ECE330: Power Circuits & Electromechanics

Lecture 19. Electric machines overview

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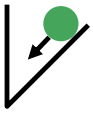
Electromechanics: Basic idea

- Current loop → electromagnet.
- **Motor:** Force does work on you.
- **Generator:** You do work against force.



No net work in a static field

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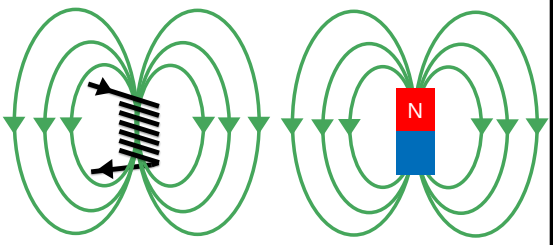
Electromechanics: Basic idea



Varying current results in dynamic field

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Today

- Overview of electric machines
- Standing vs traveling magnetic fields
- Number of poles: Electrical vs mechanical speed

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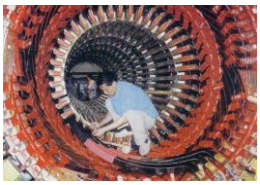
The world of electric machines



Switching DC fields

- Brushed DC motor
- → Reluctance machine
- Stepper motor
- Brushless DC motor

Rotating AC fields

- → Synchronous machine
- → Induction machine

Our focus in ECE 330

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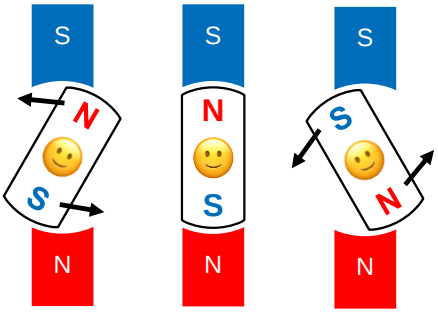
Switched rotor field: Brushed DC motor



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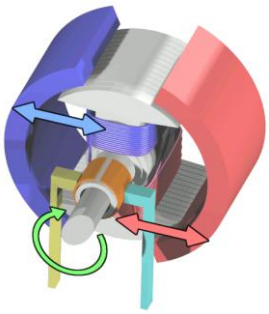
Switched rotor: Brushed DC motor



Brushes used as mechanical switch to reverse polarity of rotor field

Brushes are the weakest link

Image:Isi~commonswiki / Wikimedia

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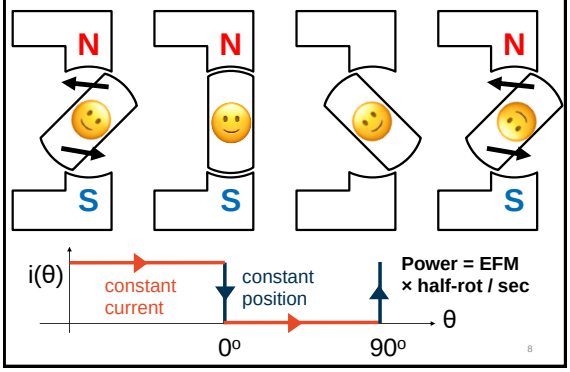
Switched stator field: Reluctance motor



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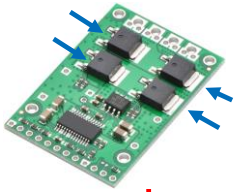
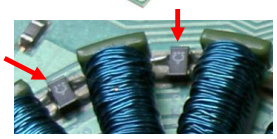
Switched stator field: Reluctance motor



MOSFET used as electrical switch to reverse polarity of stator field



Rotor position measured using hall effect sensors or optical sensors

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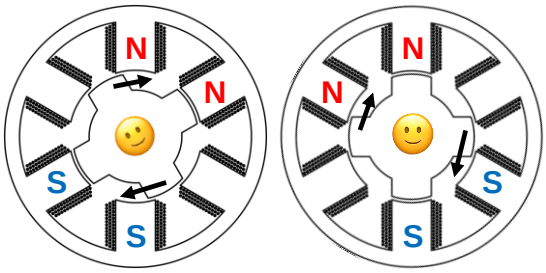
Polyphase reluctance motor (aka "stepper motor")



