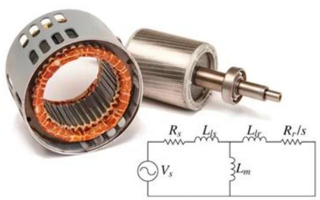
Polytech Orléans – M1 AESM

Electrical Engineering



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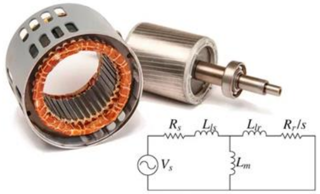


Schedule

	M1 AEMS
Lectures	14 x 1,25 h dont 2 DS
Tutorials	8 x 1,25 h
Lab work	1 x 2,50 h + 6 x 3,75 h

Outline

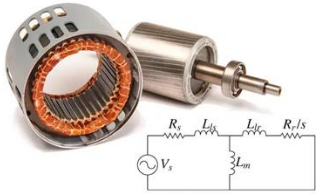
Introduction

I) Reminders (electricity)

II) Power in sinusoidal regime (single-phase and 3-phase)

III) Transformers

IV) Electric motors



Reminders: electromagnetism

- The electrical field: an electrical charge, q_A, placed at any point A in space, acts at any other point M in space, in the form of a vector field called the "electric field $E_A(M)$" expressed in $V.m^{-1}$

- **Electrical field due to charge q_A at point M**

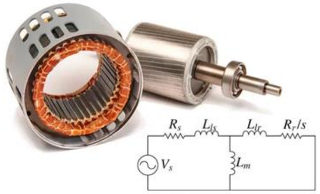
$$\overrightarrow{E_A(M)} = \frac{q_A}{4.\pi.\varepsilon_0.AM^2}.\vec{u}$$

$E_A(M)$ in $V.m^{-1}$, q_A in C, AM in m
ε_0, vacuum permittivity: $\boldsymbol{\varepsilon}_0 = 10^{-9} / 36\pi$ $F.m^{-1}$

- Properties of the electrical field:

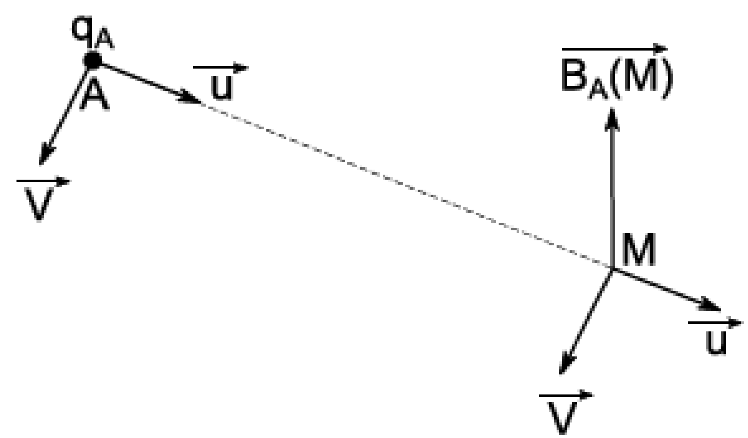
=> Inversely proportional to the square of the distance from its source. It scales with "$1/r^2$"

=> Additive quantity



Reminders: electromagnetism

- The magnetic field: An electrical charge, q_A, located at any point A in space and moving with velocity "V", acts at any other point M in space, in the form of a vector field called the "magnetic field $B_A(M)$" expressed in Tesla (T).



