EE-362

Review of Electromechanical Energy Conversion

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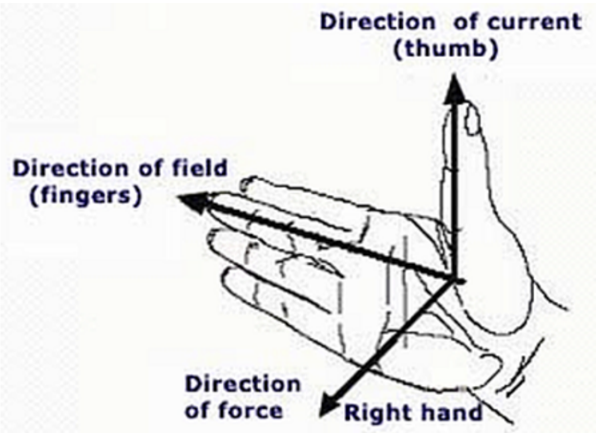
Lorenz Force

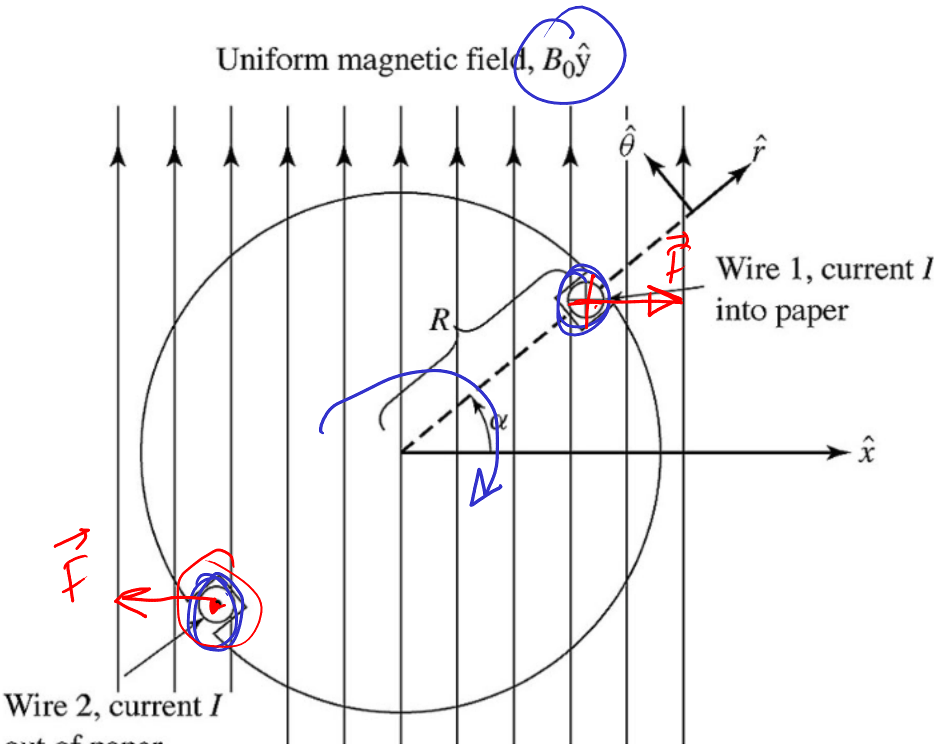
$$\vec{F} = \vec{J} \times \vec{B}$$



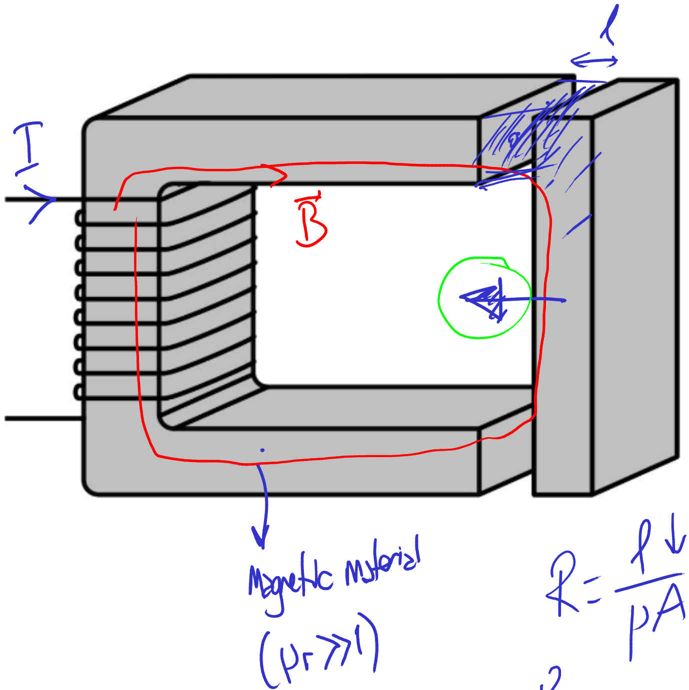
Lorenz Force Applications

- Force Demo
- Homopolar Motor
- Wolrd's Simplest Electric Train
- Electromagnetic Aircraft Launcher
- Navy Railgun, Railgun-2
- Aselsan Tufan
- Aselsan Tufan-2

Determine the direction of rotation



What would happen in the device below?



