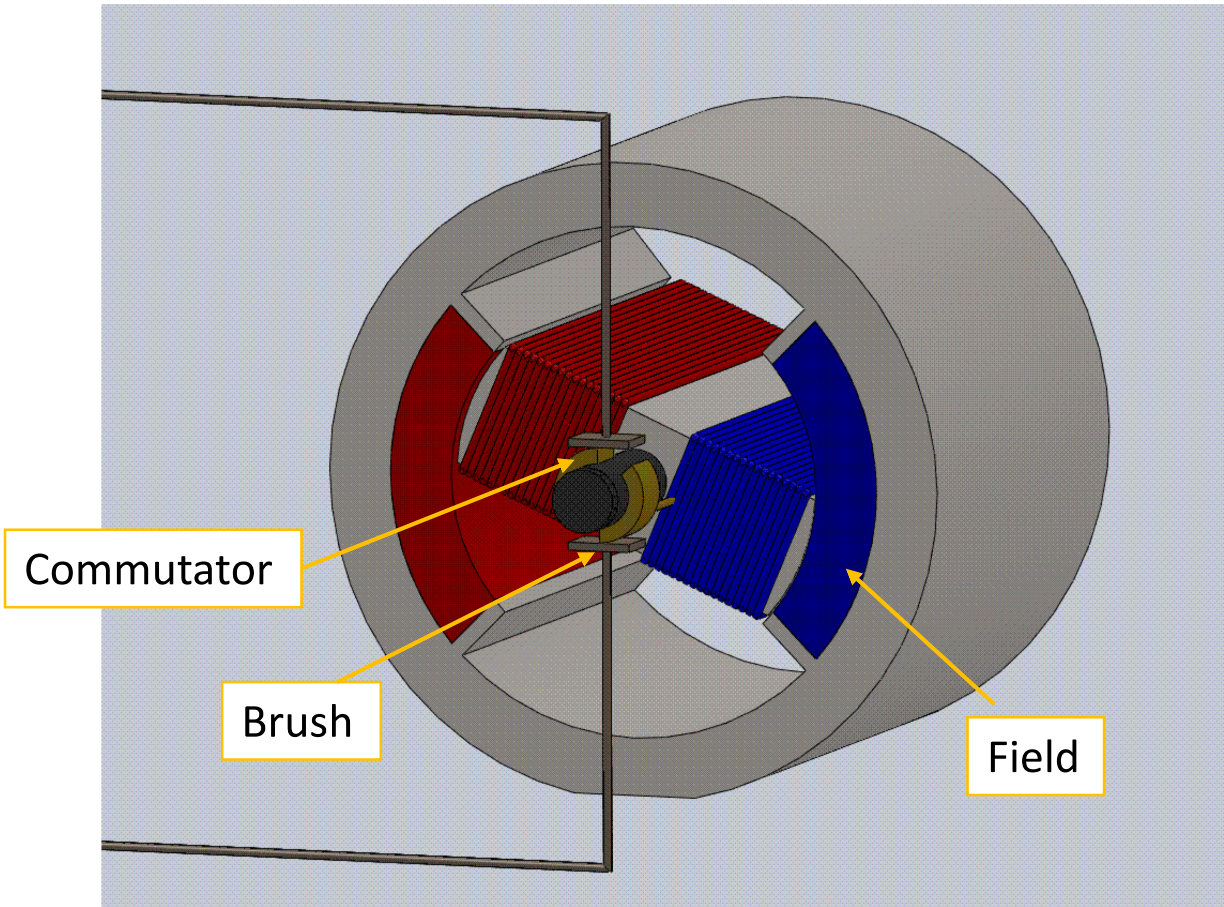




Commutator + Brushes are used to adjust current direction mechanically!

