EVROPSKÁ UNIE
Evropské strukturální a investiční fondy
Operační program Výzkum, vývoj a vzdělávání

MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY

4. Basics of magnetism and magnetic circuits

4.1 Origin of magnetic field and its quantities

4.2 Magnetic material characteristics and classification

4.3 Basic rules and laws of magnetic field

4.4 Application of magnetic field characteristics in electrical devices

Doc. Ing. Stanislav Kocman, Ph.D.
December 2017

4.1 Origin of magnetic field and its quantities

The knowledge of magnetism goes back to the ancient times. Magnetism is a physical phenomenon that is mediated by magnetic field (https://en.wikipedia.org/wiki/Magnetism). The relationship between electricity and magnetism was discovered by H. C. Oersted in the early 1800s. The origin and some sources of magnetism are as follows:

- lodestone: a natural magnet
- Earth is magnetic
- iron, nickel, cobalt and their alloys (magnets)
- electrical current
- electromagnet

4.1.1. Quantities of magnetic field

Magnetic field can be generated by electric charge in motion (e.g. electric current in a wire) and has the force effect, which is quantifies by the magnetic flux density *B*. The magnetic flux φ is defined as the flux density evaluated over surface *S*. If the flux is uniform over the surface and vertical to it, the expression is used:

$$\varphi = B \cdot S \,(\mathrm{Wb})$$

The magnetic field intensity *H* is defined as:

$$H = \frac{B}{\mu} = \frac{B}{\mu_0 \mu_r} \,(\mathrm{A/m})$$

Where μ is permeability of medium, μ_0 is permeability of free space ($4\pi \times 10{-}7$ H/m) and μ_r is relative permeability of substance (G. Rizzoni: Fundamentals of electrical engineering).

The magnetic flux linkage ψ is related to a coil with *N* turns. If assumed that each turn of the coil links the same flux so the flux linkage can be stated as:

$$\psi = N \cdot \varphi \,(\mathrm{Wb\text{-}turns})$$

To increase the strength of the magnetic field, a coils with *N* turns is used so the force of the field is also increased according to the formula:

$$F_m = N \cdot i \,(\mathrm{A\text{-}turns})$$

Where F_m is magnetomotive force (mmf) (G. Rizzoni: Fundamentals of electrical engineering).

If a moving conductor is placed into magnetic field, the electromotive force (emf) is induced into it as stated:

$$e = -\frac{\mathrm{d}\varphi}{\mathrm{d}t} \text{ or } e = -N\frac{\mathrm{d}\varphi}{\mathrm{d}t} \,(\mathrm{V})$$

To increase the emf the conductor with *N* turns must be used. The same effect can be obtain if the a static conductor is placed into time-varying magnetic field (G. Rizzoni: Fundamentals of electrical engineering).

4.2. Magnetic material characteristics and classification

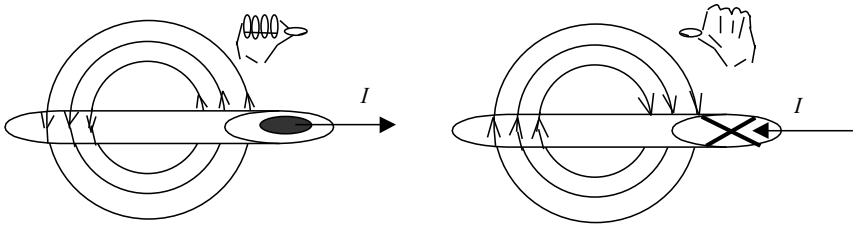
Magnetic characteristics of various substances depend strongly on the value of their relative permeability (https://en.wikipedia.org/wiki/Magnetism). A classification according its value is:

- diamagnetic: repelled by both poles of a magnet e.g. gold, silver, copper, carbon, mercury….($\mu_r \leq 1$)
- paramagnetic: weakly attracted to either pole of a magnet e.g. aluminum, lithium, magnesium, sodium….(μ_r>1 slightly)
- ferromagnetic: attracted to a magnet strongly: iron, nickel, cobalt, and their alloys…. (μ_r>>1)
- ferrimagnetic: attracted to a magnet strongly: ferrite (iron oxides with aluminum, cobalt, nickel….) (μ_r>>1)

4.3. Basic rules and laws of magnetic field

4.3.1. Ampere´s Law

Ampère's law states that the magnetic field intensity H in the vicinity of a conductor is related to the current carried by the conductor. To determine the magnetic field direction, Ampere's right-hand rules are used. The first one is used to determine the magnetic field direction for a long, straight current-carrying wire as seen in the figure (https://en.wikipedia.org/wiki/Right-hand_rule). The second one is used to determine the magnetic field direction in a coil of a current-carrying wire. It states that if the coil is handled by the right hand that fingers point in the direction of the current in turns, then the stretched thumb points in the direction of the field.



4.3.2. Faraday´s Law

Faraday's law states that a time-varying magnetic flux causes an induced electromotive force into a conductor, or induces a voltage, and therefore a current, in the conductor:

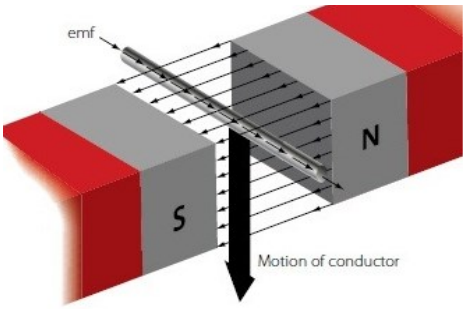
$$e = -\frac{\mathrm{d}\varphi}{\mathrm{d}t} \text{ or } v_{ind} = \frac{\mathrm{d}\varphi}{\mathrm{d}t} \text{ (V)}$$

