

ECE 330

POWER CIRCUITS AND ELECTROMECHANICS

LECTURE 11

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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ECE ILLINOIS

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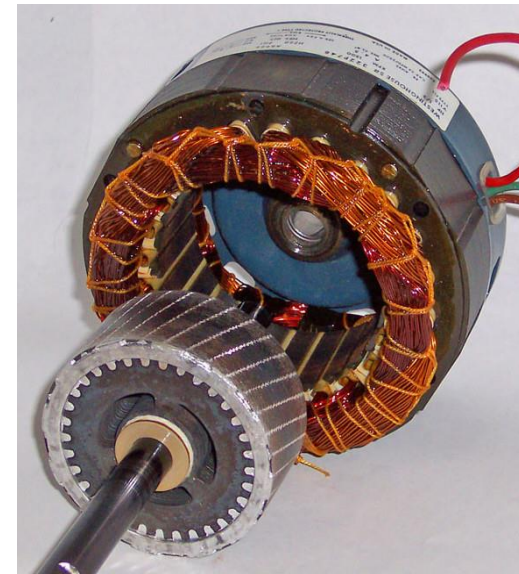
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ELECTROMECHANICAL SYSTEMS

- 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

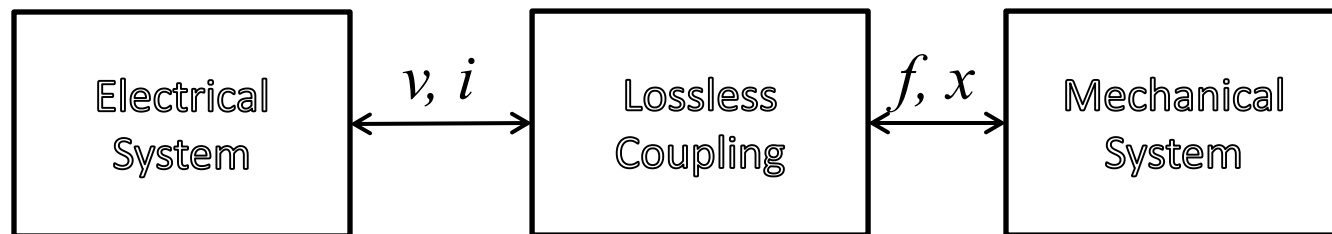
The purpose is to present techniques of systematic derivation of mathematical models (differential equations) for lumped-parameter electromechanical systems. The theory is outlined for N electrical coils and M mechanical variables.

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.

ELECTROMECHANICAL SYSTEMS

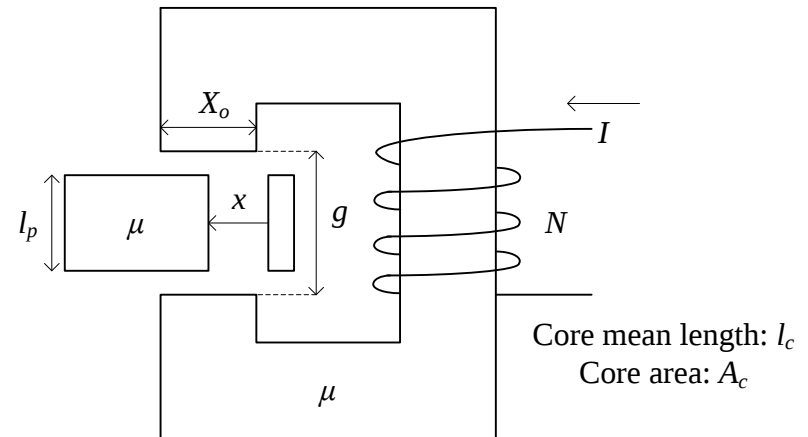
- A basic electromechanical system has an electrical part, a mechanical part, and electromechanical coupling. This coupling is assumed to be lossless.



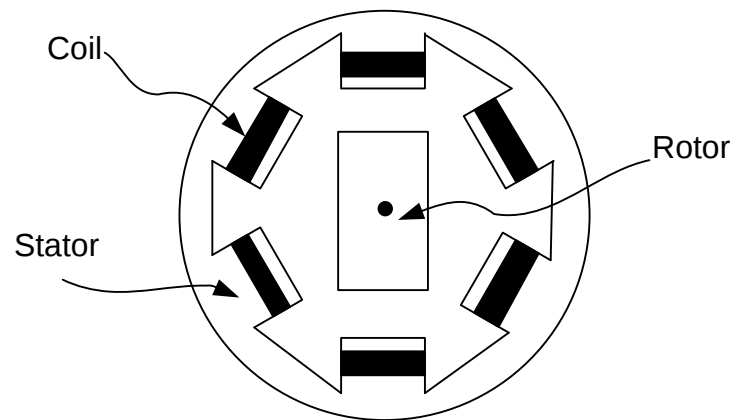
- Systems with linear motion see a force f and a displacement x , while rotational systems see a torque T and a displacement θ .