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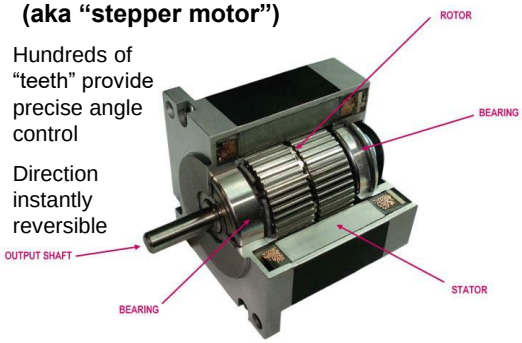
Polyphase reluctance motor (aka "stepper motor")

Hundreds of "teeth" provide precise angle control

Direction instantly reversible



https://www.heason.com/article-detail.php?aid=215&

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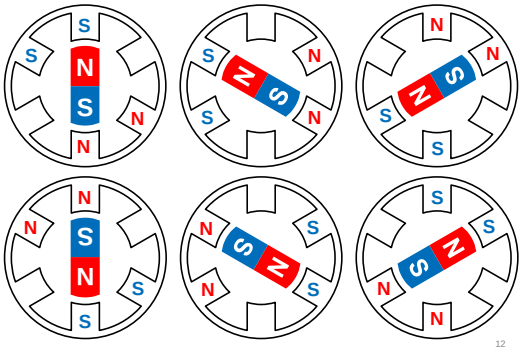
Rotating stator field: Brushless DC



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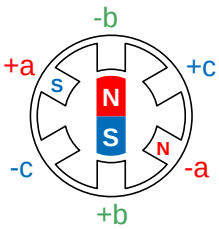
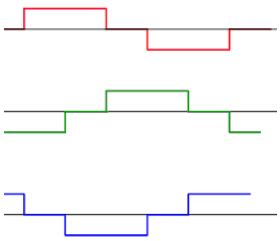
Rotating stator field: Brushless DC



Switching logic



Rotating stator field

Balanced 3ϕ current

More on this later today

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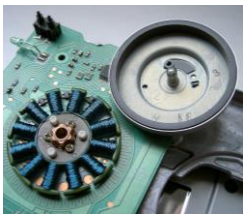
Rotating stator field: Brushless DC



Some of the highest power-to-weight and efficiency figures ever achieved

Image: Siemens

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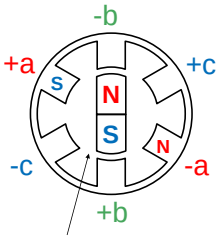
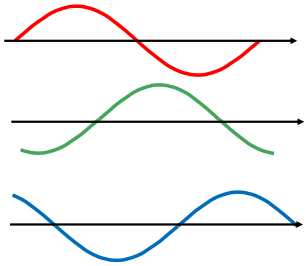
Rotating stator field, electromagnet rotor: Synchronous machine





Electromagnet

Cheaper & less dangerous at very high power

Sinusoidal balanced 3ϕ

Better power quality

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Rotating stator field, electromagnet rotor: Synchronous machine

Image: Chrisbwah / Wikimedia

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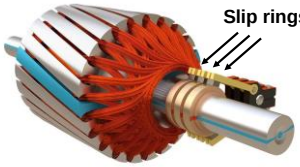
Rotating stator field, electromagnet rotor: Synchronous machine

Image: Youtube.com/LearnEngineering



- Slip rings wear out
- High centrifugal forces
- Many breakable parts
- Maintainence expensive and time consuming

Rotor is the weakest link

Too much hassle for lower power

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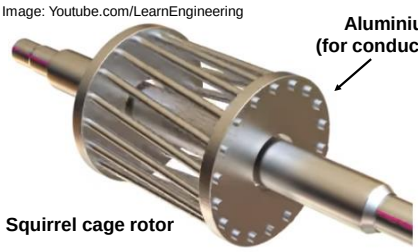
Rotating stator field, conductor rotor: Induction machine

