ECE 330
POWER CIRCUITS AND ELECTROMECHANICS

LECTURE 15
ELECTROMECHANICAL SYSTEMS (1)

Acknowledgment-These handouts and lecture notes given in class are based on material from Prof. Peter Sauer's ECE 330 lecture notes. Some slides are taken from Ali Bazi's presentations

Disclaimer- These handouts only provide highlights and should not be used to replace the course textbook.

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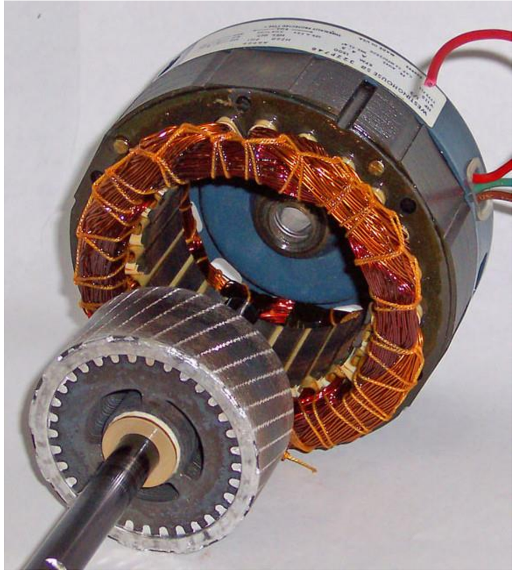
ELECTROMECHANICAL SYSTEMS

- Focus on magnetic circuits in which there is a moving member.
- It can be either a translational or rotational system.

- Source: clrwtr.com



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ELECTROMECHANICAL SYSTEMS

The purpose is to present techniques of systematic derivation of mathematical models (differential equations) for lumped-parameter electromechanical systems. The theory is outlined for N electrical coils and M mechanical variables.

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ELECTROMECHANICAL SYSTEMS

- A set of electrical coils that interact to produce the force or torque on the mechanical system.
- The force or torque of electric origin will be derived from fundamental principles of stored energy in the magnetic field.
- both the currents in the electrical coils and the force or torque are time varying.

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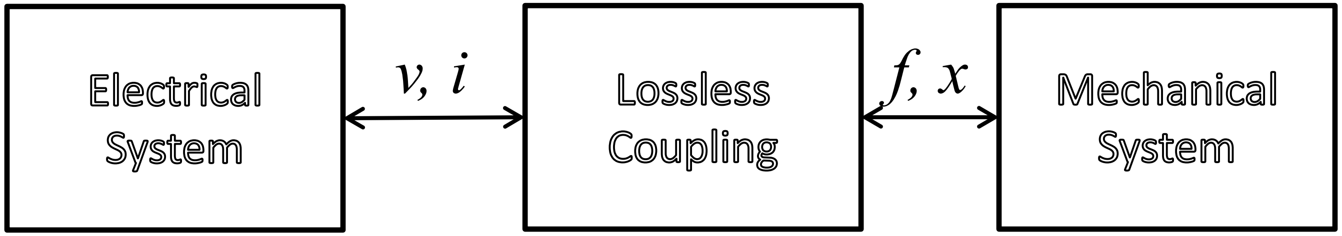
ELECTROMECHANICAL SYSTEMS

- A basic electromechanical system has an electrical part, a mechanical part, and electromechanical coupling. This coupling is assumed to be lossless.



- Systems with linear motion see a force f and a displacement x, while rotational systems see a torque T and a displacement θ.