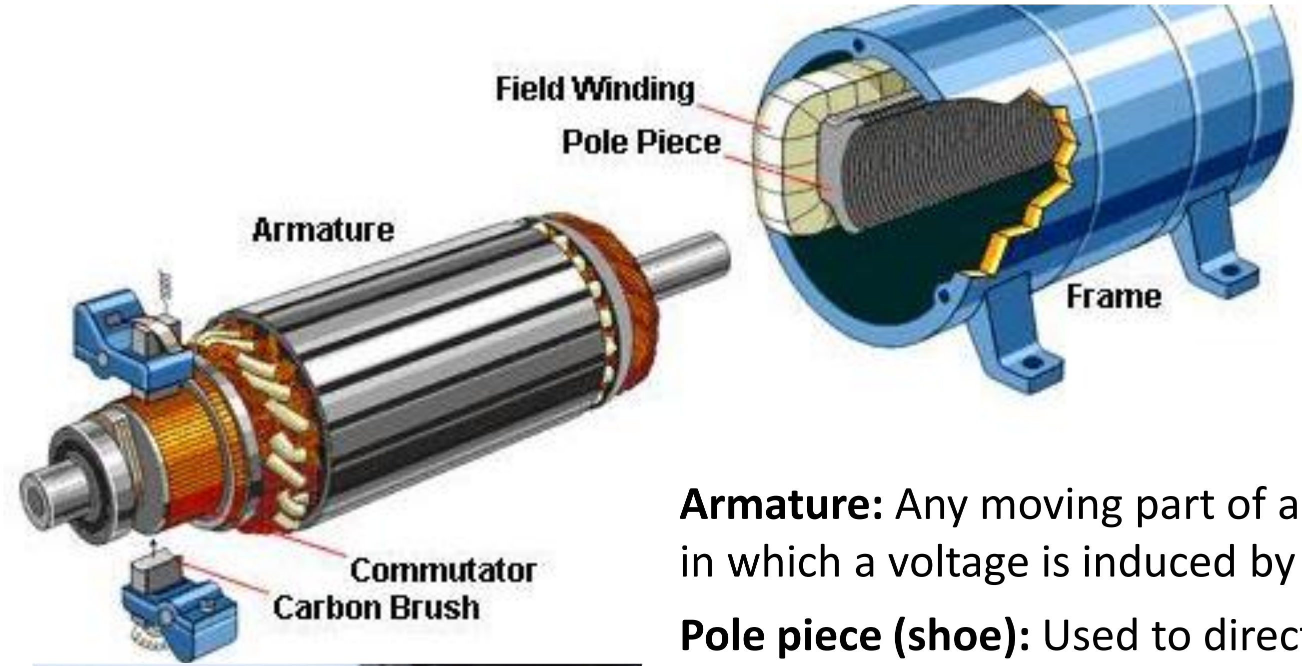
[How a DC motor work?]

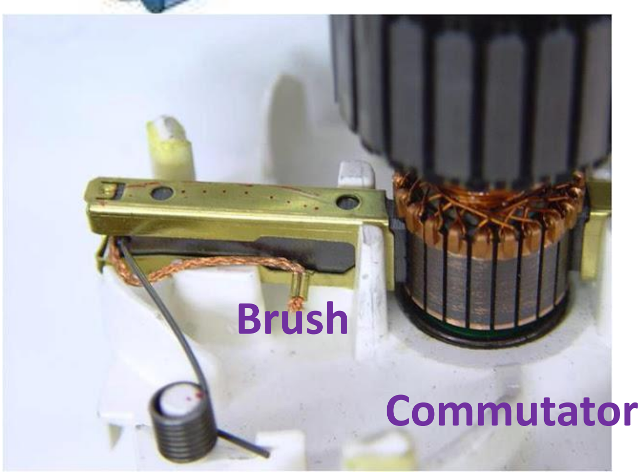
Structure of DC Machines



Need for brushes reduces system efficiency, reliability and cause safety related problems due to arcs.

Structure of DC Machines





Armature: Any moving part of an electrical machine in which a voltage is induced by a magnetic field.

Pole piece (shoe): Used to direct magnetic field.

Commutator: A commutator is a rotary **electrical** switch in certain types of **electric** motors and **electrical** generators that periodically reverses the **current** direction between the rotor and the external **circuit**. It consists of a cylinder composed of multiple metal contact segments on the rotating armature of the machine.

Elementary DC Generator

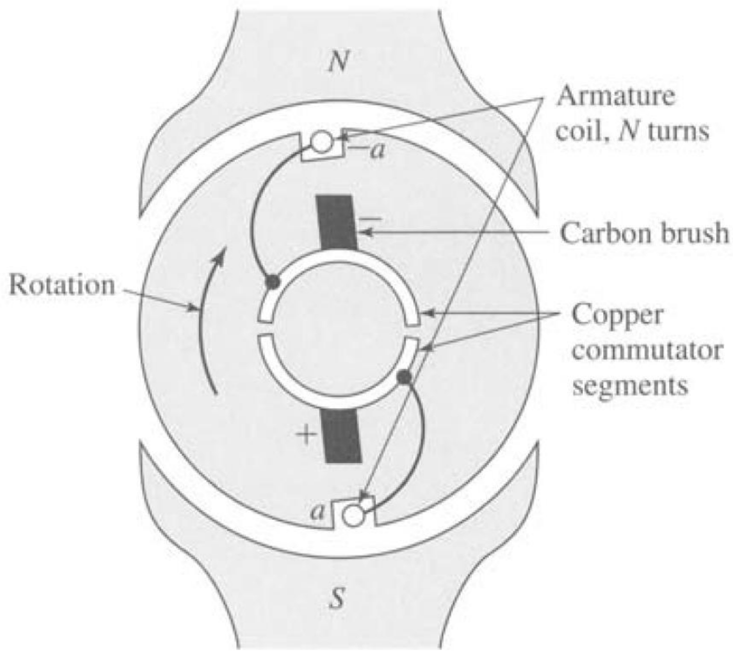


Figure 4.17 Elementary dc machine with commutator.