Image: Youtube.com/LearnEngineering



Use induced current to excite rotor

Cheap, rugged, zero-maintence

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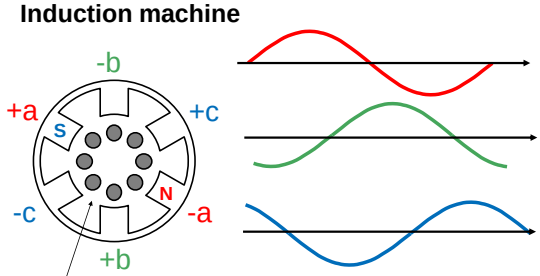
Rotating stator field, electromagnet rotor: Induction machine



Squirrel cage
nonmagnetic conductor

Asynchronous machine.
Rotor spins at a different speed than stator!

Notion of slip ≈ losses
ex: stator 100 rpm, rotor 95 rpm, slip=5%

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Map of electric machines

1. Where is the changing field?

Rotor → Brushed DC

Stator → ↓

2. What is the rotor made of?

Magnetic material	Permanent magnet	Electro-magnet	Conductive material
↓	↓	↓	↓
Reluctance machine	Brushless DC	Synchronous machine	Induction machine

Asynchronous machine

Learn more:
ECE 431
Electric Machinery
ECE 464
Power Electronics
ECE 469
Power Electronics Lab

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Today

- Overview of electric machines
- Standing vs traveling magnetic fields
- Number of poles: Electrical vs mechanical speed

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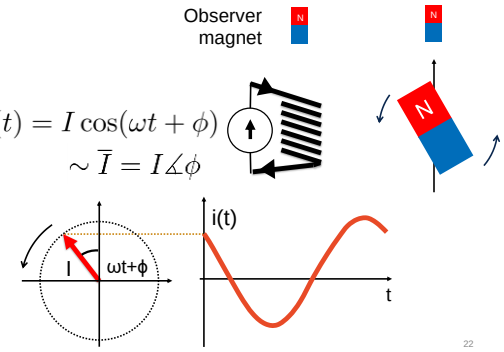
Sinusoid current is like spinning magnet

Observer magnet

$$i(t) = I\cos(\omega t + \phi)$$
$$\sim \bar{I} = I\angle\phi$$



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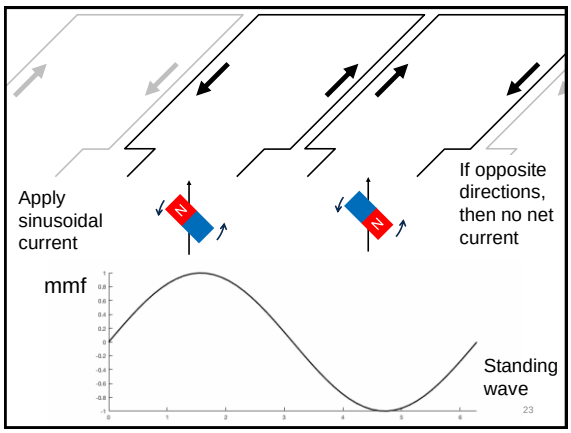

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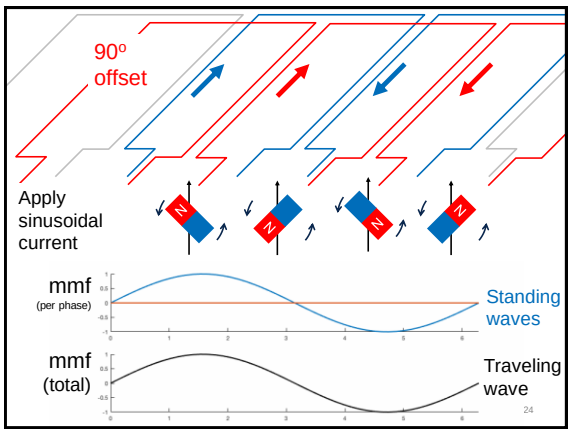

