Cairo University
Faculty of Engineering
Electrical Energy Engineering

Time Varying Field Applications
EPMN203
Sheet (1)

Revision

1. What is the force per meter of length on a straight wire carrying a 9.4 A current when perpendicular to a 0.9 T uniform magnetic field? What if the angle between the wire and field is 35?

2. A 13.0 cm diameter circular loop of wire is placed with the plane of the loop parallel to the uniform magnetic field between the pole pieces of a large magnet. When 4.2 A flows in the coil, the torque on it is 0.185 N.m. What is the magnetic field strength?

3. Two Long thin parallel wires 13.0 cm apart carry 35 A currents in the same direction. Determine the magnetic field vector at a point 10.0 cm from one wire and 6.0 cm from the other (Fig.1)

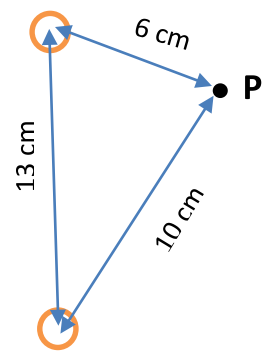


Fig. 1

4. A coaxial cable consists of a solid inner conductor of radius R_1. Surrounded by a concentric cylindrical tube of inner radius R_2 and outer radius R_3 (Fig.2). The conductors carry equal and opposite currents I_0 distributed uniformly across sections. Determine the magnetic field at a distance R from the axis for:
   a) $R < R_1$
   b) $R_1<R<R_2$
   c) $R_2<R<R_3$
   d) $R>R3$
   e) Graph B from R=0 to R= 3.00 if I_0=1.5 A, R_1=1.00 cm, R_2=2.00 cm, R_3=2.5 cm

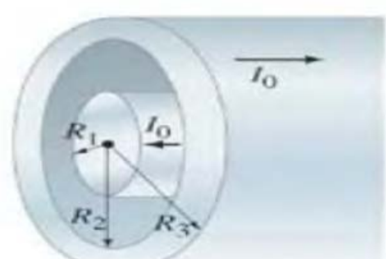


Fig. 2

5. A 40.0 cm long solenoid 1.35 cm in diameter is to produce a field of 0.385 mT at its center. How much current should the solenoid carry if it has 765 turns of wire?

6. A thin 10 cm long solenoid used for fast electromechanical switching has a total of 400 turns of wire and carries a current of 2.0 A. Calculate the field inside near the center.

7. Use Ampere's law to determine the magnetic field a) inside and b) outside a toroid, which is like a solenoid bent into the shape of a circle as shown in Fig.3.

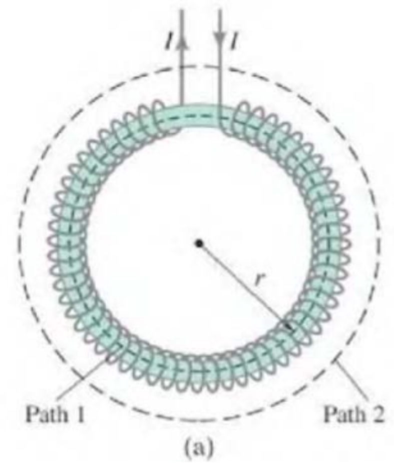
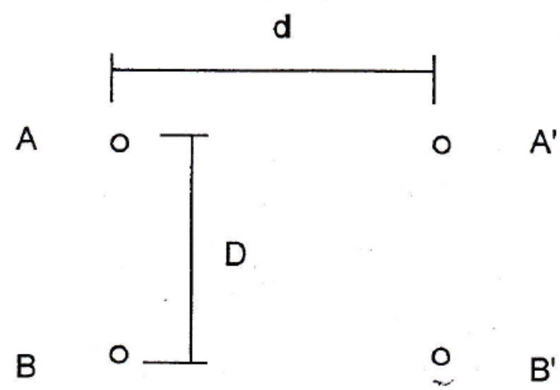


Fig. 3

8. For an infinitely long, infinitely wide current sheet carrying a current density K A/m, calculate the magnetic field intensity produced for a point at a distance d from it.
9. Calculate the mutual inductance/unit length between 2 parallel two-wire transmission lines A-A' and B-B' shown in the figure below. (Assume wire radii much smaller than separation distances).



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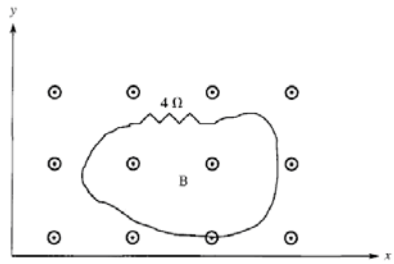
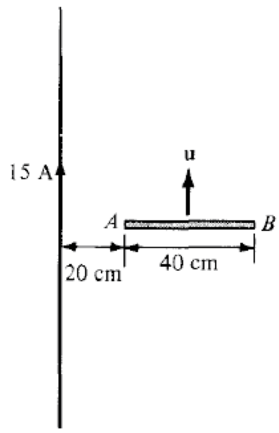
<u>Faraday's Law for Induction</u>

1. A circular loop of N turns of conducting wire lines in the x-y plane with its centre at the origin at the magnetic field specified by $\underline{B} = B_o\cos(\pi r/2b)\sin(\omega t)\ \underline{u}_z$, where b is the radius of the loop and ω is the angular frequency. Find the emf induced in the loop.