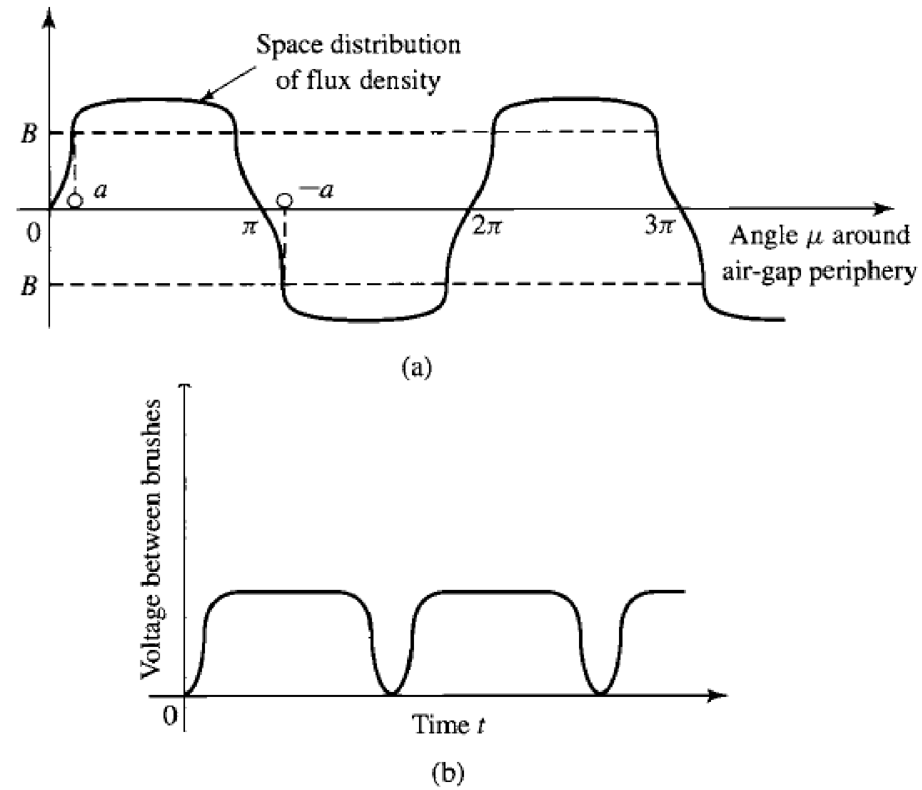


Figure 4.18 (a) Space distribution of air-gap flux density in an elementary dc machine; (b) waveform of voltage between brushes.

If armature is rotated by an external force, there will be induced voltage between brushes.

$$\textit{Induced voltage between brushes} = N\frac{d \iint B(\theta) r d\theta dl}{dt}$$

Elementary DC Machine

The effect of direct current in the field winding of a dc machine is to create a magnetic flux distribution which is stationary with respect to the stator. Similarly, the effect of the commutator is such that when direct current flows through the brushes, the armature creates a magnetic flux distribution which is also fixed in space and whose axis, determined by the design of the machine and the position of the brushes, is typically perpendicular to the axis of the field flux.

Thus, just as in the ac machines discussed previously, it is the interaction of these two flux distributions that creates the torque of the dc machine. If the machine is acting as a generator, this torque opposes rotation. If it is acting as a motor, the electromechanical torque acts in the direction of the rotation. Remarks similar to those already made concerning the roles played by the generated voltage and electromechanical torque in the energy conversion process in synchronous machines apply equally well to dc machines.

Induced Voltage in Rotating Coil

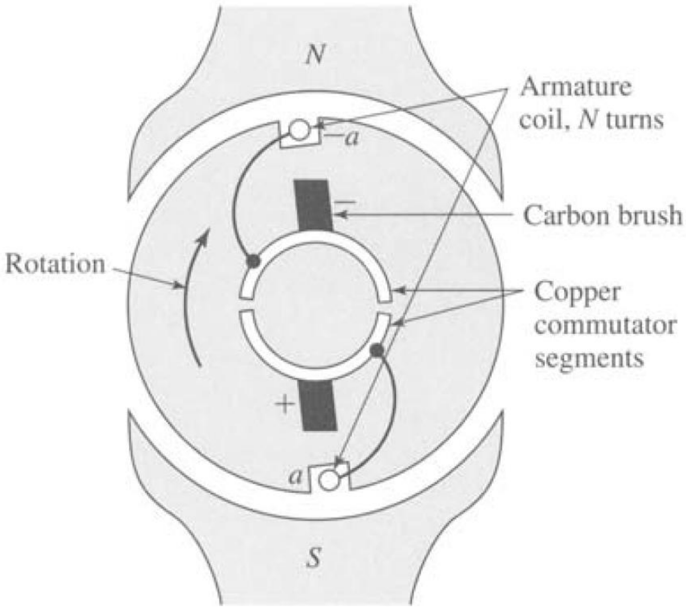


Figure 4.17 Elementary dc machine with commutator.