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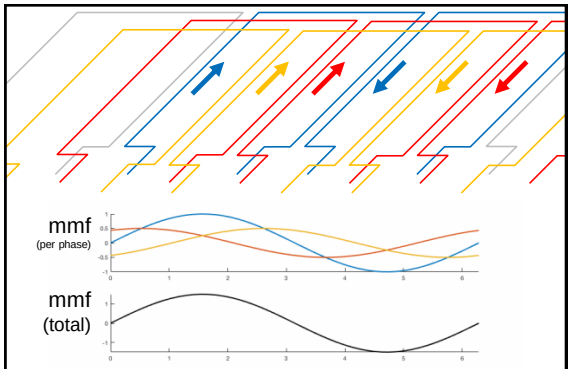

Three-phase 120 degrees apart in time and in space

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Why? Mathematical intuition

- Standing wave is sum of two traveling waves of opposite directions.

$$2\cos x \cos t = \cos(x+t) + \cos(x-t)$$

- Idea: Constructively intervere one traveling wave and destructively interfere the other

$$2\cos x \cos t + 2\cos(x+90^\circ)\cos(t+90^\circ)$$
$$= \cos(x+t) + \cos(x-t) + \cos(x+t+180^\circ) + \cos(x-t)$$
$$= \cos(x+t) + \cos(x-t) - \cos(x+t) + \cos(x-t)$$
$$= 2\cos(x-t)$$

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- Number of poles: Electrical vs mechanical speed

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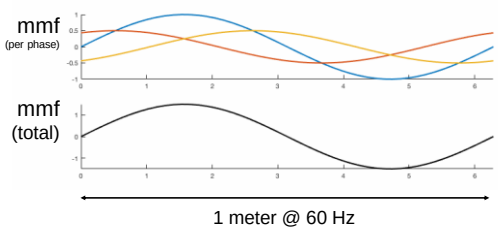
Speed of a traveling magnetic field



How fast is the wave traveling in m/s?
A) 1; B) 1 / 60; C) 60; D) 120 π; E) 1 / 120 π

distance / elapsed time = 60 m/s = 134 mph!!

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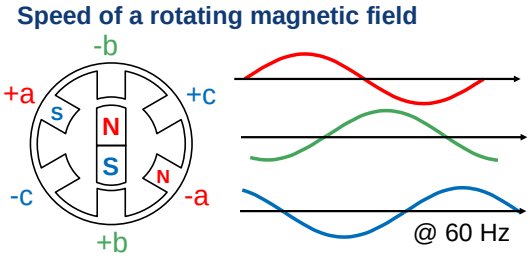
Speed of a rotating magnetic field



How fast will the rotor spin in rpm?
A) 1; B) 3.6; C) 60; D) 3600; E) 6000

60 Hz = 3600 rpm

Mechanical speed = electrical speed

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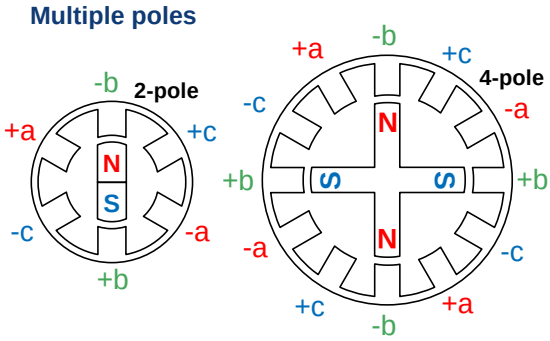
Multiple poles



3600 rpm 1800 rpm

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Mechanical speed vs electrical frequency

At 60 Hz, how fast will a 6-pole machine spin in rpm?
A) 900; B) 1200; C) 1800; D) 2400; E) 3600;

- 6-pole covers 3x the distance vs 2-pole.
- Hence, it ought to spin 3x slower
- 2-pole → 3600 rpm, so 6-pole → 1200 rpm

Synchronous **speed** = 40 π [rad/s] = 1200 rpm

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

Synchronous **frequency** = 120 π [rad/s] = 60 [Hz]

Mechanical speed

poles

Electrical frequency

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