2. The figure shows a conducting loop of area 20 cm^2 and resistance 4 Ω. If $\underline{B} = 40\cos 10^4 * t\ \underline{u}_z$ mWb/m^2, find the induced current in the loop and indicate its direction.



3. A conducting rod moves with a constant velocity of 3 $\underline{u}_z$ m/s parallel to a long straight wire carrying current 15 A as in the next figure. Calculate the emf induced in the rod and state which end is at higher potential.

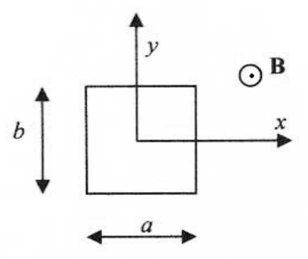


4. For the next figure, a rectangular loop lying in xy plane moves with a uniform velocity v in the direction of the positive y axis. It is subjected to sinusoidal magnetic field $\underline{B}=B_o\sin(ky)\ \underline{u}_z$.

Find:

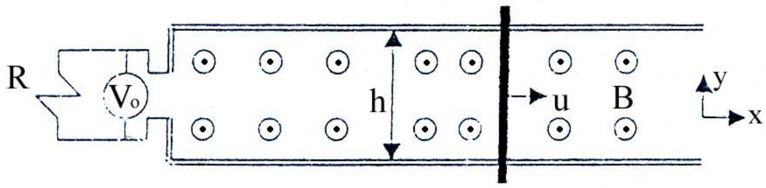
a. The flux enclosed in the loop at time t.
b. The induced emf inside the loop.

If $\underline{B}=B_o\sin(ky)\sin(\omega t)\ \underline{u}_z$, repeat a & b.

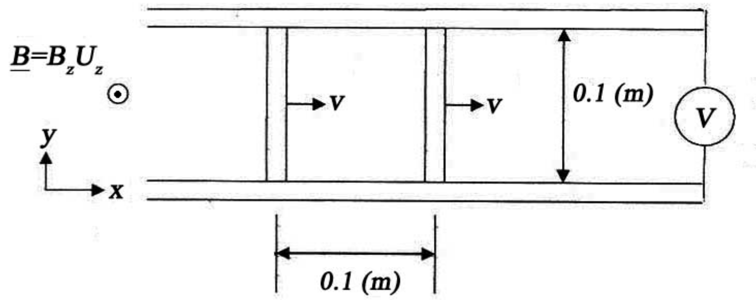


5. A metal bar sliding over a pair of conducting rails in a uniform magnetic field $\underline{B}=B_o\ \underline{u}_z$ with a constant velocity u. as shown in the next figure:

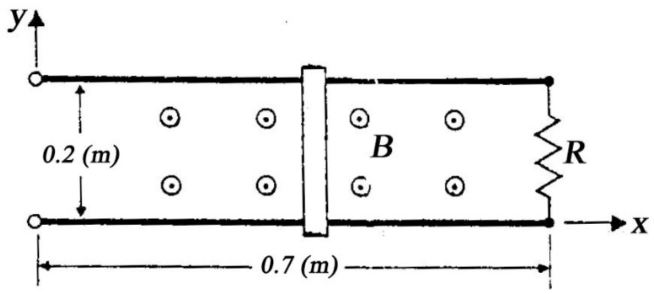
a. Determine the open circuit voltage V_o that appears across the terminals.
b. Assuming that a resistance R is connected between the terminals. Find the electric power dissipated in it.
c. Show that this electric power is equal to the mechanical power required to move the sliding bar with a velocity u. Neglect all the mechanical losses in the bar and the rails.



6. Two thin parallel bars 0.1m long spaced 0.1m apart move with equal constant velocities of 10 m/s in perfect contact with resistance less rails as shown in the next figure. The resistance of each bar is 0.01 ohm. The z-component of the static magnetic field varies as $B_z = 10^3 x^2 y$ Tesla in the region between the rails.
Find the reading of the voltmeter.



7. A conducting sliding bar oscillates over two parallel conducting rails in a sinusoidally varying magnetic field $\underline{B} = 5 \cos\omega t\ \underline{z}$ mT as shown in the next figure. The position of the sliding bar is given by x = 0.35(1-cos ωt) m, and the rails are terminated in a resistance R = 0.2 Ω. Find the current (i).



