MCE380: Measurements and Instrumentation Lab

Chapter 5: Electromechanical Transducers

Part I

Topics:
Transducers and Impedance
Magnetic Electromechanical Coupling

Reference: Holman, CH 4.

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Transducers

- A transducer is a device which converts one kind of energy into another.
- Transducers can be *sensors* or *actuators*.
- An actuator is capable of manipulating the input of the subsystem connected to its output, according to a commanded signal at the actuator's input. An actuator delivers power to a system. *The output of an actuator must not deteriorate as power is drawn from it.*
- A sensor measures the output of the subsystem connected to its input. *It must do so without drawing significant power from the measured system, so the measurand does not change because of the measuring activity*.

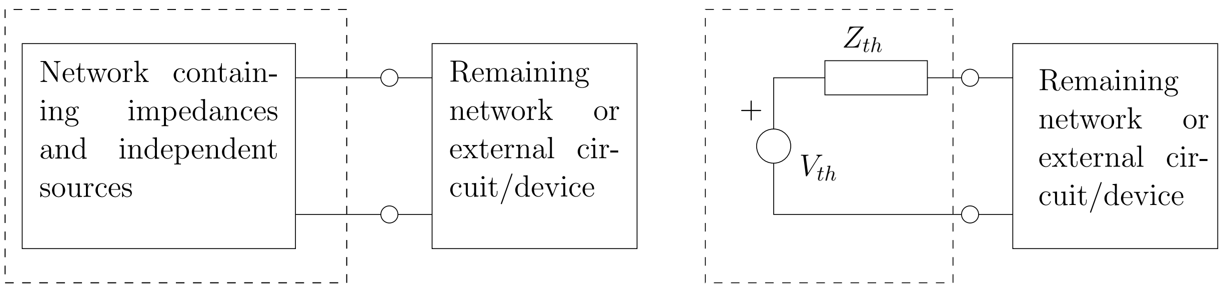
Input and Output Impedance

- The output impedance of a system is, roughly speaking, a measure of the deterioration (reduction) in output signal when power is drawn from the system.
- The input impedance of a system is, roughly speaking, a measure of the difficulty to inject power at the system imput.
- A sensor must have a —– input impedance, while the measured output should have a —– (output) impedance.
- A power supply must have a —— output impedance.
- Think of a microphone as a sound sensor. The input is a mechanical quantity (sound pressure), while the output is electrical. Find the output impedance of the following microphone:

http://www.shure.com/ProAudio/Products/WiredMicrophones/us_pro_PG48-XLR_content

Output Impedance and the Thevenin's Equivalent

Circuits containing resistors, capacitors, inductors and voltage and current sources are equivalent to a voltage source in series with a single impedance:



Example: An 10V power supply having an output impedance of 10Ω is connected to a 1kΩ resistive load. Calculate the deterioration in output signal and the power delivered. Re-calculate for loads of 10Ω and 1Ω.

Comment: The example is a simple case for a purely resistive output impedance connected to a resistive load, with constant voltage. More realistic situations and mechanical impedances are studied in Mechatronics courses (MCE403/503 and MCE603/703).

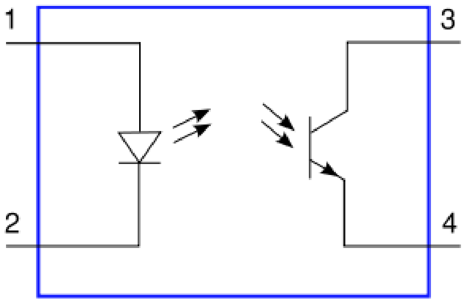
Impedance Matching Principles

As you see, the amount of power delivered to the load changes when the source is non-ideal. When the purpose is to maximize the power delivered to the load, the impedance of the load must be matched to that of the source. Matching means $R_s = R_L$ for resistive sources and loads. We now prove that this is true. A quite different principle applies when connecting a sensor output to an instrument (amplifier, oscilloscope). Here, the output impedance of the sensor must be as low as possible, while the input impedance of the instrument must be as high as possible.

We now prove that this is true.

Transformers and Optocouplers for Impedance Matching

A transformer can be used to raise the input impedance of a device relative to the output impedance of another, so that they are matched. Old TV's must use an inline transformer to match the antenna input to the cable signal. A disadvantage of transformers is that they do not operate in DC mode.
An optocoupler electrically isolates the interconnected systems. The coupling occurs through light instead of electricity and it is one-way. This effectively removes impedance mismatches.