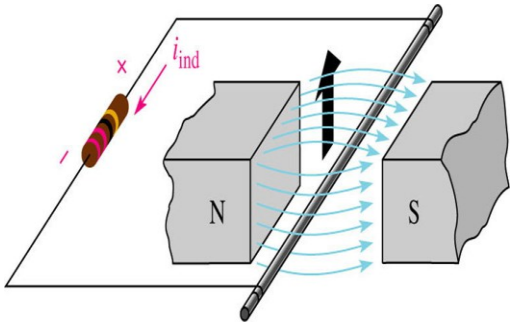
In the case of a coil with N turns the electromotive force (voltage) also depends on the number of turns on the coil (https://en.wikipedia.org/wiki/Faraday%27s_law_of_induction):

$$e = -N\frac{\mathrm{d}\varphi}{\mathrm{d}t} \text{ or } v_{ind} = N\frac{\mathrm{d}\varphi}{\mathrm{d}t} \text{ (V)}$$

4.3.3. Lenz´s Law

The current flows in the conductor in such a way that the magnetic flux generated by the current is oppose the increasing flux (https://en.wikipedia.org/wiki/Lenz%27s_law).

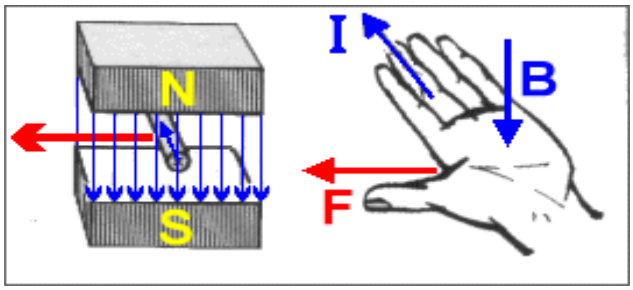




4.3.4. Fleming´s Law

If a current-carrying wire is placed into a magnetic field of e.g. a permanent magnet, the magnetic field of the permanent magnet affects the wire by a force. The direction of the force is determined by using Fleming's left-hand rule:

1) The magnetic field of the permanent magnet enters into the open left hand.
2) The fingers point in the direction of the current flowing through the wire.
3) The stretched thumb points in the direction of the motion of the wire (it is in the direction of the force).



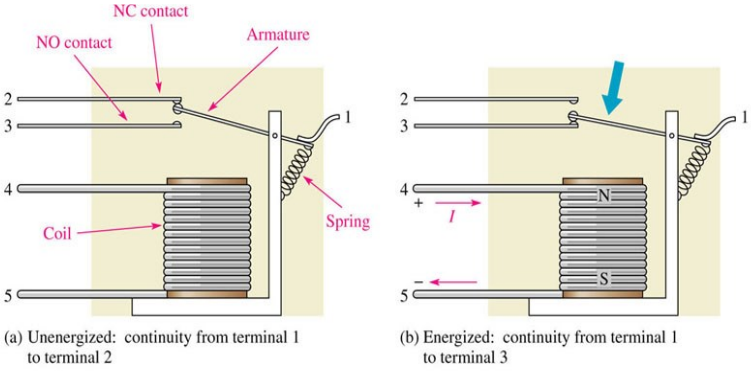
The value of the force is calculated as:

$$F = B \cdot I \cdot l$$

Where l is length of the wire in the magnetic field, which is vertical to the magnetic field. Other variant to determine the direction of the force on the conductor is also used (https://en.wikipedia.org/wiki/Fleming%27s_left-hand_rule_for_motors).

4.4. Application of magnetic field characteristics in electrical devices

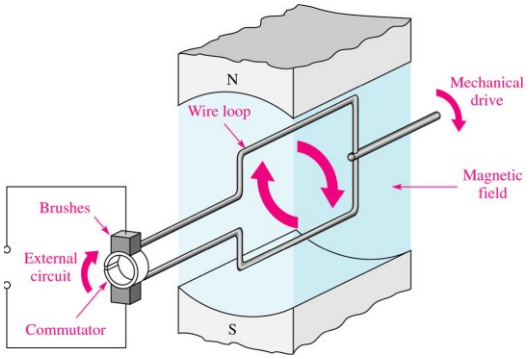
There are a lot of practical applications of magnetism or electromagnetism in the practice. Many technical devices are kind of an electromechanical system which includes an electrical system and a mechanical system. Electrical signals can be converted into mechanical forces, and vice versa. The household applications are e.g. the lighting, kitchen appliances, audio/video devices, security systems, etc. The industrial applications are e.g. measuring instruments, relays, contactors, electrical machines (motors, generators, and transformers), electromagnets, sensors, actuators, etc.



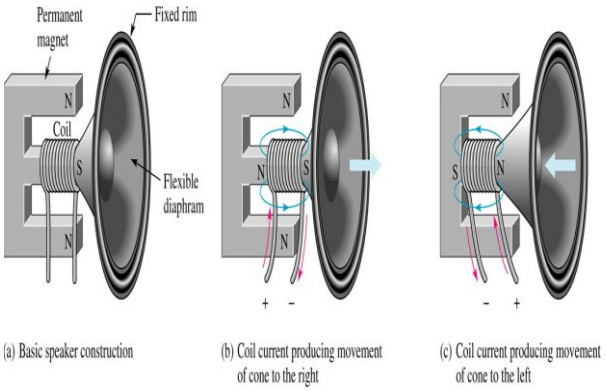
(a) Unenergized: continuity from terminal 1 to terminal 2

(b) Energized: continuity from terminal 1 to terminal 3









(a) Basic speaker construction

(b) Coil current producing movement of cone to the right

(c) Coil current producing movement of cone to the left

