Introduction to Electrical Engineering

Course Code: EE 103

Department: Electrical Engineering

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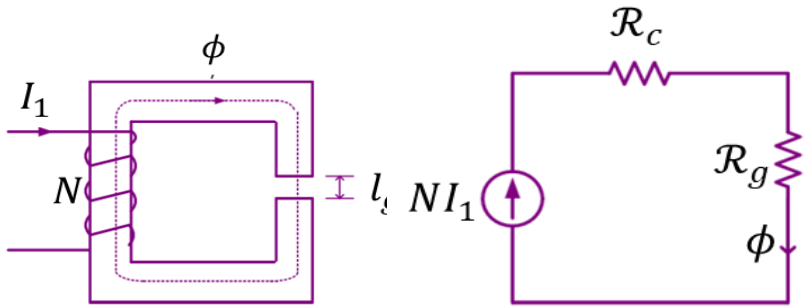
Review:

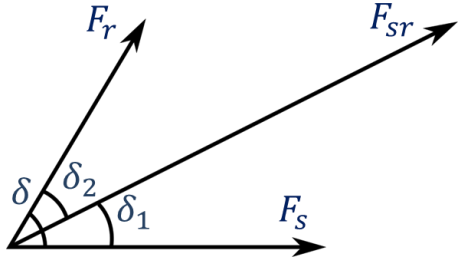
$$\omega_{elec} = \frac{P}{2} \cdot 2\pi \cdot \omega_{mech} (\text{rotations per second})$$

- If a conductor is rotated in a magnetic field, voltage induced in it is 'AC' (average value = 0)
- Flux in the coil is determined by the supply voltage alone, provided that the frequency is constant
- As the core permeability is very high, $\mu \to \infty \Rightarrow R_c \to 0$
- Thus, the entire MMF (NI_1) is applied across the $\mathcal{R}_g$, that is, the air gap



- Total flux produced by the coil =flux in the core + leakage flux
- Torque is produced by the tendency of two magnetic fields to align

$$T \propto F_s F_r \sin\left(\angle_{F_s}^{F_r}\right)$$
$$T \propto F_s F_r \sin(\delta)$$