EXAMPLES

- Linear(translational) motion:



- Rotational motion:

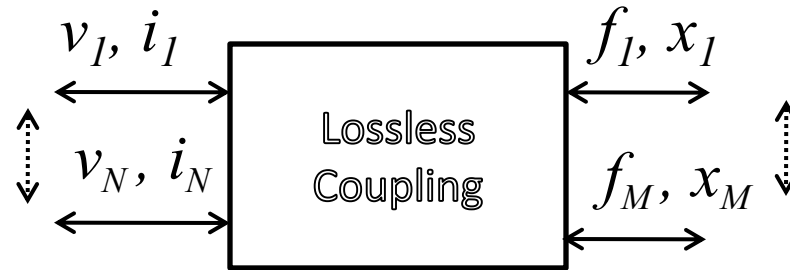


FLUX LINKAGE AND VOLTAGE

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

MULTI-PORT SYSTEMS

$$\lambda_k = \lambda_k(i_1, i_2, i_N, \dots, x_1, x_2, \dots, x_N), \quad k = 1, \dots, N$$



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

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

$$f_i^e = f_i^e(i_1, i_2, \dots, i_N, x_1, x_2, \dots, x_M)$$

LINEAR SYSTEM EXAMPLE

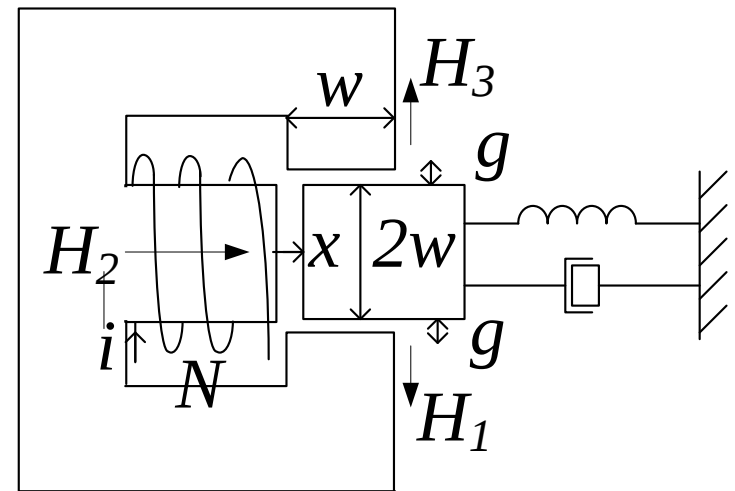
Basic configuration is used for tripping circuit breakers, operating valves, etc. It consists of:

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

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

$$H = 0 \quad \text{in the iron}$$

- H exist only in the air gap



LINEAR SYSTEM EXAMPLE

- Ampere's loops:

$$H_3 g - H_1 g = 0$$

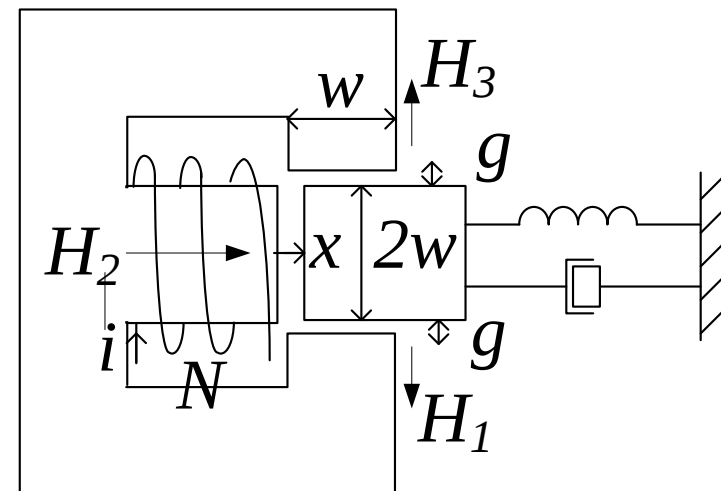
$$H_2 x + H_1 g = N i$$

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

$$\Rightarrow 2\mu_o H_1 w d - 2w d \mu_o H_2 = 0$$

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

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



d is the depth of the structure

LINEAR MOTOR EXAMPLE

$$\lambda = N \phi_2$$

$$\lambda = L i$$

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

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

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

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

Transformer
voltage

Speed
voltage