Electromagnetic Induction Principles

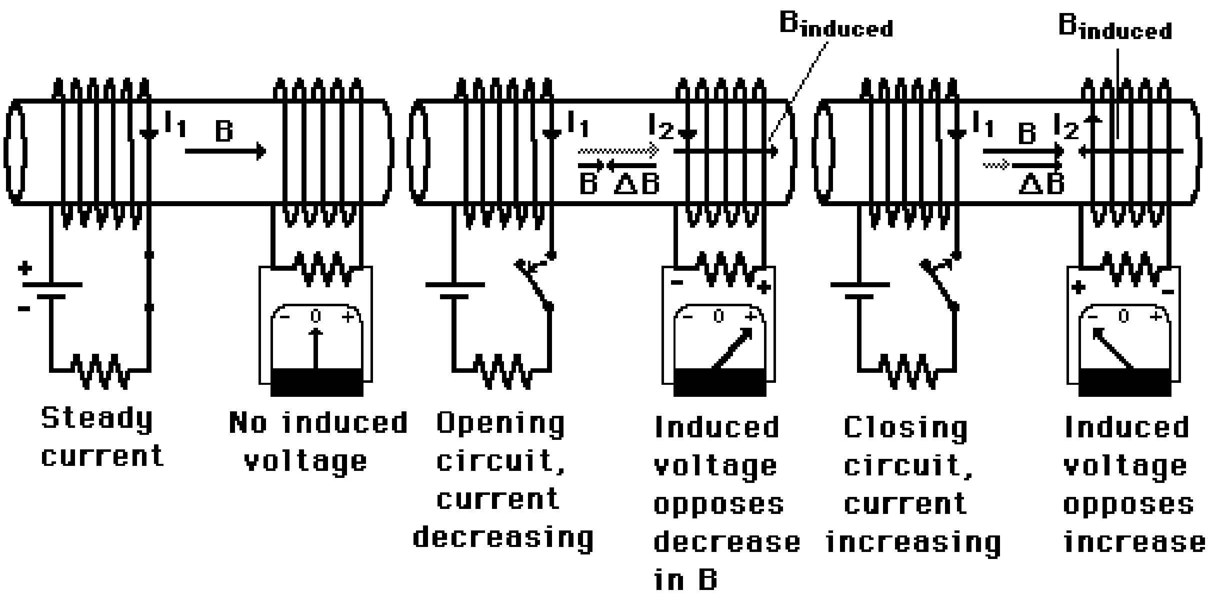
- A large number of electromechanical sensors and actuators are based on electromagnetic force (Lorentz force) and induction.
- Rotary and linear motors, DC, AC or pulsed (stepper motors) are based on these principles.
- Electric generators used for sensing are based on the same principles.
- Faraday's induction law:

$$\varepsilon = -\frac{\Phi_B}{dt}$$

  where ε is the electromotive force and Φ_B is the magnetic flux in Webers (Wb).
- Faraday's law explains the operation of electrical transformers. In particular it is evident why a transformer cannot work with constant voltage.

Mutual Inductance and Lenz's Law

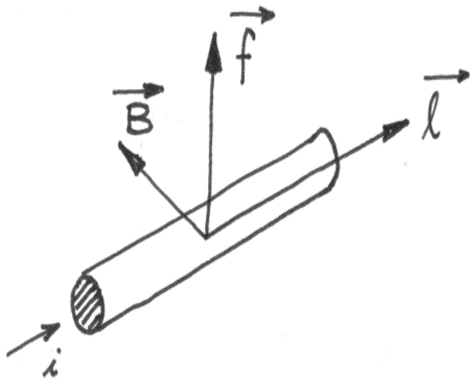
Lenz's Law: The induced emf has a polarity such that the resulting magnetic flux opposes the change of the incoming flux.



Electromagnetic Conversion in DC Machines

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/m^2), 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

$$\boxed{F = Bli}$$

Example

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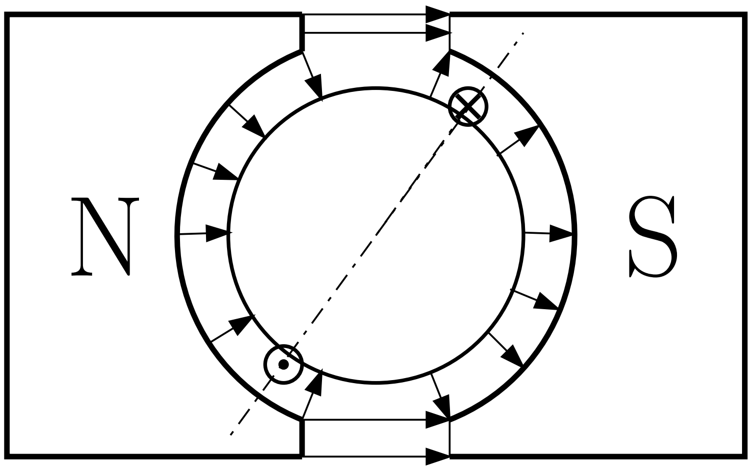
⊙ out of the page

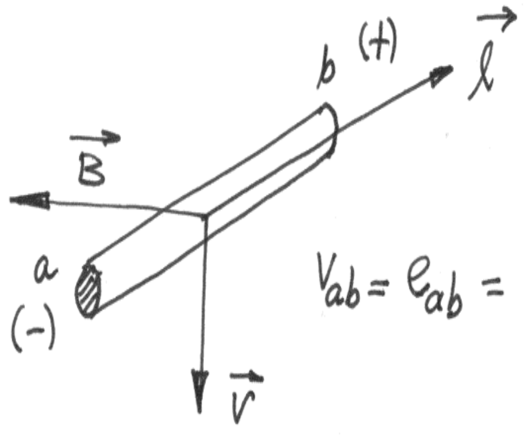


In which direction will the rotor turn?

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)



$$V_{ab} = e_{ab} = e_{induced}$$

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

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

$$\boxed{e_{ind} = Blv}$$

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 curret throught the coils and the delivered torque.

DC Generator as Speed Sensor

- A *tachometer* is an angular velocity sensor. A DC generator can be used for the purpose
- The output voltage is αw when connected to a measuring device having a high input impedance
- Many motors used for control purposes have a built in tachometer:

Commutation in DC Machines