

MCE441: Intr. Linear Control Systems

Lecture 4: Dynamic Modeling of Engineering Systems Electromechanical Systems

Cleveland State University

Mechanical Engineering

Hanz Richter, PhD

Instructor

MCE441 – p.1/1

Transducers

A transducer is a device that converts one kind of energy into another. Transducers can be sensors or actuators.

Examples:

- Mechanical to mechanical: Gearbox
- Electromechanical: DC motor, generator
- Fluid-mechanical: Pump, turbine

Many devices exist that are based on every imaginable effect or physical principle:

- Hall effect (proximity sensors)
- Piezoelectric effect (load cells, microphones)
- Electrobiological effects: EEG, ECG...

Rare effects listed in Ballentyne, D.W.G., 1980.

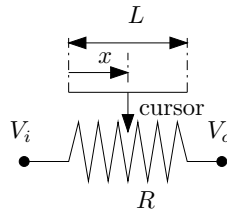
MCE441 – p.2/1

Electromechanical Coupling

We will concentrate on electromechanical coupling, including magnetic effects.

Resistive Coupling Devices translate a mechanical displacement into a change in resistance. Allows to manipulate voltage by means of displacement.

Example: Linear potentiometer

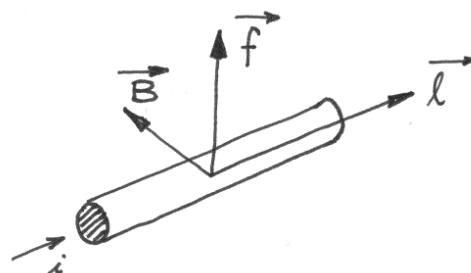


$$R(x) = \frac{x}{L} R$$

Coupling by a Magnetic Field

2 physical principles involved:

A) Electromagnetic force



“When a current-carrying conductor is placed in a magnetic field, a force is exerted on the conductor (motor effect)”

$$\vec{f} = i (\vec{l} \times \vec{B})$$

Electromagnetic force...

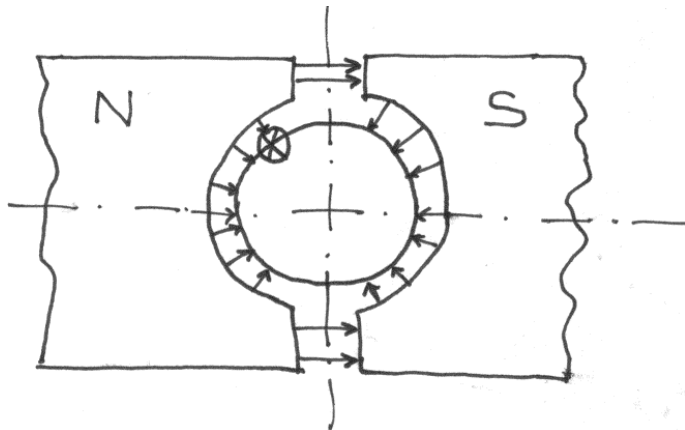
- i : Current (A), scalar
- \vec{l} : length vector (m), defined in the same direction as i .
- \vec{B} : Magnetic flux density vector (Wb/m²), always directed from N to S
- \vec{f} : Force: using the above units results in Newtons (N).

If \vec{l} and \vec{B} are perpendicular (many devices satisfy this) then

$$F = Bli$$

MCE441 - p.5/1

Example



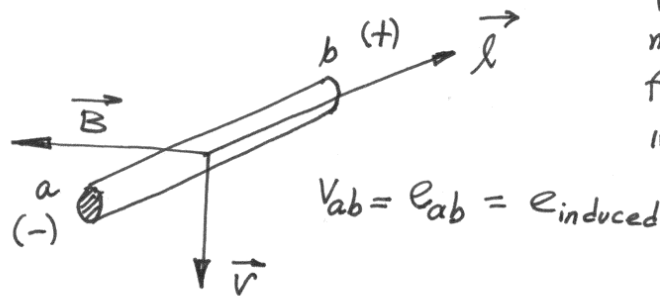
If the current flows into the page for the conductor shown, in which direction will the rotor turn?

CW CCW

MCE441 - p.6/1

Electromagnetic Induction

B) Electromagnetic induction : It is the dual principle to electromagnetic force.



"When a conductor moves in a magnetic field, a voltage is induced (generator effect)"

$$e_{ind} = (\vec{v} \times \vec{B}) \cdot \vec{l}$$

MCE441 - p.7/1

Electromagnetic induction...