- **Magnetic field in vacuum at point M due to charge displacement q_A**

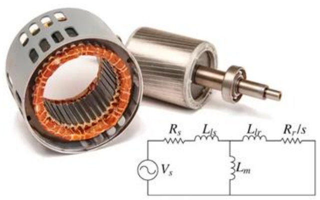
$$\overrightarrow{B_A(M)} = \frac{\mu_0}{4.\pi}.\frac{q_A.\vec{V} \wedge \vec{u}}{AM^2}$$

$B_A(M)$ in Tesla, q_A in C, V in m/s, AM in m
μ_0, vacuum permeability in $m.T.A.m^{-1}$, $\mu_0 = 4.\pi.10^{-7}$ $m.T.A.m^{-1}$ (or $H.m^{-1}$)

- Properties of the magnetic field:

=> Inversely proportional to the square of the distance from its source. It varies in "$1/r^2$".

=> Additive quantity



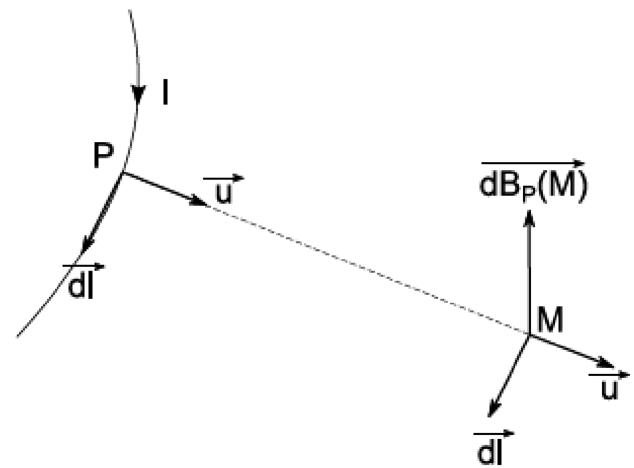
Reminders: electromagnetism

- The Biot and Savart's law: The elementary part dl of an electrical circuit in P through which a current of intensity I flows creates the "magnetic field $dB_P(M)$" at a point M in space

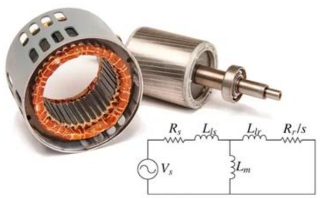
- **Magnetic field at point M due to the current I flowing through the elementary part dl**

$$\overrightarrow{dB_P(M)} = \frac{\mu_0}{4.\pi}.\frac{I.\overrightarrow{dl}\wedge\overrightarrow{PM}}{PM^3}$$

$$\boldsymbol{\overrightarrow{dB_P(M)} = \frac{\mu_0}{4.\pi}.\frac{I.\overrightarrow{dl}\wedge\vec{u}}{r^2}}$$



- Total magnetic field in M created by the electrical circuit : $\boldsymbol{\overrightarrow{B(M)} = \frac{\mu_0}{4.\pi}.\int_{P\in circuit}\frac{I.\overrightarrow{dl}\wedge\vec{u}}{r^2}}$



Reminders: electromagnetism

- The excitation magnetic field $\vec{H}$: dHP(M), is related to the state of magnetic excitation of the medium and is given in A.m^{-1}.

- Magnetic excitation field at point M due to the current I flowing through portion dl:

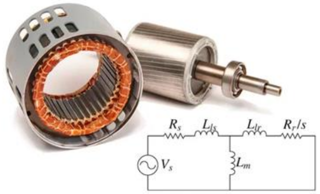
$$\overrightarrow{dH_P(M)} = \frac{1}{4.\pi}.\frac{I.\overrightarrow{dl}\wedge\vec{u}}{r^2}$$

- Total magnetic excitation field at M created by the wire through which a current I flows:

$$\overrightarrow{H(M)} = \frac{1}{4.\pi}.\int_{P\in fil}\frac{I.\overrightarrow{dl}\wedge\vec{u}}{r^2}$$

- If $\vec{H}$ is the excitation magnetic field, $\vec{B}$ is the magnetic induction field: $\vec{B} = \mu_0\mu_r\vec{H}$

