CG1111: Engineering Principles and Practice I

Basic Principles of DC Motors

NUS
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Learning Outcomes

- Learn about the different types of motors
- Understand the parameters of DC motor and its circuit representation
- Understand DC motor specifications

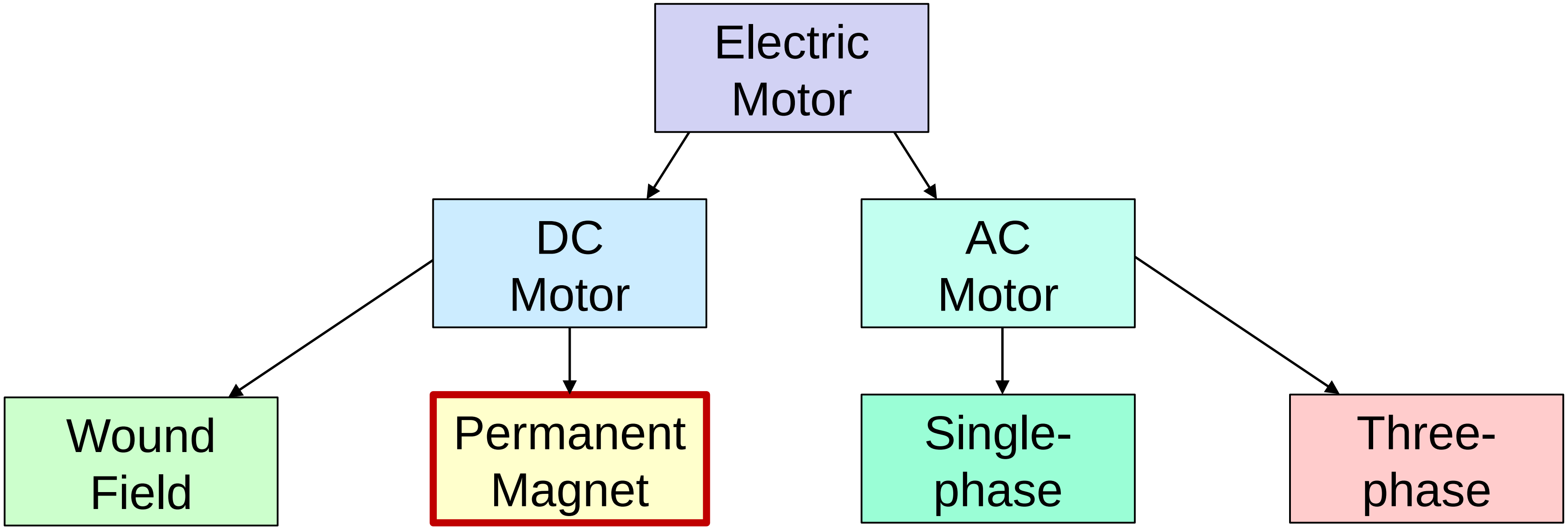
Introduction

- Motors convert electrical energy to mechanical energy, by using the force created by interacting magnetic fields

- List of some common household appliances that use motors:
  - Fan, refrigerator, DVD player, computer's cooling fan, vacuum cleaner, hairdryer, etc.

- All motors have a stationary part and a moving part:
  - Stationary part: "stator"
  - Moving part: "rotor" if it produces rotational motion

Classification of Motors



- There are many ways to construct a motor. Not all of them are shown here.
- For CG1111, we shall focus on permanent magnet DC (PMDC) motor

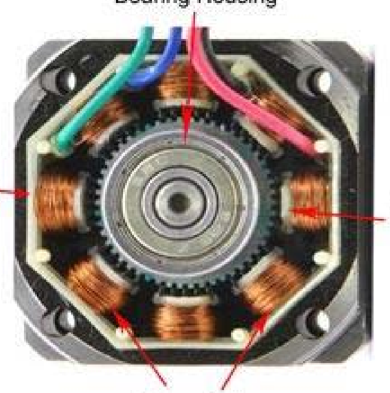
Some Special DC Motors

- Brushless DC Motor
  - Requires an electronic circuit between motor & power supply, which produces alternating current in motor coil from DC
  - Comes with 3 wires, unlike normal DC motors (2 wires)

Credit: www.robotshop.com

Credit: www.dys.hk

- Stepper Motor
  - DC motors that move in discrete steps
  - With computer control, can achieve very precise positioning & speed control