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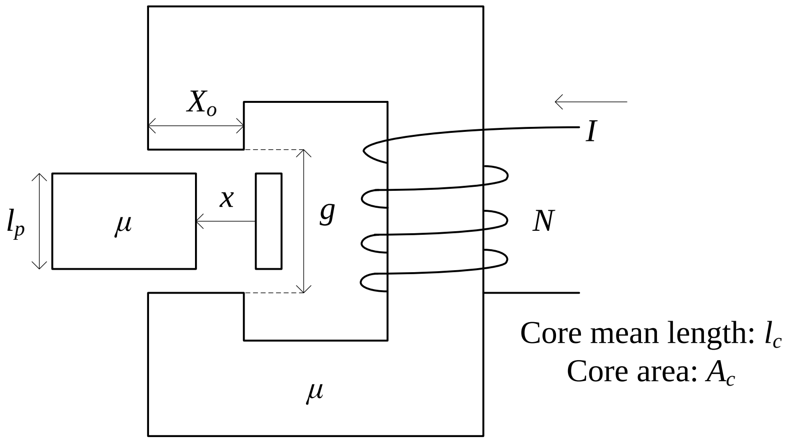
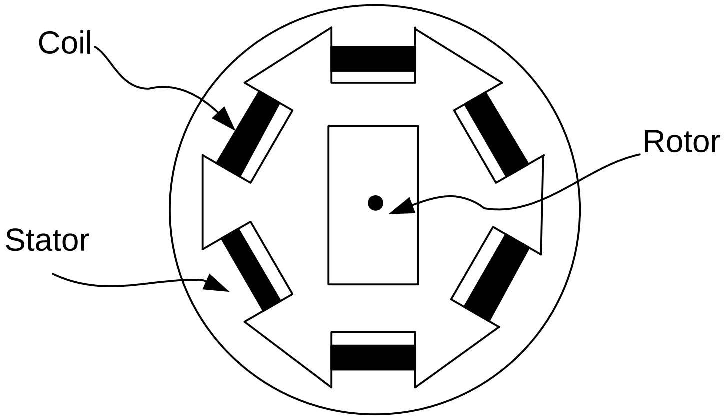
EXAMPLES

- Linear(translational) motion:



- Rotational motion:



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FLUX LINKAGE AND VOLTAGE

- *The flux linkage* λ can be a function of the displacement x and the current i.

- The voltage becomes: $$v = \frac{d\lambda}{dt} = \frac{\partial \lambda}{\partial i}\frac{di}{dt} + \frac{\partial \lambda}{\partial x}\frac{dx}{dt}.$$

- If $\lambda = L(x)\, i$, $$v = \frac{d\lambda}{dt} = L(x)\frac{di}{dt} + i\frac{\partial L(x)}{\partial x}\frac{dx}{dt}.$$

- If $L(x) = L =$ constant, $$v = \frac{d\lambda}{dt} = L\frac{di}{dt}.$$

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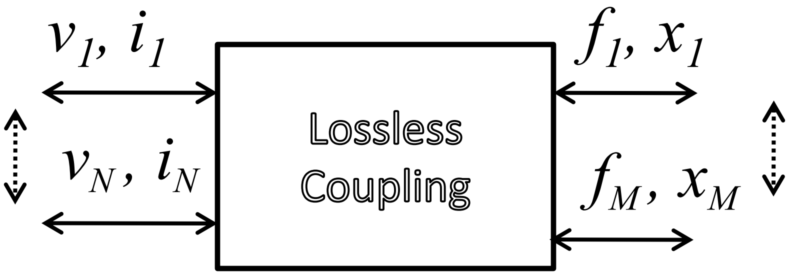
MULTI-PORT SYSTEMS

$$\lambda_k = \lambda_k(i_1, i_2, i_N, \ldots\ldots x_1, x_{2,\ldots\ldots} x_N), \qquad k = 1\ldots\ldots N$$



$$v_k = \frac{d\lambda_k}{dt} = \sum_{j=1}^{N} \frac{\partial \lambda_k}{\partial i_j} \frac{di_j}{dt} + \sum_{j=1}^{M} \frac{\partial \lambda_k}{\partial x_j} \frac{dx_j}{dt}, \qquad k = 1,\ldots.\mathrm{N}$$

- The force of electric origin at the mechanical ports can be functions of all the variables.

$$f_i^{\,e} = f_i^{\,e}(i_1, i_2, \ldots\ldots i_N, x_1, x_{2,}\ldots\ldots x_M)$$