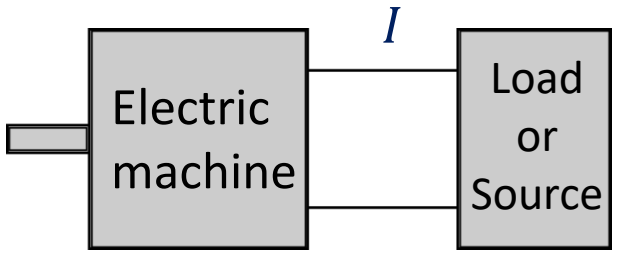


- For steady torque, F_s & F_r should be stationary with respect to each other

Classification of Machines

DC machine → stator → DC

DC machine → rotor → 'I' flowing in the load OR from an external source is DC



AC machine

synchronous machine

stator → AC/DC

rotor → DC/AC

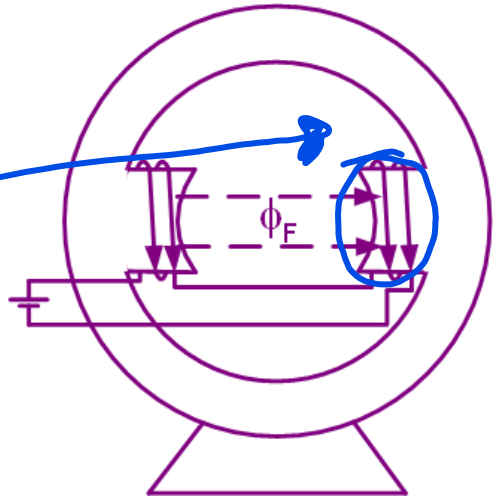
asynchronous machine

stator → AC

rotor → AC

DC Machine

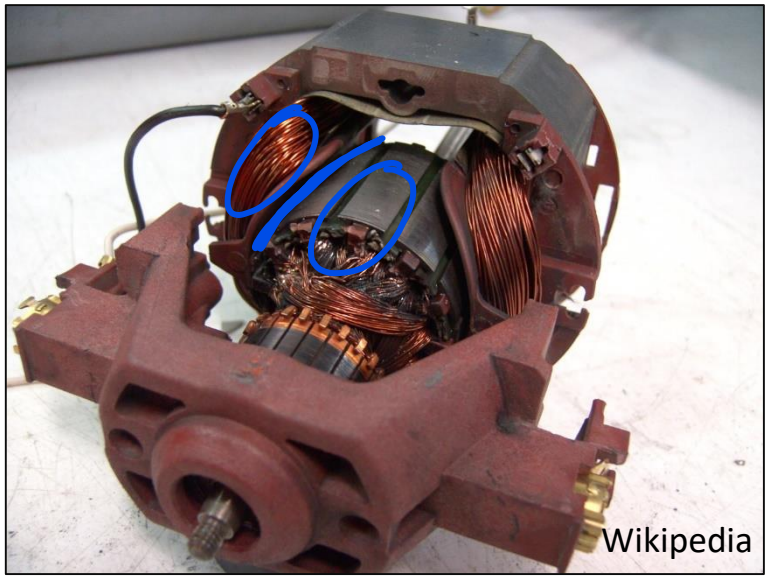
Stator:



- Field coils are mounted on the projected part & connected to a dc source
- Coil is stationary and 'I' is dc (can be replaced by PM)
- Time invariant field → angular speed of $F_s = 0$

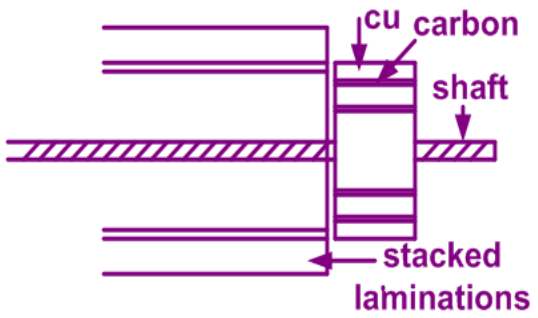
- In the airgap, either the conductor is rotated or external 'I' should be supplied

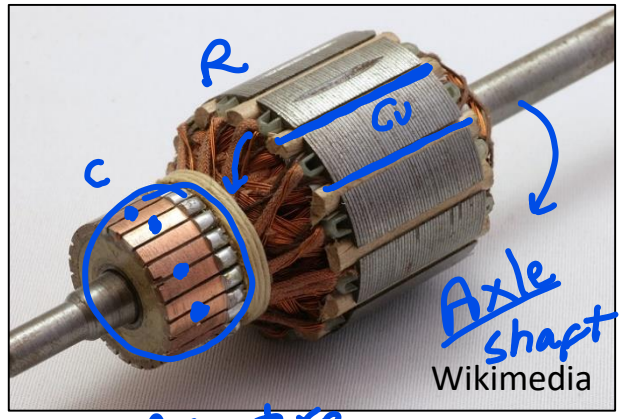
?



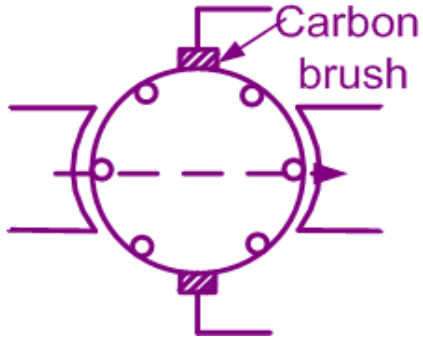
Rotor:

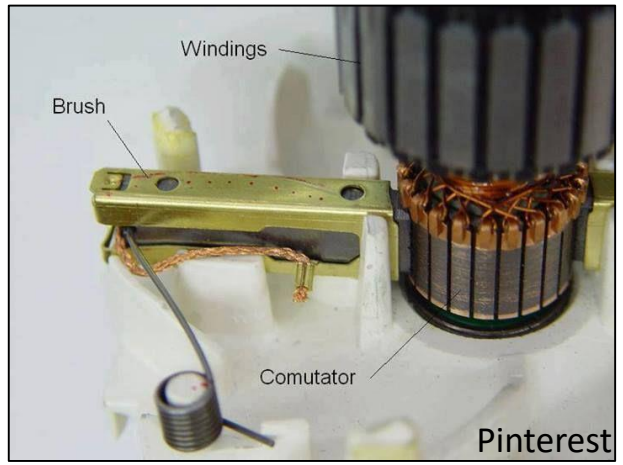
- Rotor has slots at the outer periphery
- In addition, there is a commutator → it has large number of copper segments & these segments are insulated by mica
- Coils having desired number of turns are placed in these slots and two ends of the coil are connected to the copper strips
- Two carbon brushes are placed as shown on the copper commutator
- These carbon brushes are mounted on the commutator but fixed to the stator