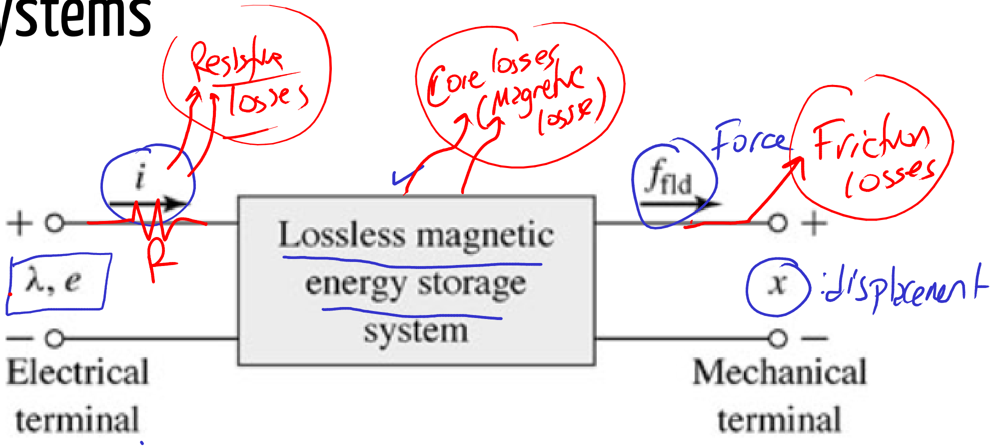
$F = \vec{J} \times \vec{B}$

$\int_{volume} \underbrace{\int BH}_{J/m^3}$ — Joule

$R = \frac{l \downarrow}{\mu A}$

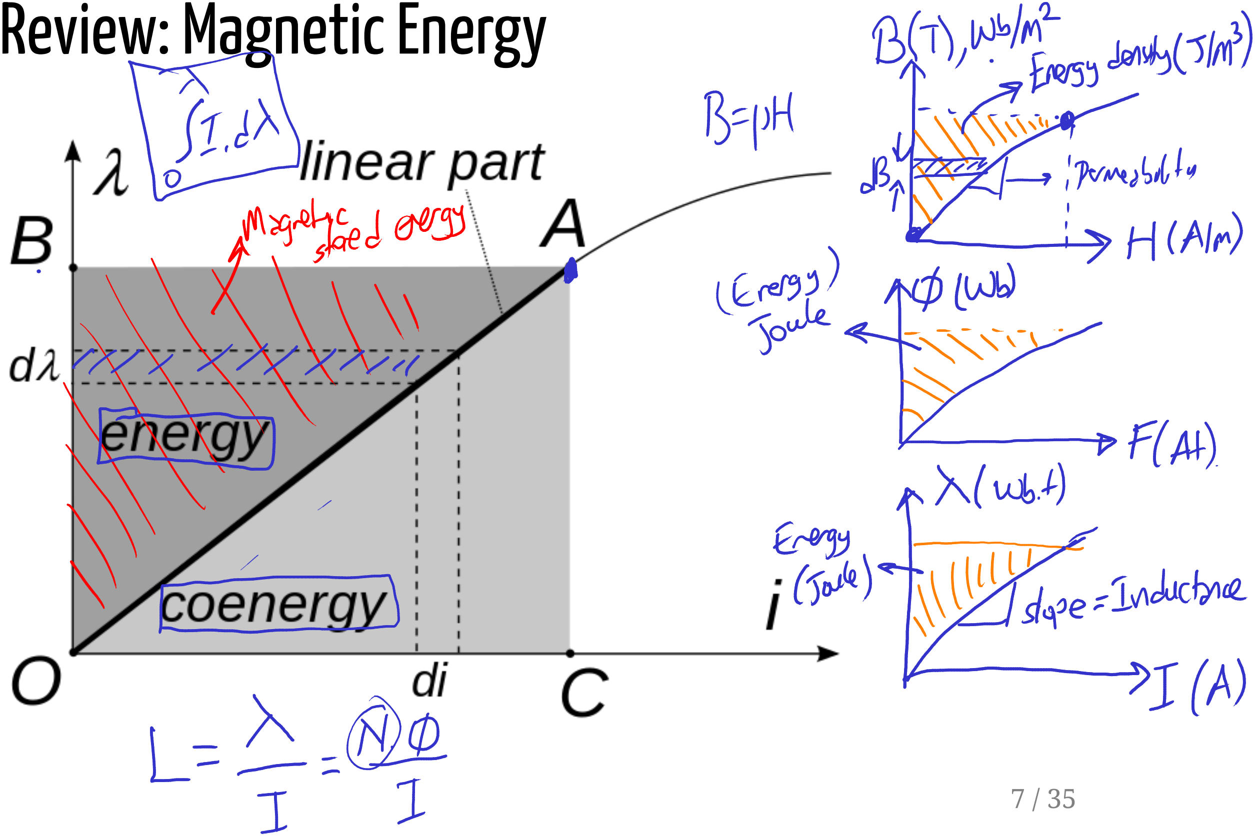
$\uparrow L = \frac{N^2}{R \downarrow}$

Link Between Electrical and Mechanical Systems



Electric Energy Input = Stored Magnetic Energy + Mechanical Work

Review: Magnetic Energy



Review: Magnetic Energy

$$W_{stored} = \int_0^{\lambda} i(\lambda) d\lambda$$

Review: Magnetic Energy

$$W_{stored} = \int_0^\lambda i(\lambda) d\lambda$$

or from B-H curve

J/m³

$$W_{stored} = \int_{volume} \left(\int_0^B H dB \right)$$

Magnetic Energy

In Linear Systems:

Magnetic Energy

In Linear Systems:

Magnetic Energy = Magnetic Co-Energy