$\emptyset_{pp} = 2\hat{B}rl$ ($\emptyset_{pp}$: Flux per pole, r: armature radius & l: axial machine length)

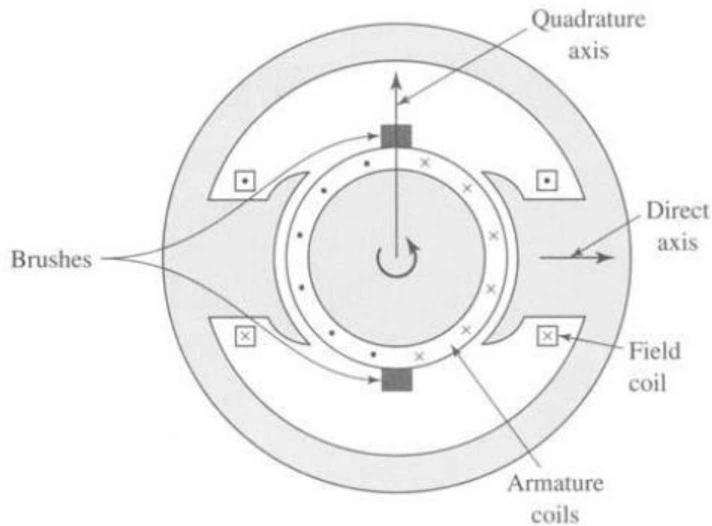
When the coil is rotating with ω_m (mechanical speed or armature speed or rotor speed)

$\emptyset_{pp}$(t)=$\emptyset_{pp}$cos(ω_mt)

$E_a = -N\frac{d\emptyset}{dt} = N\omega_m\emptyset_{pp}sin(\omega_m$t) (rectified due to commutation)

$E_{a_{\text{avg}}} = \frac{2}{\pi}N\omega_m\emptyset_{pp}$ ➔ $K_a\omega_m\emptyset_{pp}$($K_a$: machine constant)

DC Machine with Multiple Armature Coils



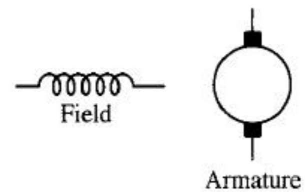


Figure 7.1 Schematic representations of a dc machine.

Take the fundamental component of B distribution in the air-gap.

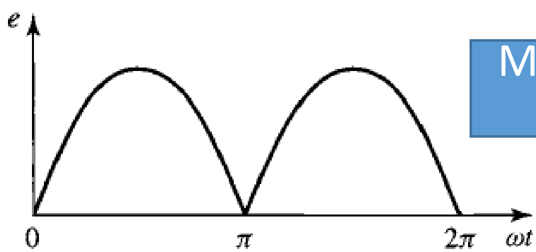


Figure 4.33 Voltage between the brushes in the elementary dc machine of Fig. 4.17.

Multiple coils

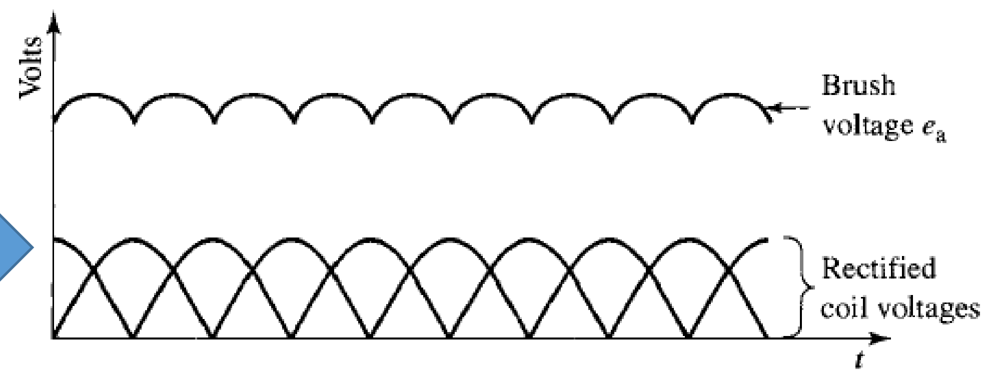


Figure 7.2 Rectified coil voltages and resultant voltage between brushes in a dc machine.

A DC voltage is generated as result of rotation!

Induced Voltage in Rotating Coil

For a DC machine having p number of poles.

$\emptyset_{pp} = \frac{4}{p}\hat{B}rl$ ($\emptyset_{pp}$: $\text{Air} - \text{gap flux per pole}$, r: armature radius & l: axial machine length)

