Actuators in Electro- and Magnetostatics

Outline

Lorentz Force Law
MEMs Devices
Homopolar Motor
Speakers
Homopolar Generator
TRUE or FALSE?

1. Tangential electric field is always continuous at a surface.

2. Tangential magnetic field is always continuous at a surface.

3. An electric generator, or dynamo, is created by running a motor in reverse, i.e. hooking up the power source with the opposite polarity.
Lorentz Force Law (1892)

\[ \vec{f} = q(\vec{E} + \vec{v} \times \mu_0 \vec{H}) \]

Replaced Ampere’s force law, widely used in the 1800s

\( \vec{v} \times \vec{B} \) term had been known earlier; was published by Maxwell in 1861

Note that this law does not explain forces on dielectrics or magnetically permeable materials. Most common actuators employ these forces.

Hendrik Lorentz

Portrait in United States Public Domain
Digital Light Processing
Normal Force between Two Charged Plates

Gauss’s Law:

\[ E = \hat{x} \frac{q}{\varepsilon_0 A} \]

- In electric field systems, force tends to increase capacitance
- In magnetic field systems, force tends to increase inductance
For a current carrying wire

\[ \vec{f} = q(\vec{E} + \vec{v} \times \mu_0 \vec{H}) \]

Note this follows the ‘right-hand’ rule

Section of wire in a magnetic field: force per unit length is:

\[ \vec{f}_m = I \times \mu_0 \vec{H} \]

Check units: A X H/m X A/m = J/m^2 = N/m
First magnetic motor as created by Michael Faraday in 1821

Homopolar Motor
Homopolar Motor
Speakers

“Music! I feel happy, yay!”

Current (I) waveform

Pressure waves
Loudspeaker

The loudspeaker is just a coil that makes a force applied to the paper cone. It has a low force spring to keep things centered (not shown below).

We will get to how the magnetic field is made later.

http://static.howstuffworks.com/flash/speaker-working.swf
Force exerted on the voice coil: (up)

\[ F = 2\pi R N I \mu_0 H_r = KI \]

\[ E_B = Ku \]

Suppose the voice coil is light and produces a force: \( F = \beta u \)

Then:

\[ E_B = K \frac{F}{\beta} = \frac{K^2}{\beta} I = Z_0 I \]

And here is the electrical equivalent circuit:

So now you know what they mean when they talk of an 8 ohm speaker.
Today’s Culture Moment

Vocoders

A vocoder is an audio processor that captures the characteristic elements of an audio signal and then uses this characteristic signal to affect other audio signals. The technology behind the vocoder effect was initially used in attempts to synthesize speech. The effect called vocoding can be recognized on records as a “talking synthesizer”, made popular by artists such as Stevie Wonder.

Image by snackfight on flickr [http://www.flickr.com/photos/snackfight/3486304280/]
Speakers

Why is it hard for earbuds to have good bass?
Electrostatic Speakers

Lower distortion
Extremely light weight diaphragm
Exemplary frequency response (both in amplitude and phase)

Lack of good bass response
Homopolar Generator
Dynamo Brain Teaser

(a) Dynamo A

(b) Dynamo B

Only one of these devices can be a dynamo
Summary

• Lorentz force law \( \vec{f} = q(\vec{E} + \vec{v} \times \mu_0 \vec{H}) \)
• MEMs actuators (such as DLP arrays) rely on electrostatic attraction
• A commutator periodically reverses the current direction between the rotor
• Speakers (vibrating diaphragm) can utilize magnetostatic or electrostatic forces
• Induced current is always in such a direction as to oppose the motion or change causing it
6.007 Electromagnetic Energy: From Motors to Lasers
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