Magnetic Energy

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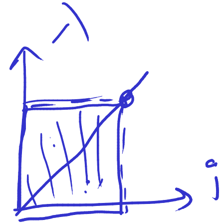
Magnetic Energy + Magnetic Co-Energy = λi



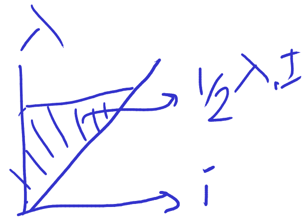
Magnetic Energy

$L = \frac{\lambda}{I}$ $\lambda = LI$

In Linear Systems:

Magnetic Energy = Magnetic Co-Energy

Magnetic Energy + Magnetic Co-Energy = λi



Thus (only in linear systems)

$$W(\text{magnetic}) = \frac{1}{2}\lambda i = \frac{1}{2}L i^2 = \frac{1}{2L}\lambda^2$$

Joule

Force from the Stored Energy

Δx Joules

Joule

$mg\,\Delta x = F \cdot \Delta x$

$F = mg$

$F = m \cdot g$

Newton (kg)

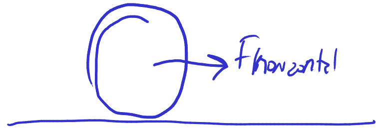
Force from the Stored Energy

Derivative of Energy w.r.t. position gives the force!