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Some Special DC Motors

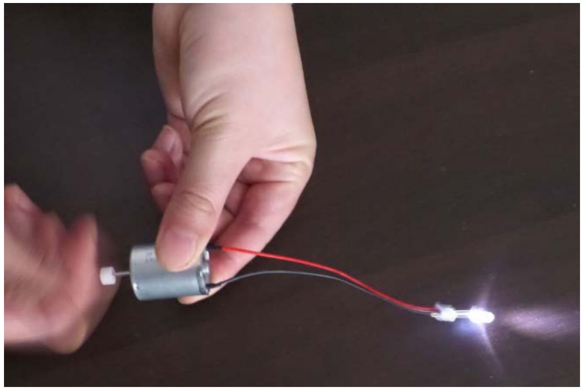
- Gear Motor
  - Made up of electric motor combined with a geared speed reducer
  - For a motor of a given power, higher torque can be produced by decreasing the speed:

$$Power = Torque \times Speed$$

Credit: www.robotshop.com

Motor vs. Generator

- If a torque is applied to a DC motor's shaft to spin it, a voltage is produced between its terminals

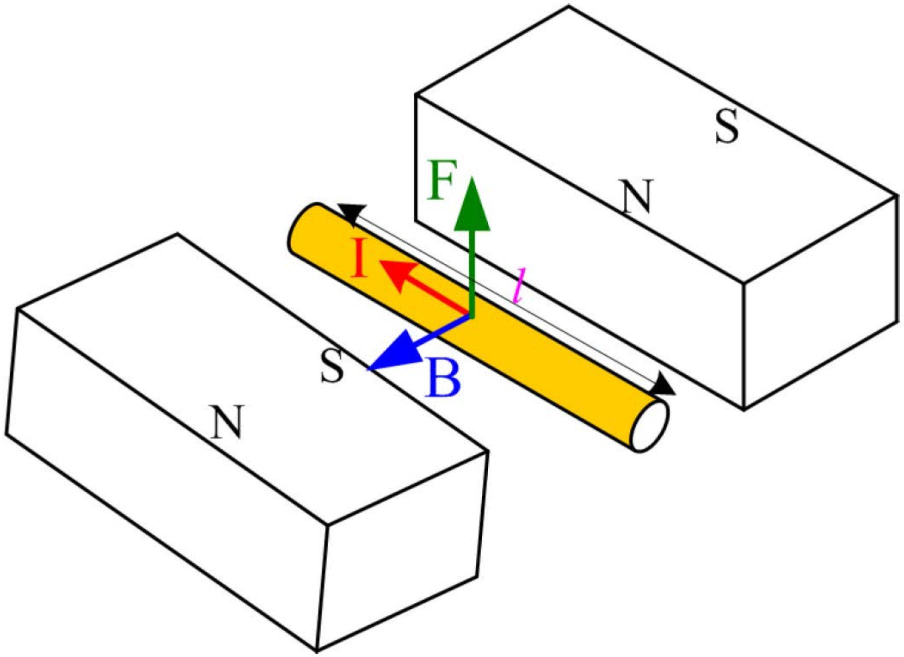


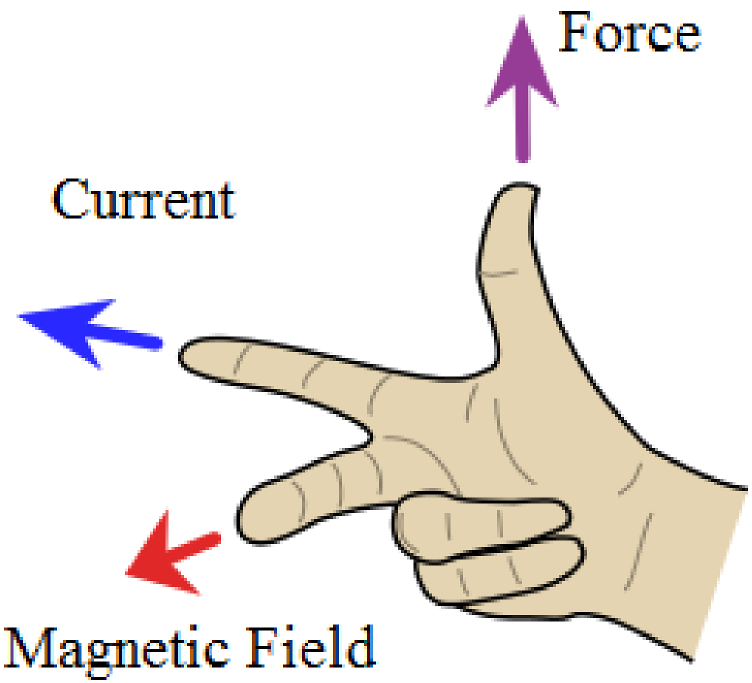
Credit: aliexpress.com

- Simple test:
  - Connect an LED between the terminals of a small DC motor (e.g, used in toys) and spin the shaft by fingers
  - The LED will be ON for one direction of spin, and not for the reversed spin (LED is reversed biased)

How Does A PMDC Motor Work?