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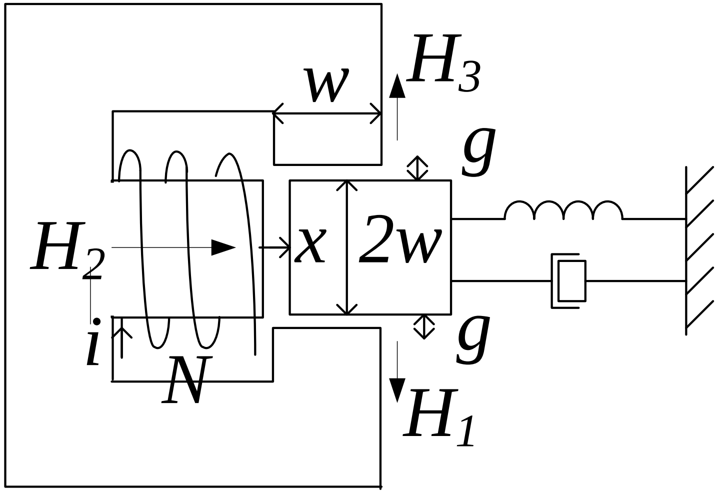
LINEAR SYSTEM EXAMPLE

Basic configuration is used for tripping circuit breakers, operating valves, etc. It consists of:

- Fixed structure made of highly permeable material.
- A movable plunger of non magnetic sleeve.

$$B = \mu H \quad , \quad \mu = \infty$$

$$H = 0 \quad in \quad the \quad iron$$



- H exist only in the air gap

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LINEAR SYSTEM EXAMPLE

- Ampere's loops:

$$H_3 g - H_1 g = 0$$

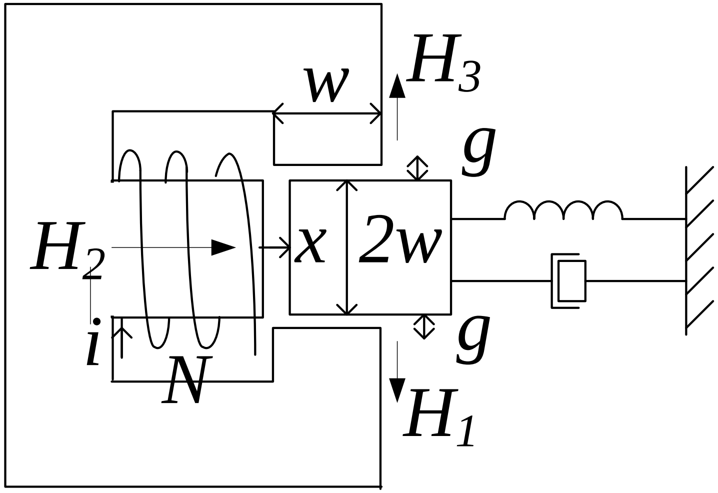
$$H_2 x + H_1 g = N\, i$$

$$\Rightarrow B_1 A_1 + B_3 A_3 - B_2 A_2 = 0$$

$$\Rightarrow 2\mu_o H_1 wd - 2wd\,\mu_o H_2 = 0$$

$$\Rightarrow H_1 = H_2 = \frac{Ni}{g+x}$$

$$\Rightarrow \phi_2 = \mu_o H_2 (2wd) = \frac{2wd\,\mu_o Ni}{g+x}$$



d is the depth of the structure

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LINEAR MOTOR EXAMPLE

$$\lambda = N\,\phi_2$$

$$\lambda = L\,i$$

$$\Rightarrow L(x) = \frac{\lambda}{i} = \frac{2w\,d\,\mu_o N^2}{g+x}$$

$$v = L(x)\frac{di}{dt} + i\,\frac{dL(x)}{dx}\frac{dx}{dt}$$

$$\Rightarrow v = \underbrace{\frac{2w\,d\,\mu_o N^2}{g+x}\frac{di}{dt}}_{\text{Transformer voltage}} - \underbrace{i\,\frac{2w\,d\,\mu_o N^2}{(g+x)^2}}_{\text{Speed voltage}}\frac{dx}{dt}$$

Transformer voltage

Speed voltage

This problem can be easily solved using the magnetic equivalent circuit !

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READING MATERIAL

- Reading material: Sections 4.1-4.3.

- Next time: Continue Section 4.3.

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