Force from Stored Energy

Take derivative of magnetic energy

Force from Stored Energy



Take derivative of magnetic energy

$$Force = -\frac{\partial W_{mag}(\lambda, x)}{\partial x}\Big|_{\lambda=constant}$$

Some useful reading:

- **MIT From Lasers to Motors**
- **Fitzgerald-Electromechanical Energy Conversion**

Force from Stored Energy

$$Force = -\frac{\partial W_{mag}(\lambda, x)}{\partial x}\Big|_{\lambda=constant}$$

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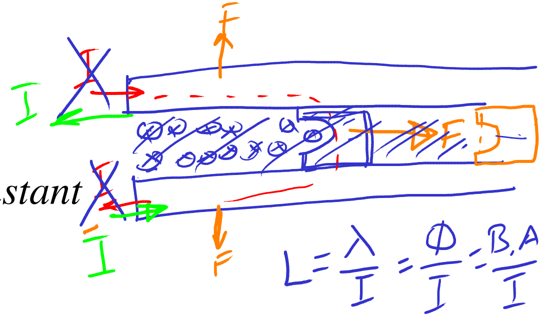
For Linear Systems

$$Force = -\frac{\partial}{\partial x}(\frac{\lambda^2}{2L(x)}) = \frac{\lambda^2}{2L(x)^2}(\frac{dL(x)}{dx})$$

Force from Stored Energy

$$Force = -\frac{\partial W_{mag}(\lambda, x)}{\partial x}\Big|_{\lambda=constant}$$



For Linear Systems

$$Force = -\frac{\partial}{\partial x}\left(\frac{\lambda^2}{2L(x)}\right) = \frac{\lambda^2}{2L(x)^2}\left(\frac{dL(x)}{dx}\right)$$

$$Force = \frac{1}{2}i^2\frac{dL(x)}{dx}$$

Summary

Magnetic Circuit Tries

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- To reduce $W_{magnetic}$ if Φ is constant

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- To reduce $W_{magnetic}$ if Φ is constant
- To maximize the inductance

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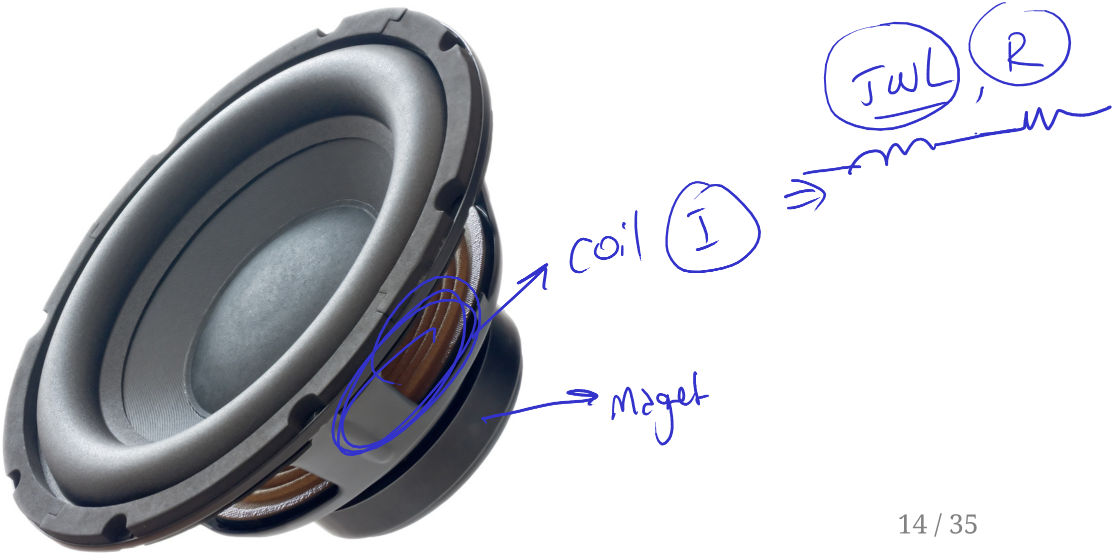
Magnetic Circuit Tries

- To reduce $W_{magnetic}$ if Φ is constant
- To maximize the inductance
- To minimize the reluctance $(L = N^2/R)$

Some Applications

Some Applications

How a speaker works?