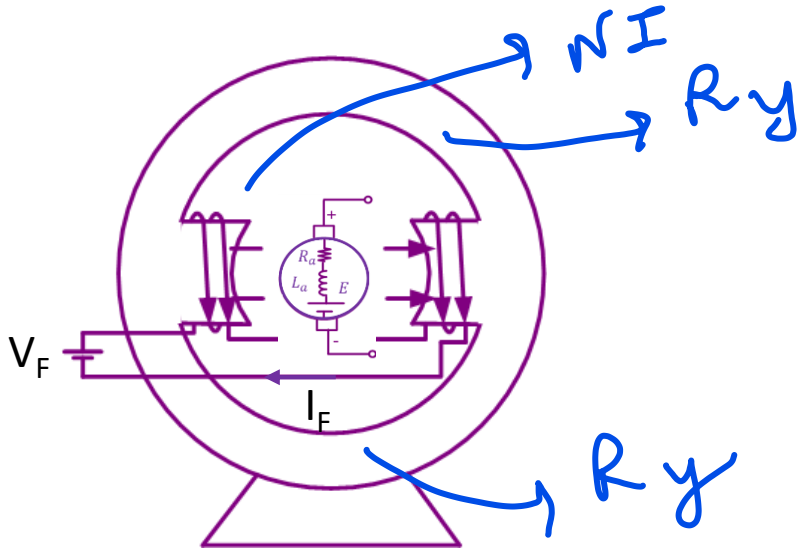


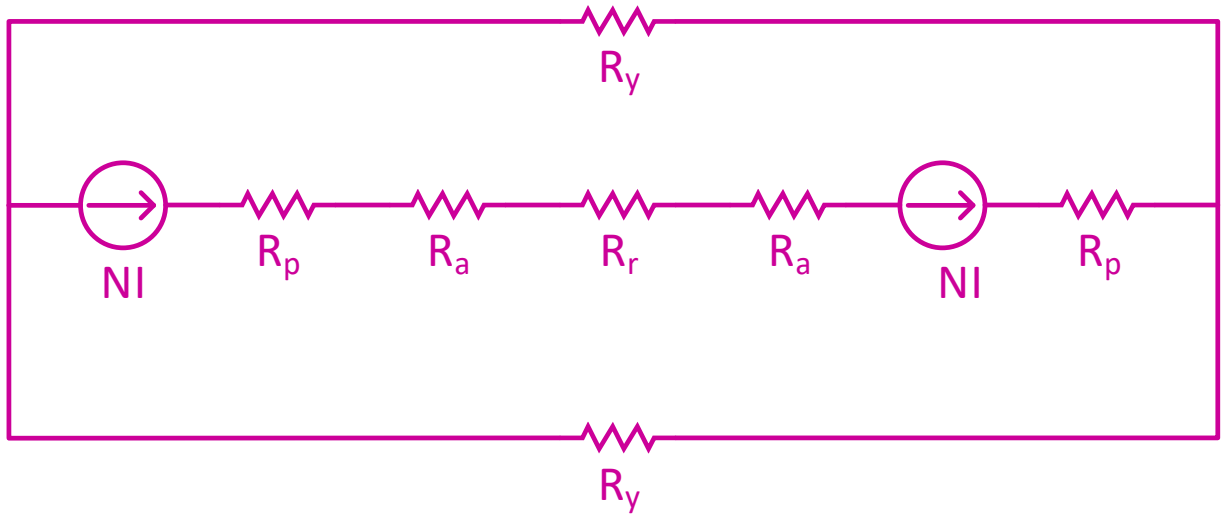
Armature





Magnetic Equivalent circuit of DC Machine



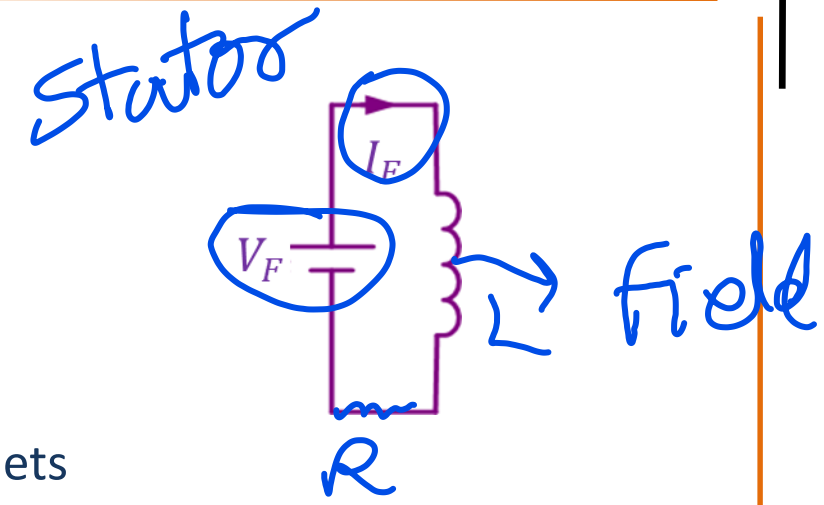


$$\Phi_F \cong \frac{NI_F}{R_a}$$

$$2R_p + R_r \ll R_a$$

$$\& \quad R_y \ll R_a$$

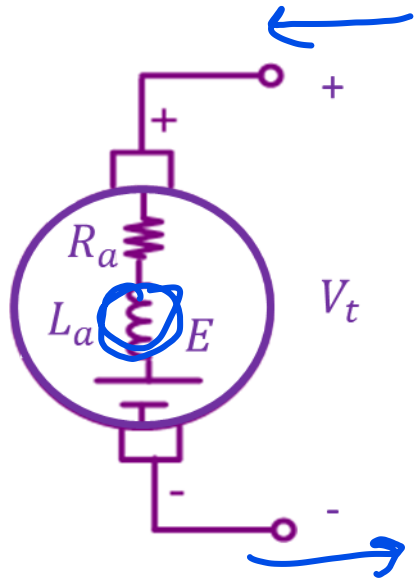
Equivalent circuit of a DC machine



- dc current (I_F) is flowing in the field coil
- $R_F \rightarrow$ field winding resistance
- $L_F \rightarrow$ field winding inductance
- At steady state $V_F = R_F I_F$
- To improve the efficiency, field coil can be replaced by Permanent magnets → PMDC machine

Armature is rotating.