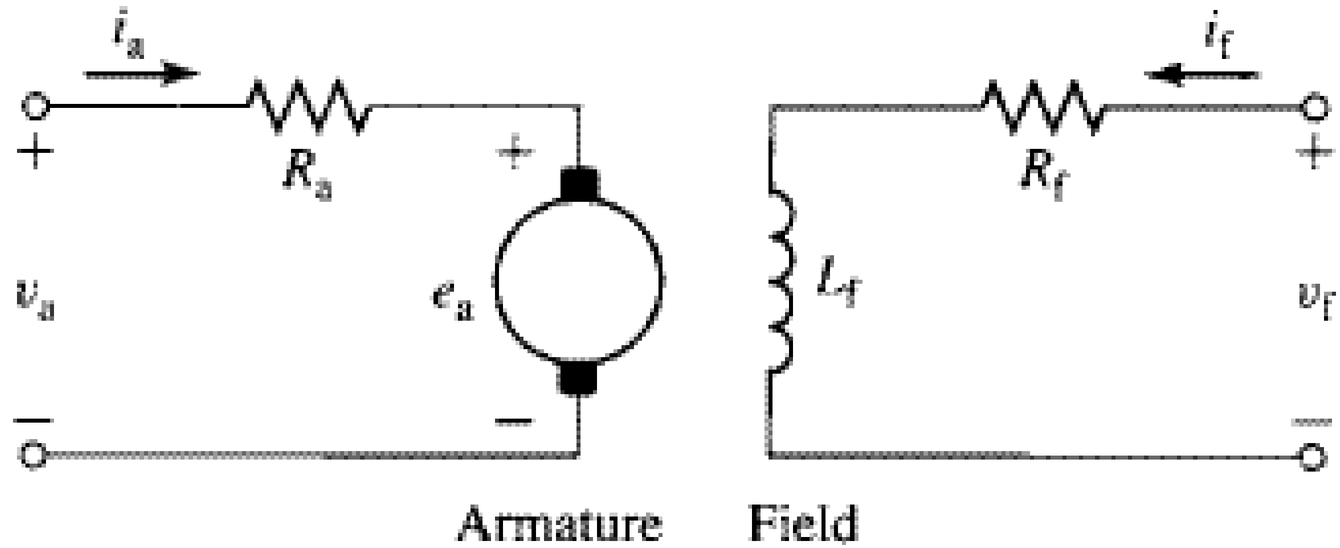
When the coil is rotating with ω_m (mechanical speed or armature speed or rotor speed)

$\emptyset_{pp}$(t)=$\emptyset_{pp}$cos($\frac{p}{2}\omega_m$t)

$E_a = -N\frac{d\emptyset}{dt} = N\omega_m\emptyset_{pp}\frac{p}{2}\ sin(\frac{p}{2}\omega_m$t) (rectified due to commutation)

$E_{a_{\text{avg}}} = \frac{2}{\pi}\frac{p}{2}N\omega_m\emptyset_{pp} = \frac{p}{\pi}N\omega_m\widehat{\Phi}$ ➔ $K_a\omega_m\emptyset_{pp}$($K_a$: machine constant)

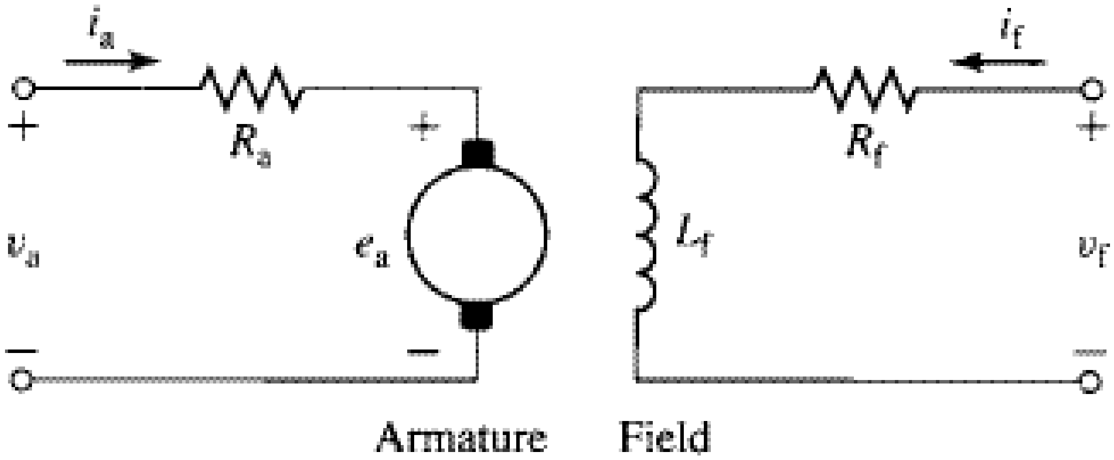
Simplest Equivalent Circuit of a DC Machine



If $V_a > E_a$ motoring action
If $V_a < E_a$ generator action

Motor Action: Electrical Energy is converted to Mechanical Energy
Generator Action: Mechanical Energy is converted to Electrical Energy

Electromechanical Power



Electromechanical Power = Armature Power - Armature Losses

$$P_e = V_a I_a - I_a R_a = \underbrace{E_a I_a}_{\textbf{Electromechanical Power}}$$

- Either converted from electrical energy to mechanical energy (motoring mode)
- or converted from mechanical energy to electrical energy (generating mode)

Electromechanical Power

$$P_e = V_a I_a - \underbrace{I_a R_a}_{\text{Electromechanical Power}} = E_a I_a$$

$$P_e = T_e \omega_m = E_a I_a$$
$$T_e \omega_m = K_a \omega_m \emptyset_{pp} I_a \quad \Rightarrow \quad T_e = K_a \emptyset_{pp} I_a$$