- \vec{l} : length vector (m), defined in the same direction as i .
- \vec{B} : Magnetic flux density vector (Wb/m^2), always directed from N to S
- \vec{v} : Velocity vector (m/s)
- e_{ind} : Induced voltage, scalar. Using the above units results in Volts (V). It is polarized as shown in the picture. (Thumb indicates +)

If \vec{l} and \vec{B} are perpendicular then

$$e_{ind} = Blv$$

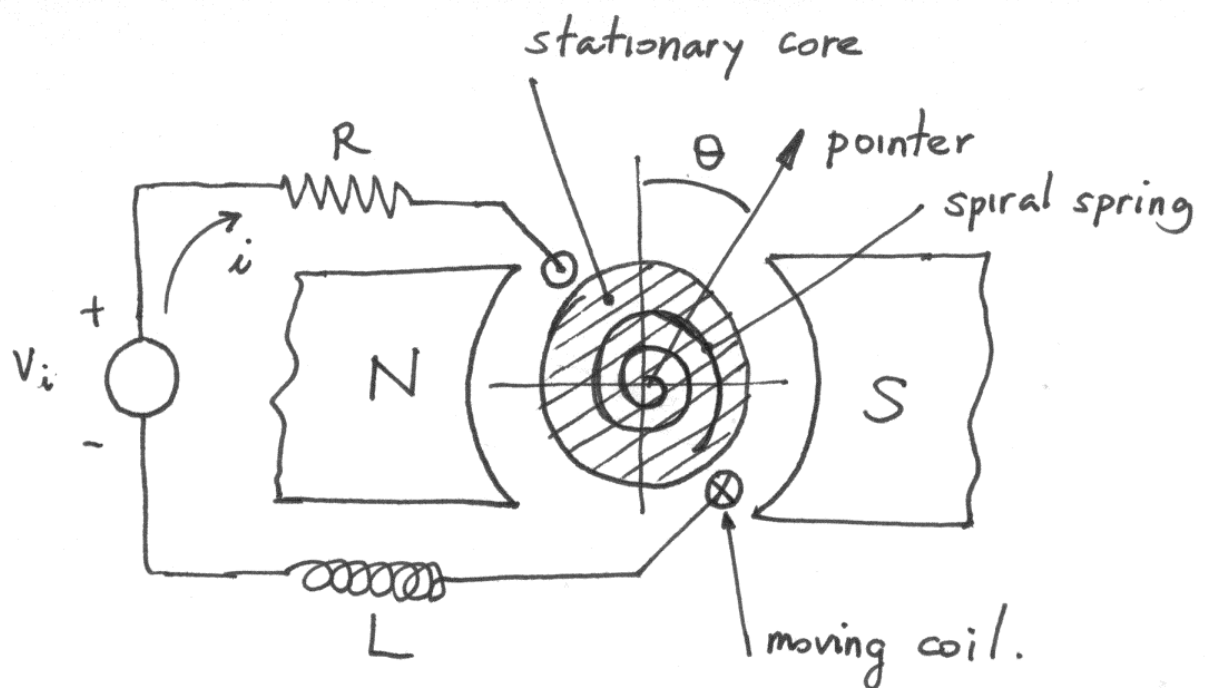
MCE441 - p.8/1

Important

In electromechanical devices coupled by a magnetic field (speakers, motors, generators, microphones...) both effects are present at the same time and interact dynamically. In generator technology, the effect is known as “armature reaction” and it is the origin of the torque required to drive the generator. In motors, the armature reaction creates an induced voltage that opposes the applied one, effectively reducing the current through the coils and the delivered torque.

MCE441 – p.9/1

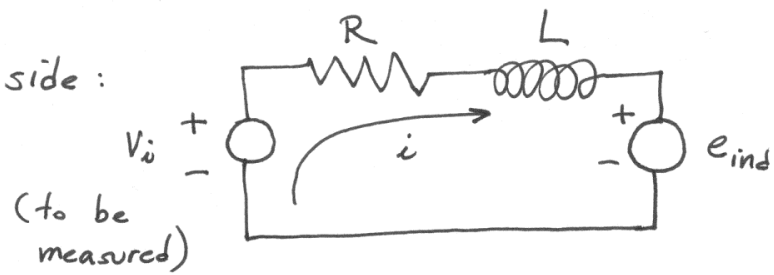
Example: Moving-coil galvanometer



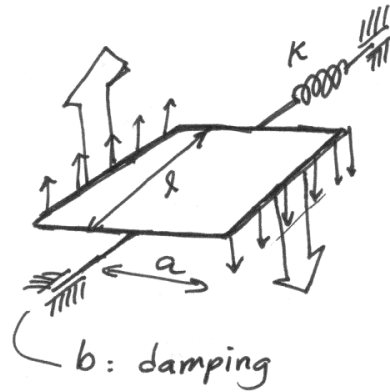
MCE441 – p.10/1

Moving-coil galvanometer..