- Armature is rotating in the magnetic field, voltage induced is $E \propto \phi\omega$, where ϕ flux setup by field, and ω is angular speed
- E can be represented by $E = K\phi\omega$

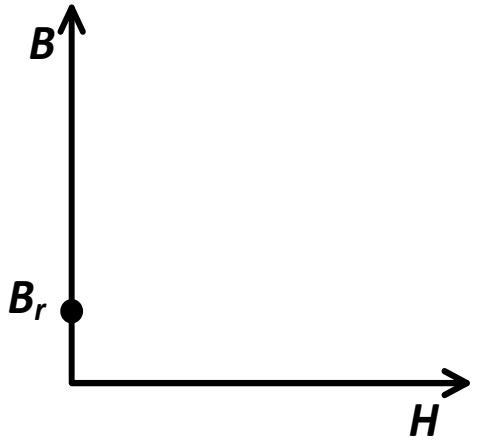


- In motoring mode, terminal voltage, V_t is given as: $V_t = E + I_a R_a$
- In this mode, I_a enters the armature from '+' terminal of supply, and 'E' opposes it. Hence, 'E' is also known as 'back-emf'

- In generating mode: $V_t = E - I_a R_a$
- In this mode, I_a leaves the armature from '+' terminal of V_t. Here, 'E' is known as 'induced emf'

Self Excitation in DC Generator

- Electromagnet retain same magnetism when the supply is switched off



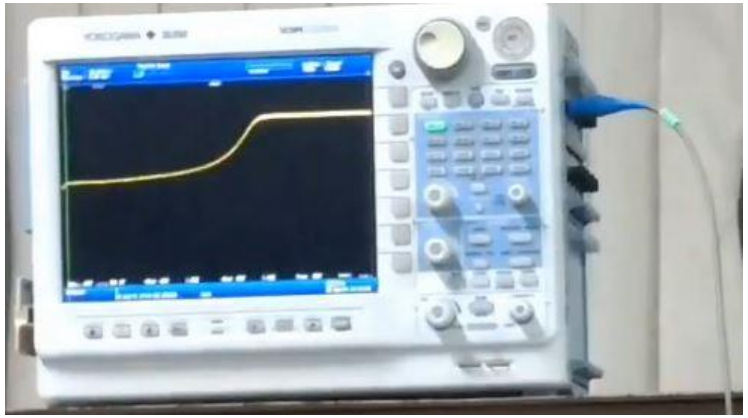
→ Residual Magnetism (B_r)