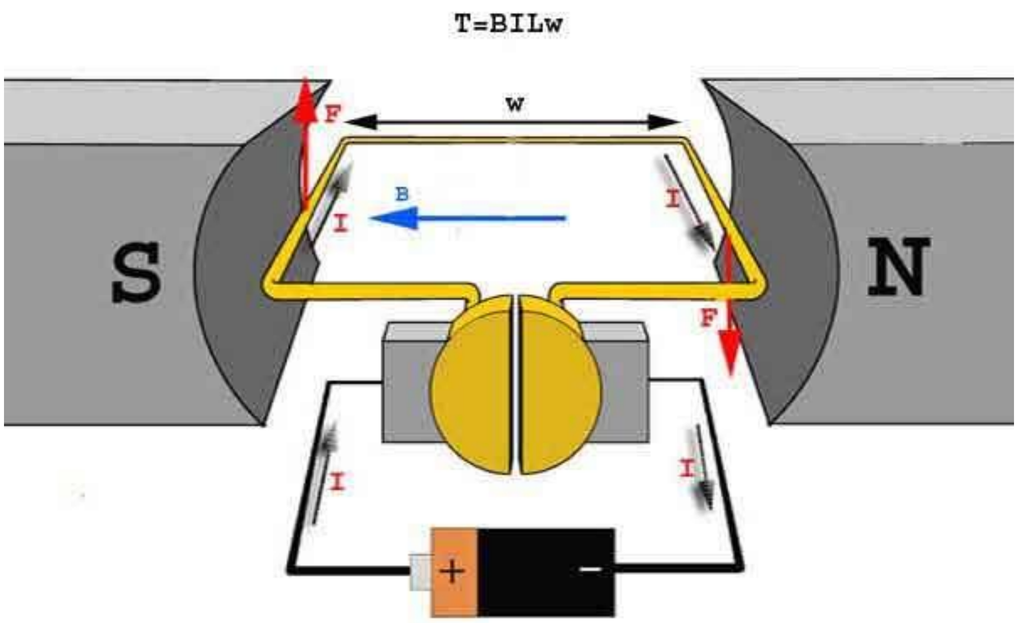
$\boldsymbol{E_a \text{ and } T_e \text{ both depend on } K_a: \text{machine constant}}.$

$E_a = K_a \omega_m \emptyset_{pp} I_a \Rightarrow$ **Induced armature voltage (Induced EMF)**

$T_e = K_a \emptyset_{pp} I_a \Rightarrow$ **Electromagnetic torque**

Next question: How is the air-gap flux generated?

DC Motor



Ways to increase torque in a DC Motor?

- Increase Field Density (More Magnet, or less reluctance)
- More Current (Limited by cooling)
- Increase the length (force increases)
- Increase the radius (torque increases)

Magnetization Characteristics

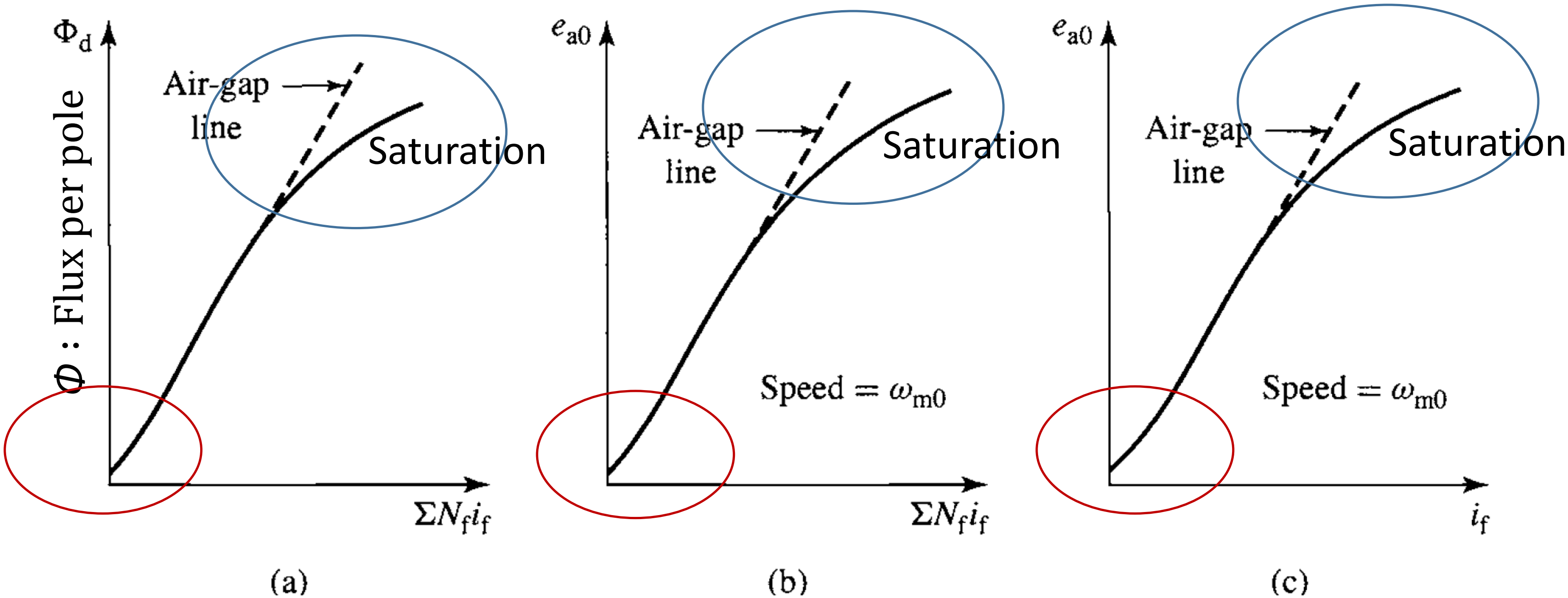


Figure 7.3 Typical form of magnetization curves of a dc machine.