- Let us first look at a phenomenon:
  - In the presence of a magnetic field, a current-carrying conductor experiences a force
  - The direction of the force can be determined using the right-hand rule:





How Much Force is Exerted?

- The magnitude of the force exerted on the conductor is given by

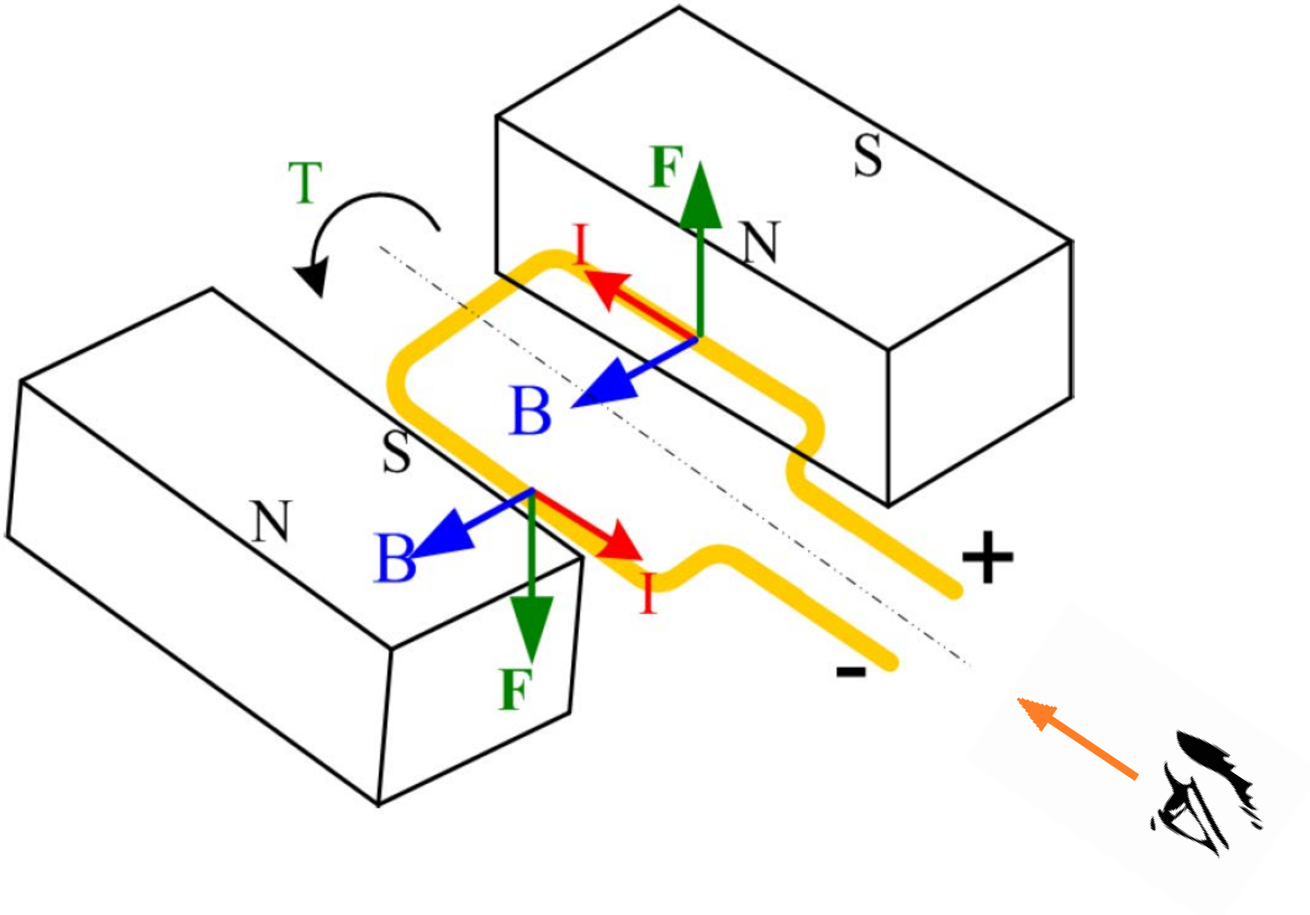
$$F = B \times I \times l \times \sin\theta \, ,$$

where:

- – B is the magnetic flux density,
- – I is the current through the conductor,
- – l is the length of the conductor,
- – θ is the angle between the direction of the magnetic field and the direction of the current

What Happens When the Conductor is a Loop?