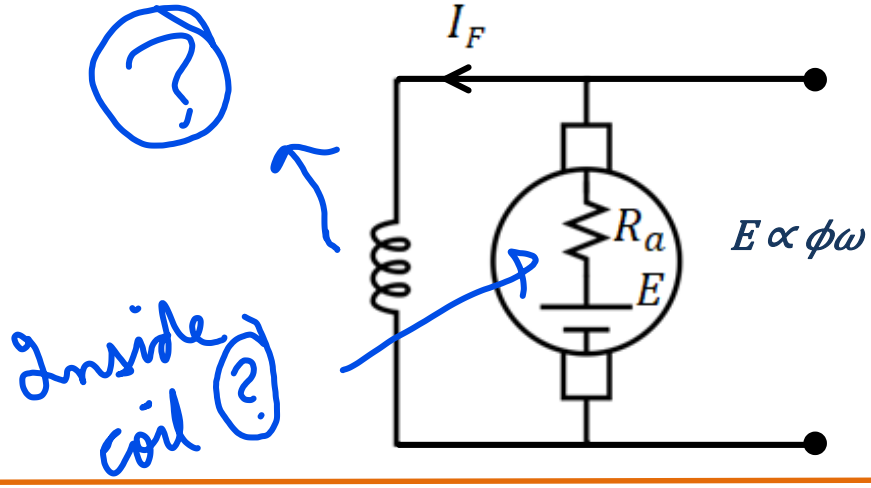
→Rotate the armature in the field created by B_r

→ A small voltage $(E \propto \phi\omega)$ is induced in the armature

→If the circuit is complete small I_F will flow

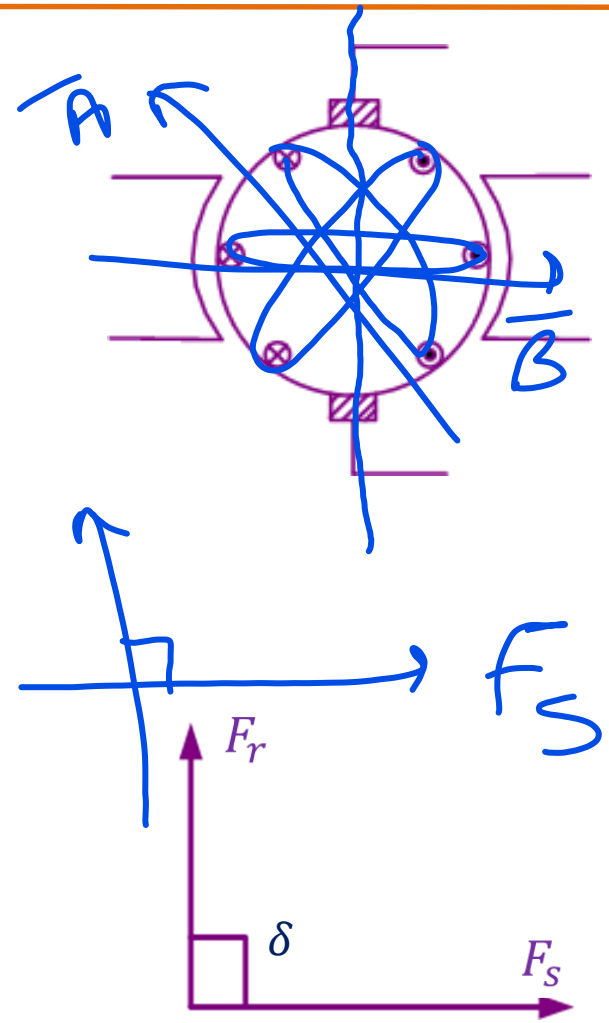
→ If ϕ produced by I_F aids the residual flux, net flux in the air-gap increases & hence E↑





Torque in DC machines

- Carbon brushes are stationary
- Direction of 'I' reverses when the coil crosses the brushes
- Conductors under one pole carry 'I' in one direction
- Armature MMF axis is fixed and it is along brush axis
- Angle between F_s and F_r is 90° and is fixed, this angle is independent of load



$$\delta = 90° \therefore T \propto F_s \cdot F_r$$

$F_r \propto I_a$ → armature current (∵ no. of turns in armature is constant)