Electrical side :



Mechanical side :



Derivation of Galvanometer Equations

Derivation of Galvanometer Equations

MCE441 – p.13/1

Derivation of Galvanometer Equations

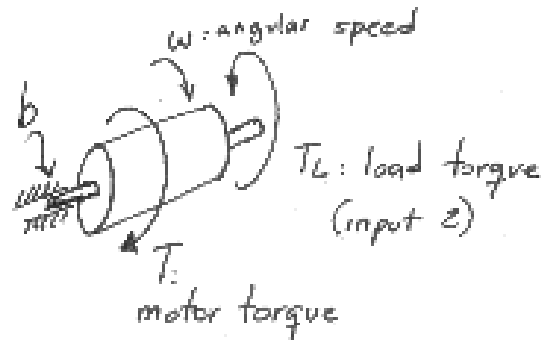
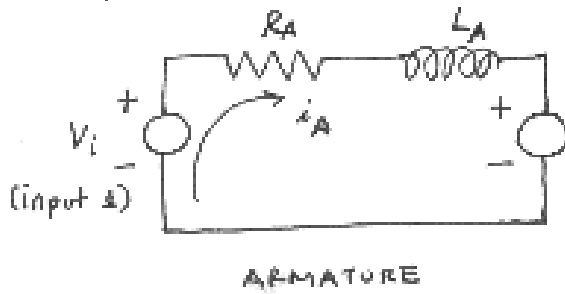
$$\begin{aligned}L \frac{di}{dt} + iR + \alpha \dot{\theta} &= V_i \\ J \ddot{\theta} + b \dot{\theta} + k\theta &= \alpha i\end{aligned}$$

The equations can be decoupled by differentiation and substitution or, more easily, with the Laplace transform.

MCE441 – p.14/1

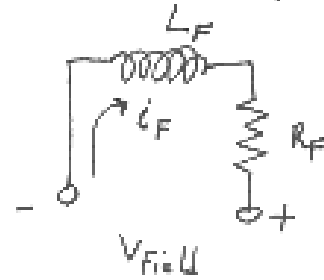
DC Motor, Independent Field Excitation

Simple linear model:



For fixed i_F :

$$\begin{cases} T = \alpha i \\ e_{ind} = \alpha \omega \end{cases}$$



α is, in general, a nonlinear function of i_F .

DC Motor Equations

DC Motor Equations

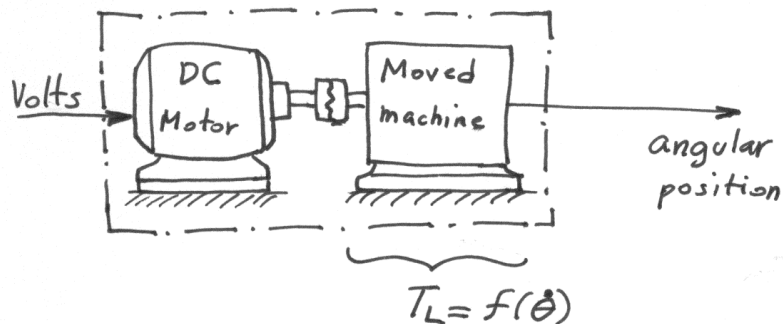
If we eliminate the armature current from the above equations (do it!) we obtain a single I/O equation with 2 inputs (load torque and driving voltage):

$$\ddot{w} + \left(\frac{R_A}{L_A} + \frac{b}{J} \right) \dot{w} + \left(\frac{R_A b + \alpha^2}{J L_A} \right) w = \frac{\alpha}{J L_A} V_i - \frac{1}{J} \dot{T}_L - \frac{R_A}{J L_A} T_L$$

MCE441 - p.17/1

Important

The load will have its own dynamics (torque-velocity characteristic). If we take this into account, T_L may be eliminated by substitution of $T_L = T_L(\dot{\theta})$. In that case, J represents the combined inertia of the motor and load, and b represents the combined damping.



MCE441 - p.18/1