- Field current $N_f I_f$ generates flux in the air-gap (Ampere's Law) and as a result of this air-gap flux and mechanical rotation there will be induced armature voltage E_a.
- If there is no magnetic saturation, these characteristics are linear. However, at high field current values there will be saturation. Air-gap line shows the characteristics with no saturation.
- Flux and E_a do not start from 0 due to residual magnetization of the core.

Connection Types

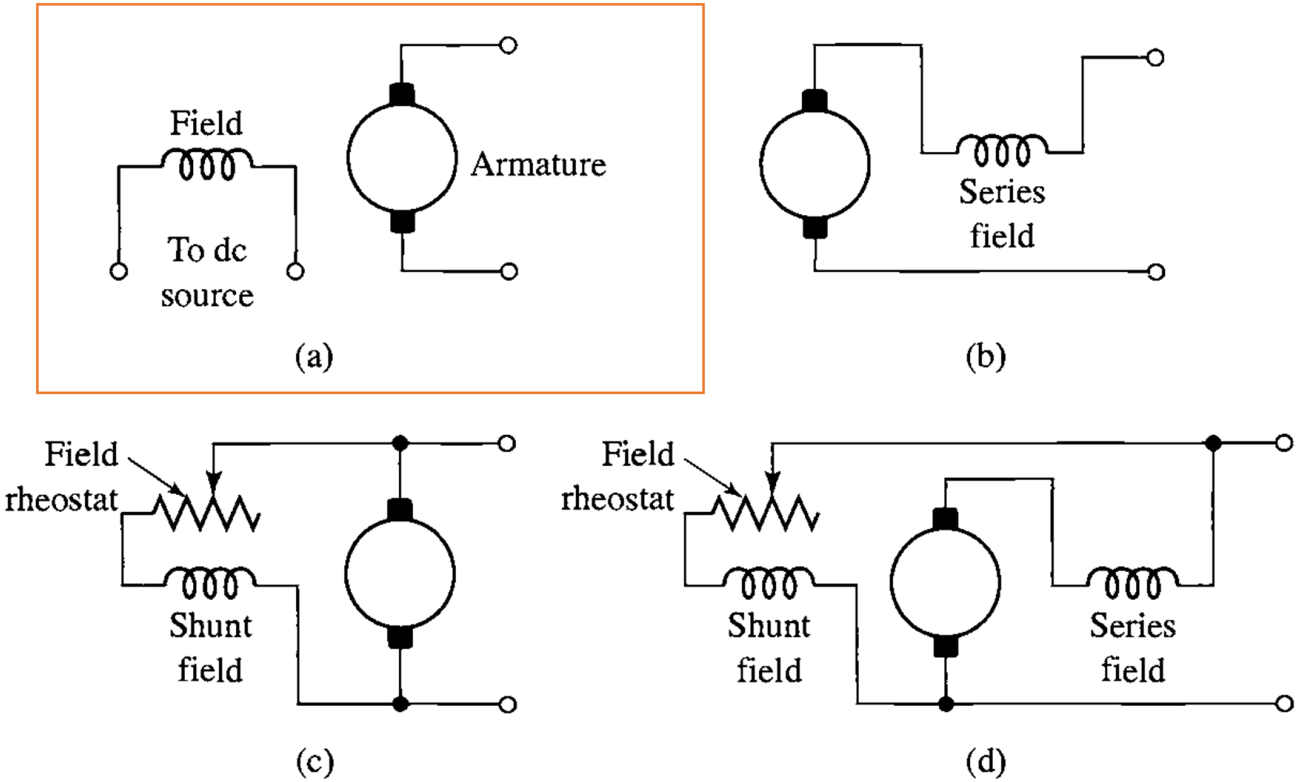


Figure 7.4 Field-circuit connections of dc machines: (a) separate excitation, (b) series, (c) shunt, (d) compound.

We are going to look at the drive configurations of seperately excited DC machines.