Therefore, 'torque per ampere' is MAXIMUM in DC machines,

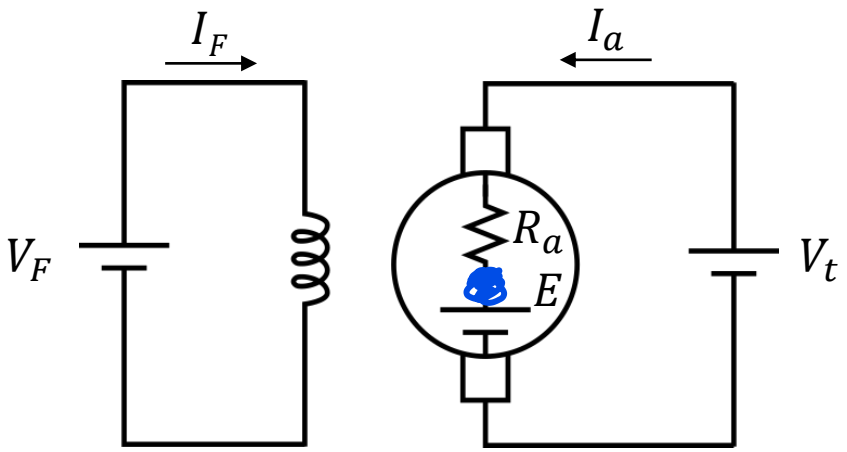
or, $\delta = 90°$ is the condition to get maximum 'torque per ampere'

Separately excited dc motor

- Field is connected to a separate dc source

Terminal voltage: $V_t = E + I_a R_a \;\therefore E = V_t - I_a R_a$

$EI_a = V_t I_a - I_a^2 R_a$



$V_t I_a$ → Armature power input

$I_a^2 R_a$ → Loss in armature winding, since the winding is made up of copper wire, this loss is also known as armature copper loss

Now, Input power – loss → Power developed in the armature

Armature is rotating → there will be small friction loss, ignore this loss

Power developed in the armature = Power available at the motor shaft = EI_a

$$T = \frac{\text{Power available at shaft}}{\omega} = \frac{EI_a}{\omega} = \frac{(K\phi\omega)I_a}{\omega} = K\phi I_a$$

Recall,

$$T \propto F_s F_r \sin(\delta)$$

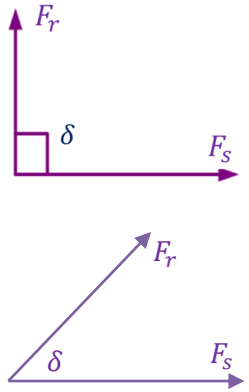
here, $F_s \rightarrow$ stator produces 'ϕ'

$F_r \propto I_a$ and $\delta = \frac{\pi}{2}$

$$\therefore T \propto \phi I_a$$

Advantages of DC machines:

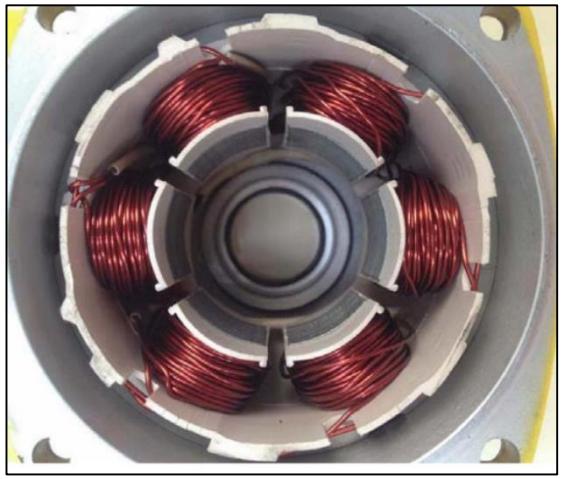
- The armature and field MMF can be controlled independently
- Torque control is simple
- 'Torque per ampere' is maximum



Limitations of DC machines:

- Commutator and brushes wear over time → require regular maintenance
- Short-circuiting commutator segments give rise to spark → can not be used in explosive environments

- In DC machine → Stator field is 'time-invariant'
  → Stator winding is concentrated and connected to a DC supply



Wikipedia

*Induction Motor Market Size, Share & Industry Analysis, https://www.fortunebusinessinsights.com/industry-reports/induction-motor-market-101639
$ Induction Motor Market - Growth, Trends, and Forecast (2020 - 2025), https://www.mordorintelligence.com/industry-reports/induction-motor-market