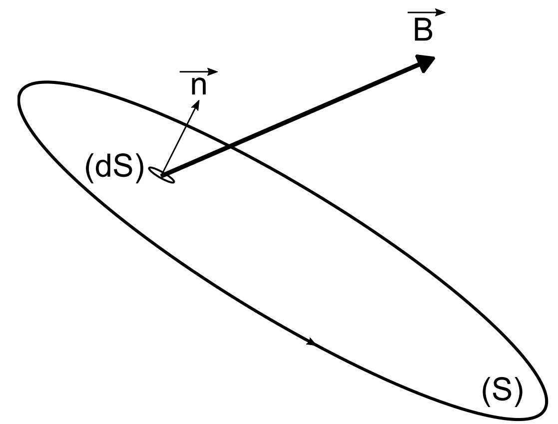
μ_0 vacuum permeability, μ_r the relative permeability



Reminders: electromagnetism

- The magnetic flux: The flux of induction magnetic field B across a closed surface (S) is the quantity ϕ_B given in Weber (Wb)

$$\boldsymbol{\Phi_B = \oiint_{(S)} \vec{B}.\overrightarrow{n_{ext}}.dS}$$



- The magnetic flux F is usually given by the product B.S
- If magnetic leakage is neglected, the flux in a magnetic circuit is conservative

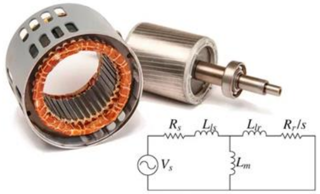
$$\boldsymbol{\Phi = B.S}$$

Analogy with the garden hose :

magnetic flux F → flow

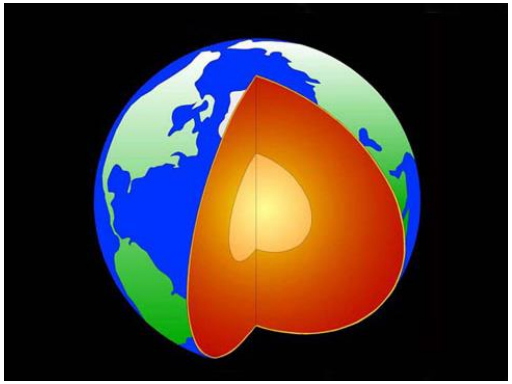
magnetic field B → water speed

solenoid cross-section S → pipe cross-section



Reminders: electromagnetism

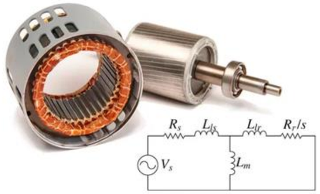
- Orders of magnitude



- Earth induction magnetic field: 50.10^{-6} T

In electrical machines:

- Induction magnetic field: 1 T à 1,5 T
- Excitation magnetic field : 1000 à 100000 $A.m^{-1}$
- Magnetic flux: 10^{-5} à 10^{-3} Wb

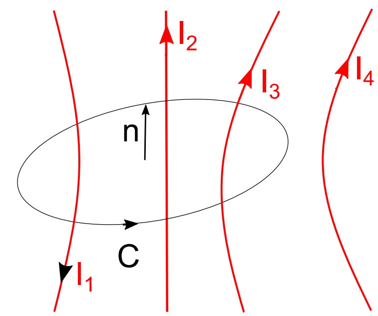


Reminders: electromagnetism

- Ampere's theorem: If (C) is a closed contour of space surrounding N wire conductors through which currents of intensities I_k flow, then the circulation of the magnetic excitation vector H along a closed contour l is equal to the sum of the entwined currents

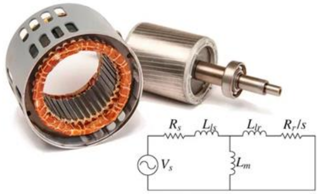
$$\oint_{(C)} \vec{H}.\overrightarrow{d\ell} = \sum_{k=1}^{k=N} i_k \qquad \boldsymbol{H.\ell = N.I}$$