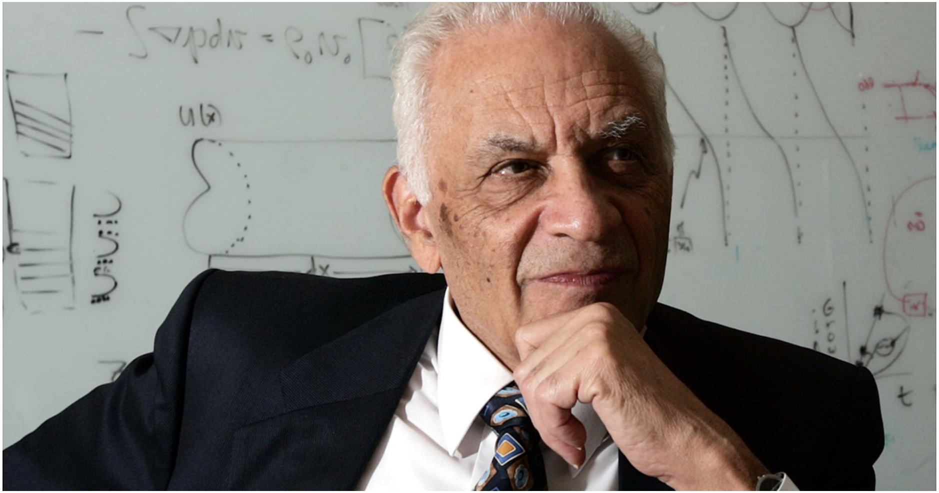


You can think it is just a basic solenoid, but it's more complex than that.

How Speakers Work

(Reading assignment)

Who is this guy?



Amar Bose

Founder of Bose Corp, MIT Professor, Electrical Engineering

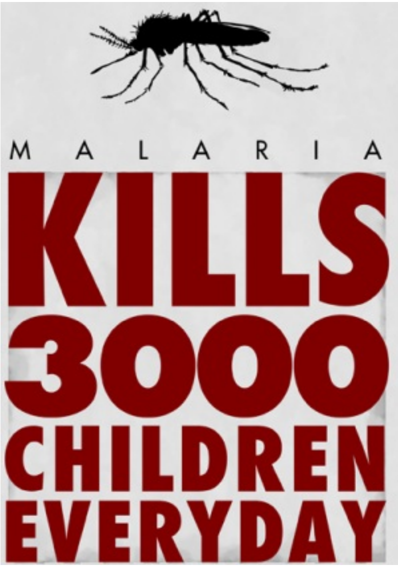
How Amar Bose used research to build better speakers

Now MIT owns the majority shares in Bose Corp.

Magnetism in Medicine:

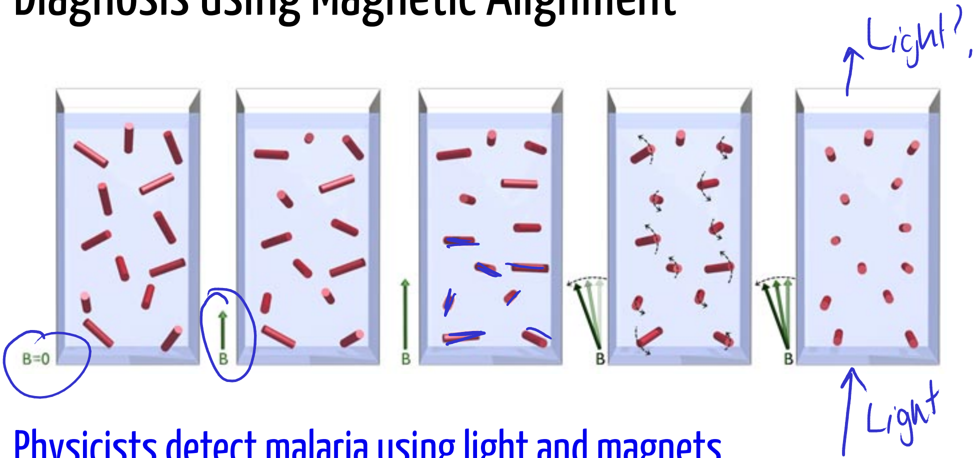
Magnetism in Medicine:

Malaria



Malaria vs Permeability

Diagnosis using Magnetic Alignment



[Physicists detect malaria using light and magnets]

[Magnets diagnose malaria in minutes]

Malaria Treatment

[Malaria's Magnetic Properties May Pull Treatments Forward]

Summary

Magnetic Circuit Tries

- To reduce $W_{magnetic}$ if Φ is constant
- To maximize the inductance
- To minimize the reluctance ($L = N^2/R$)

Mechanical Power & Energy:

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Linear Motion:

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Linear Motion: $P = Fv = F\frac{dx}{dt}$ Watt

N velocity (m/s)

Mechanical Power & Energy:

Linear Motion: $P = Fv = F\frac{dx}{dt}$ Watt

Rotational:

Mechanical Power & Energy:

Linear Motion: $P = Fv = F\frac{dx}{dt}$ Watt

Rotational: $P = T\omega = T\frac{d\theta}{dt}$ Watt

$\omega = \frac{d\theta}{dt}$

N, m/s, Δx

Torque (N.m), rad/s

Mechanical Power & Energy:

Linear Motion: $P = Fv = F\frac{dx}{dt}$ Watt

Rotational: $P = T\omega = T\frac{d\theta}{dt}$ Watt

Linear Motion: $W = \int P dt = Fx$ Joule

Mechanical Power & Energy:

Linear Motion: $P = Fv = F\frac{dx}{dt}$ Watt

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Linear Motion: $W = \int Pdt = \underline{Fx}$ Joule

Rotational: $W = \int Pdt = \underline{T\theta}$ Joule

Linear Acceleration:

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$$F = ma = m\frac{dv}{dt}$$

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Rotational Acceleration:

Linear Acceleration:

$$F = ma = m\frac{dv}{dt}$$

$\frac{1}{2}mv^2$

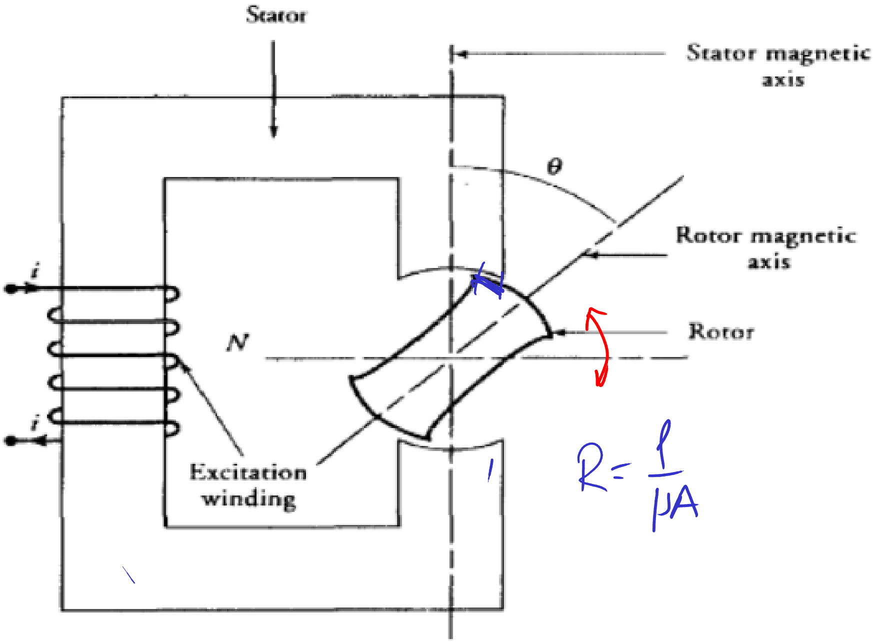
Rotational Acceleration:

$$T = J\frac{d\omega}{dt} \text{ Watt}$$

$\frac{1}{2}J\omega^2$

J: Rotational Inertia (kgm^2)

Can you guess the torque expression in this circuit?



Rotational Sytems:

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Remember in linear systems:

$$f = -\frac{\partial W_{mag}(\Phi, x)}{\partial x}|_{\Phi=constant}$$

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Remember in linear systems:

$$f = -\frac{\partial W_{mag}(\Phi, x)}{\partial x}|_{\Phi=constant}$$

In rotational systems, just take the derivative wrt θ not x:

$$T = -\frac{\partial W_{mag}(\Phi, \theta)}{\partial \theta}|_{\Phi=constant}$$

More information

Rotational Sytems:

Take the derivative wrt θ not x:

Rotational Sytems:

Take the derivative wrt θ not x:

$$T = -\frac{1}{2}\Phi^2 \frac{dR(\theta)}{d\theta}\Big|_{\Phi=constant}$$

or alternatively

$$T = \frac{1}{2}I^2 \frac{dL(\theta)}{d\theta}\Big|_{i=constant}$$

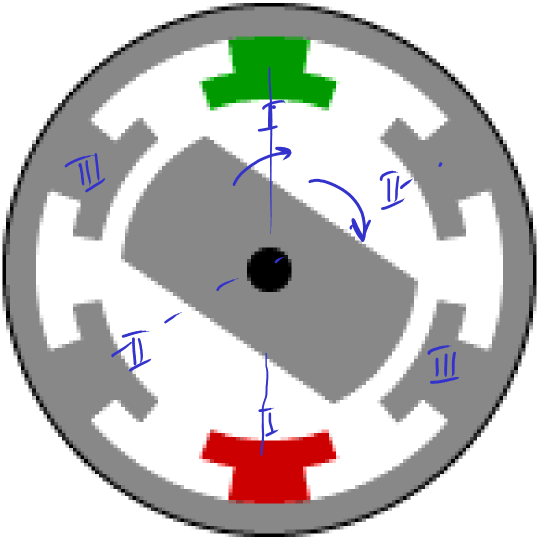
How can we achieve a constant rotation?

How can we achieve a constant rotation?

Single Phase Reluctance Motor

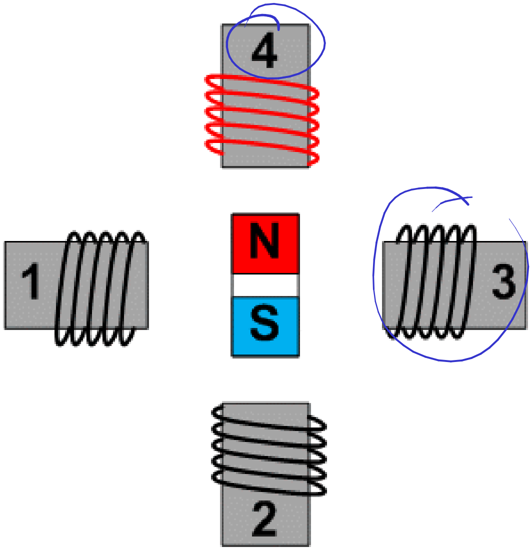
How can we achieve a constant rotation?