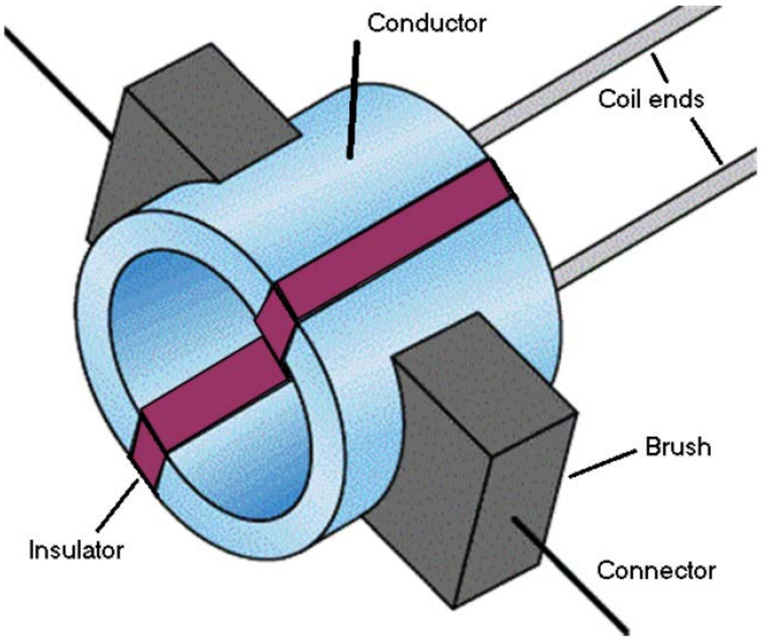
- In the case of a current-carrying loop, a torque is produced that can turn the loop



The Need for “Commutation”

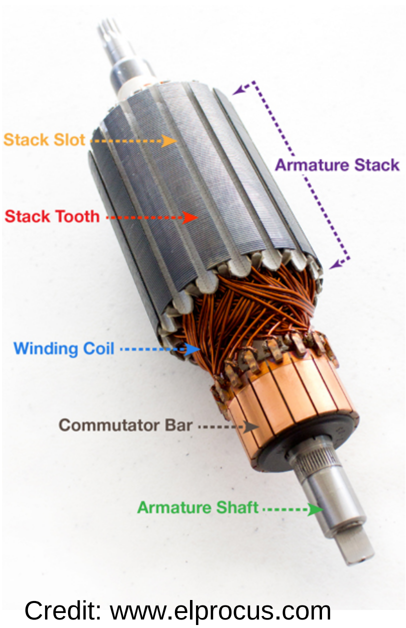
- For the loop to continue spinning, the loop’s current needs to be reversed in direction every half a turn, a procedure called “commutation”

- Accomplished either mechanically via the use of commutator & carbon brush, or electronically via electronic commutation



Real DC Motor has Many Loops

- A real motor consists of many loops spread over the circumference of a core known as “armature”:
  - Total torque is much higher than single loop
  - They allow the motor to turn continuously



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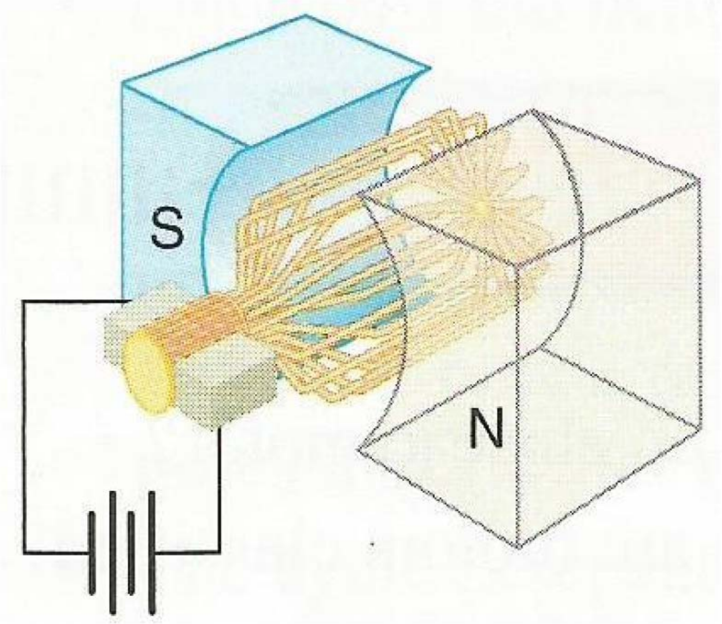