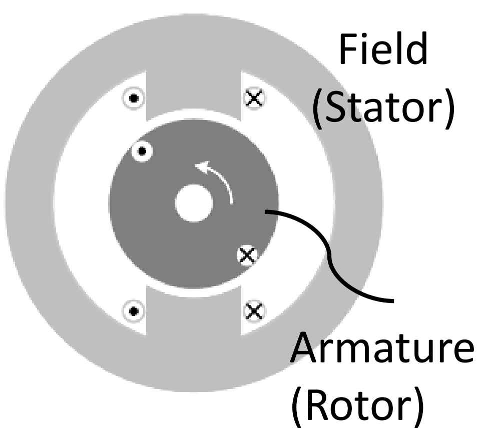
Discussion

Torque Generated by a DC Machine

What we have found using energy method:

$$T_{\mathrm{fld}} = \left.\frac{\partial W'_{\mathrm{fld}}(i_1, i_2, \theta)}{\partial \theta}\right|_{i_1, i_2}$$

$$= \underbrace{\frac{i_1^2}{2}\frac{dL_{11}(\theta)}{d\theta} + \frac{i_2^2}{2}\frac{dL_{22}(\theta)}{d\theta}}_{\text{Reluctance Torque}} + \underbrace{i_1 i_2 \frac{dL_{12}(\theta)}{d\theta}}_{\text{Mutual-interaction Torque}}$$



What we have found in DC machine analysis:

$$T_e = K_a \emptyset_{pp} I_a$$

Question: How are those related?

What do you remember from EE361?

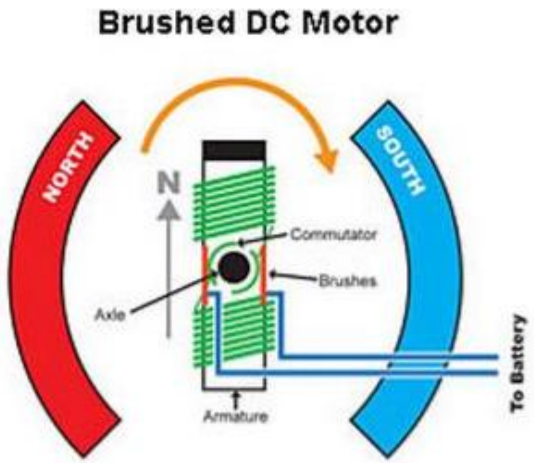
Draw the magnetic configuration of a 2-pole separately excited DC machine.

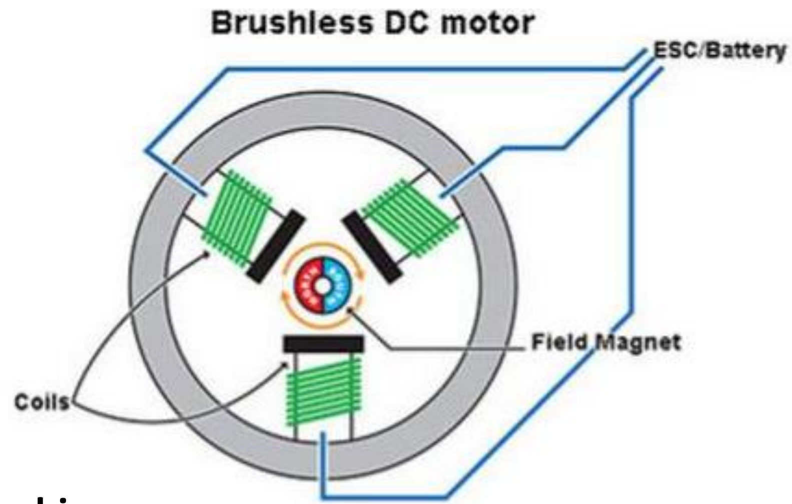
What is armature reaction and how can we compensate it?

Draw the equivalent circuit of the DC machine, specify induced voltage as a function of rotational speed and torque as a function of armature current.

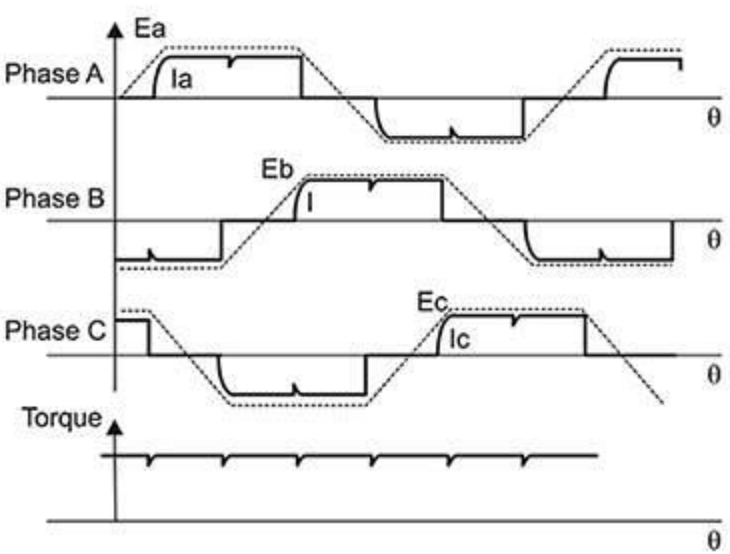
What is a universal machine?

Brushed vs. Brushless DC Machine





Phase voltages and currents of a BLDC machine:



Brushless DC (BLDC) machine is called DC due to its similarity to Brushed DC Machine.

BLDC is a inside out Brushed DC machine with field winding replaced with PMs.

Since rotor has only PMs, no rotary connection is required → No brushes!

Induced EMFs in stator phases of a BLDC machine attain both positive and negative values (there is no mechanical rectification).

- ➢ So, we should supply both positive and negative currents. There is a need for power electronic circuit.