Single Phase Reluctance Motor



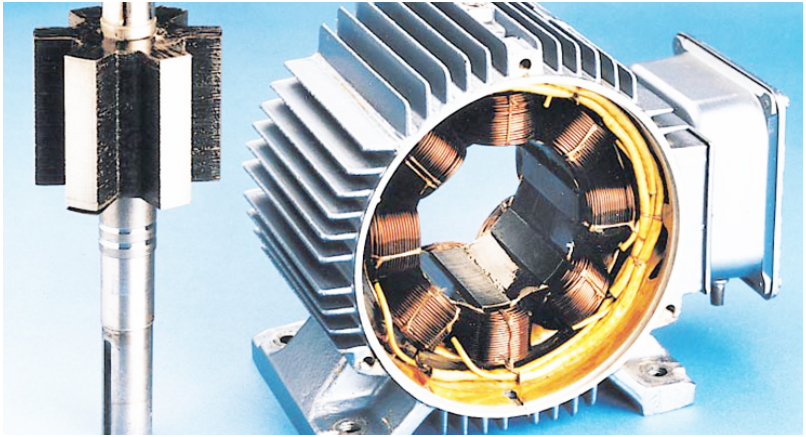
Single Phase Reluctance Motor

Single Phase Reluctance Motor



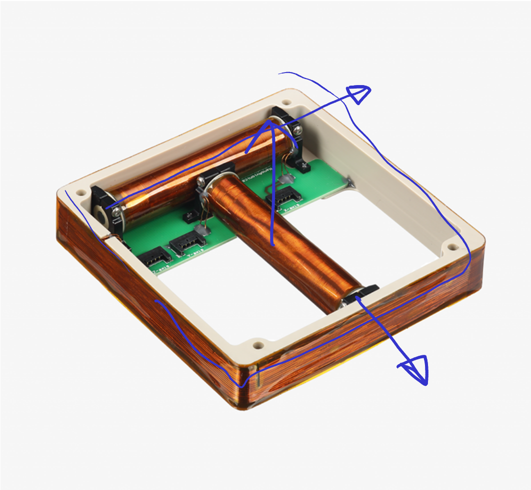
Magnetic Flux, Micro-stepping for higher accuracy

Reluctance Motors



[More info]

Magnetorquer: How small satellites align themselves?



[Magnetorquer]

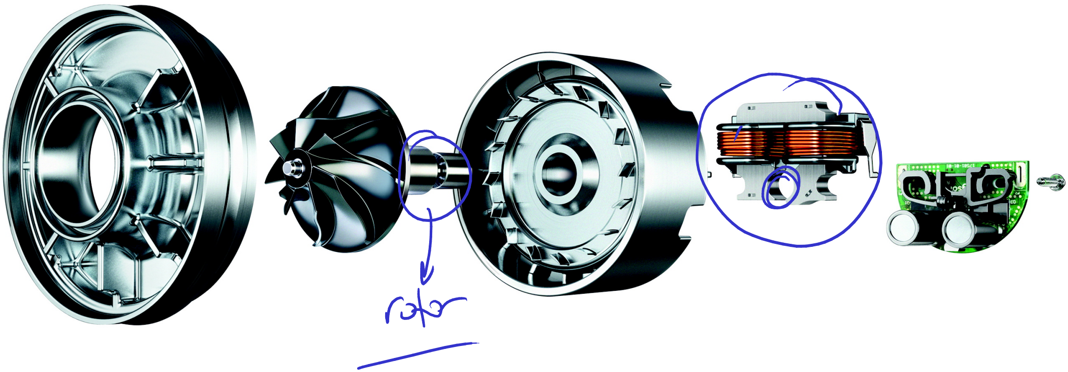
[CubeSat Magnetorquer]

Who is this guy?

James Dyson

[Digital Motor], [Operating Principle], [Manufacturing]

Dyson uses Reluctance Motors



Digital Motor, Operating Principle, Manufacturing

Summary

Magnetic Circuit Tries

Summary

Magnetic Circuit Tries

- To maximize the inductance, to minimize the reluctance ($L = N^2/R$)
- To decrease the magnetic energy (increase co-energy)

Rotational systems are similar to linear systems, but take the derivative of magnetic energy in terms of θ instead of x.

You can download this presentation from:
keysan.me/ee362