Motor Speed

- Motor speed is often specified as RPM (revolutions per minute)

- Relation between RPM & angular speed ω:

$$\omega = 2\pi \times (rev\ per\ second)$$

$$\boxed{= 2\pi \times \frac{RPM}{60}\ \ [\mathrm{rad/s}]}$$

Motor Constant: K_t

- Torque produced is proportional to motor current I_m:

$$\boxed{T_{\text{shaft}} = K_t I_m \ \ [\mathrm{N.m}]}$$

- K_t is called "torque constant"
  - It describes how well the motor converts current into torque
  - Depends on magnetic properties & geometry of motor
  - Normally measured after motor was built

Motor Constant: K_e

- When a motor shaft spins, the magnetic flux passing through the rotor coil changes
- The changing flux induces an electromotive force (emf) in the coil, which opposes the source current
- The induced emf is called "back emf", and is proportional to rotational speed:

$$\boxed{E_b = K_e \omega \ \ [\mathrm{V}]}$$

- K_e is called "back emf constant"
  - Depends on magnetic properties & geometry of motor
  - For PMDC motor:

$$\boxed{K_t = K_e}$$

Power

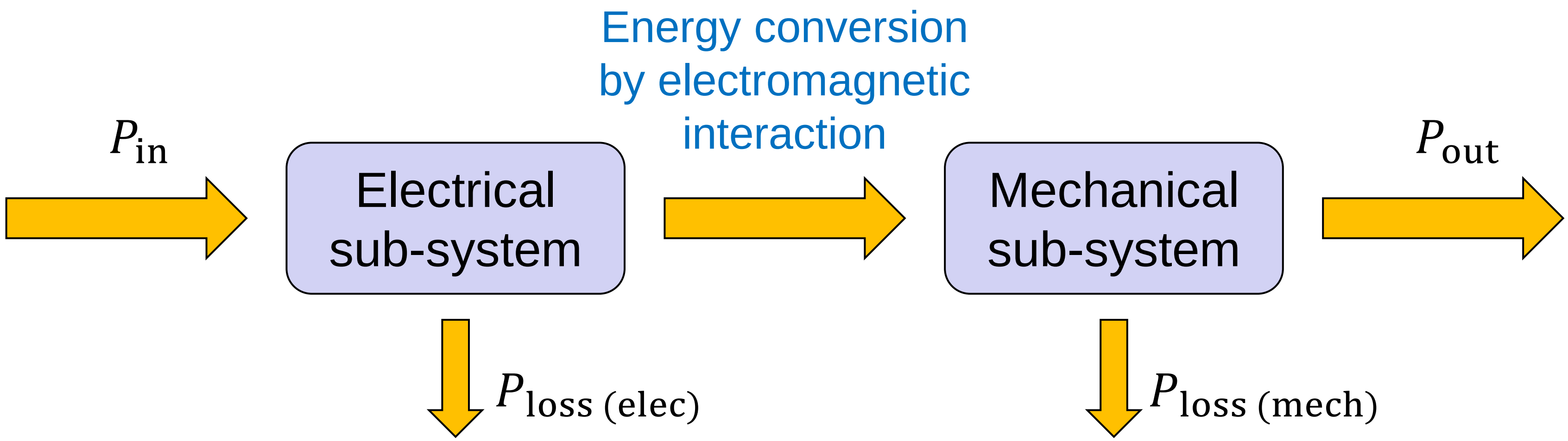
- Mechanical power at motor shaft:

$$\boxed{P_{\text{out}} = T_{\text{shaft}}\,\omega \;\; [\text{W}]}$$

- Electrical power supplied to motor:

$$\boxed{P_{\text{in}} = V_m\, I_m \;\; [\text{W}]}$$

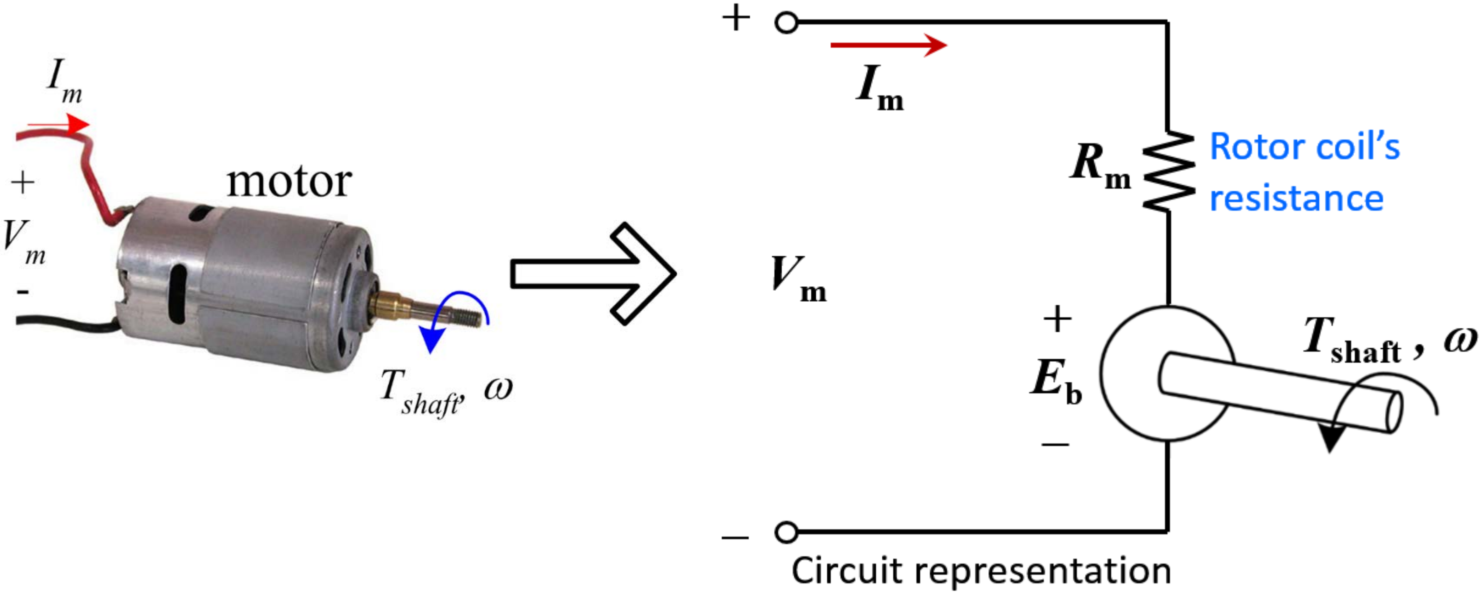
Motor Efficiency



- Electric motors are energy conversion devices
- Part of energy is always lost in any energy conversion process
- Mechanical power available at shaft is always less than electrical power input
- Efficiency of motor:

$$\boxed{\eta = \frac{P_{\text{out}}}{P_{\text{in}}}}$$

Circuit Representation: PMDC Motor



- From the circuit: $\boxed{I_m = \dfrac{V_m - E_b}{R_m}}$
- Since $E_b = K_e\omega$, we have: $\boxed{I_m = \dfrac{V_m}{R_m} - \dfrac{K_e\omega}{R_m}}$

Basic Properties of PMDC Motor

Rearranging: $$\boxed{\omega = \frac{V_m}{K_e} - \frac{R_m I_m}{K_e}}$$

- For a fixed load (i.e., fixed T_{shaft}, which implies fixed I_m since $T_{\text{shaft}} = K_t I_m$):

  Shaft speed ω can be increased by increasing motor voltage V_m

- For a fixed voltage V_m, if T_{shaft} increases, I_m increases, and hence ω decreases:

  Shaft speed ω decreases with increasing load T_{shaft}

Key Parameters in Datasheet

- No-load speed:
  - Speed at which shaft spins without mechanical load
- No-load current:
  - Current drawn under no-load condition

- Note:
  - When no load is attached to the motor shaft, the motor is still required to produce torque to overcome the friction torque

Key Parameters in Datasheet

- Stall torque:
  – Amount of load that causes motor to stop ($\omega = 0$)
  – This is the maximum torque the motor can produce
- Stall current:
  – Current drawn under stall condition
  – Most motors will be damaged if subjected to stall conditions for too long

THANK YOU