- Example:



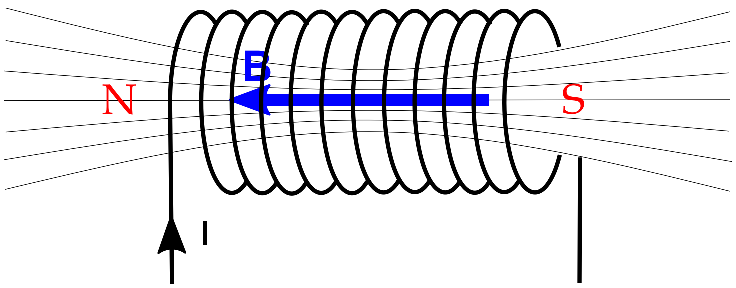
$$\oint_{(C)} \vec{H}.\overrightarrow{d\ell} = -i_1 + i_2 + i_3$$

- i_1 is counted as negative,
- i_2 and i_3 are counted as positive
- i_4 is outside the contour (not taken into account)



Reminders: electromagnetism

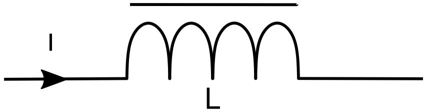
- Example: magnetic field created by a solenoid



- A solenoid is a straight winding with length l greater than its radius r.
- Inside the solenoid, far from its ends, the magnetic field is uniform.
- The field lines are parallel
- They enter at the coil's SOUTH face and exit at its NORTH face (corkscrew rule).

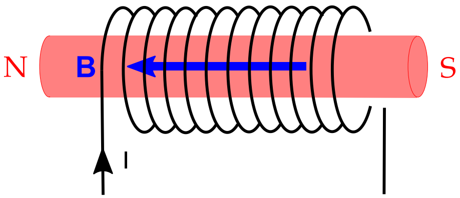
N: number of turns, l : length of solenoid

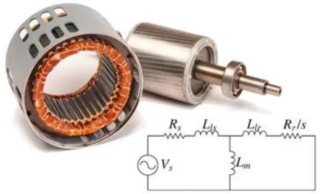
$$H = \frac{N.I}{l} \qquad B = \mu_0 . \frac{NI}{l}$$



$$\vec{B} = \mu \times \vec{H}$$

$$\mu = \mu_0 \times \mu_R$$





Reminders: magnetic materials

- Materials are classified according to their magnetic susceptibility χ

=> χ is related to the relative permeability through: $\mu_r = 1 + \chi$

- Para-magnetic materials: $\chi > 0$, between 10^{-3} and 10^{-7}

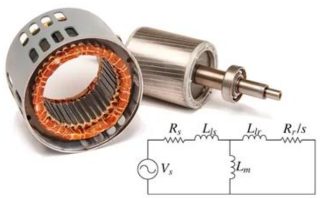
=> These materials are rare and their magnetization is negligible (Al, W, Pt, Sn…)

- dia-magnetic materials: $\chi < 0$, between 10^{-4} and 10^{-6}

=> These materials are common and their magnetization is negligible (non magnetic materials such as Cu, Bi, Au, Ag…)

- Ferro-magnetic materials: $\chi > 0$, between 10^{3} and 10^{6}

=> These are magnetic material of interest for magnetic circuits or transformer core (Fe, Ni, Co)



Reminders: magnetic materials

- Magnetic materials are characterized by their hysteresis loop

  => B=f(H) curve showing magnetizing/demagnetizing of the ferromagnetic material

- A ferromagnetic material that has never been magnetized will magnetize starting from O ("first magnetizing curve")

- The loop is run only in the direction of the arrows

- B_S: saturation induction magnetic field

- B_R: point of retentivity

=> Remanence of residual magnetism in the material

- H_C: point of coercivity

=> Coercive excitation magnetic field required to remove the residual magnetism in the material