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Magnetic Circuits

1. The thickness of the magnetic circuit shown in the figure is 10 cm and the relative permeability of the iron core is 5000.
    a. Find the MMF required to produce a core flux of 0.0025 Wb.
    b. If the coil has 50 turns, find the needed current that should flow through the coil.

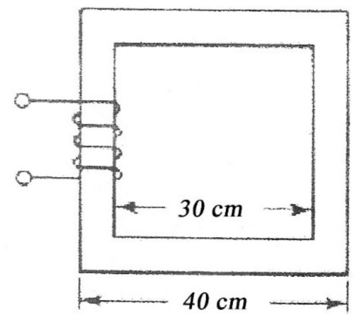


Fig. 1

2. A ferromagnetic core is shown in Fig. 2. The depth of the core is 5 cm. The other dimensions of the core are as shown in the figure. Find the value of the current that will produce a flux of 0.005 Wb. With this current, what is the flux density at the top of the core? What is the flux density at the right side of the core? Assume that the relative permeability of the core is 1000.

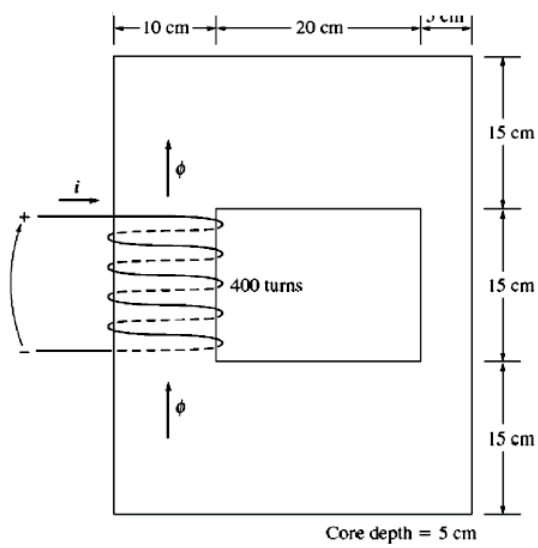


Fig. 2

3. The thickness of the magnetic circuit shown in the figure is 0.04 m and the relative permeability of the iron core is 8000. Determine the coil MMF needed to produce a flux of 0.0014 Wb in the right leg of the core.

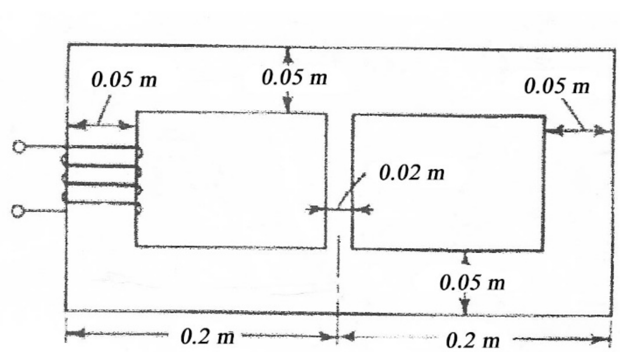


Fig. 3

4. For the magnetic circuit shown in Fig.(4), neglecting leakage and fringing, Determine the MMF of the exciting coil required to produce a flux density of 1.6 T in the air gap. The core has a relative permeability of 2500. The dimensions are: l_{m1} = 60 cm, A_{m1} = 24 cm^2, l_{m2} = 10 cm, A_{m2} = 16 cm^2, l_g = 0.1 cm.

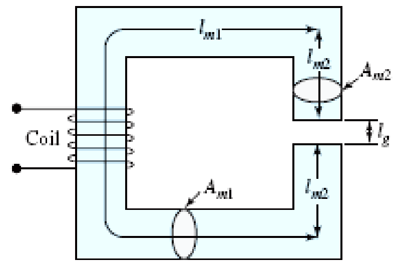


Fig. 4

5. The configuration of a magnetic circuit is given in Fig.(5). Assume the relative permeability of the ferromagnetic material to be 1000. Neglect leakage and fringing. The magnetic material has a square cross-sectional area of 4 cm^2. Find the air-gap flux density, and the magnetic field intensity in the air gap. Find the self-inductance of each coil and also the mutual inductance between the two coils.

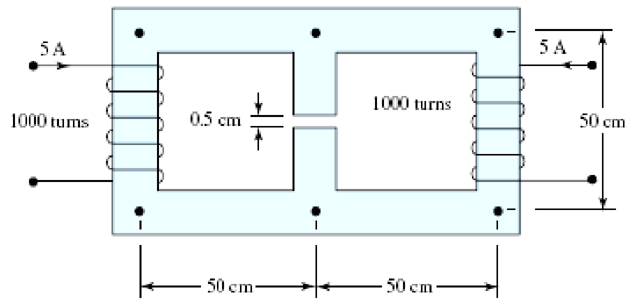
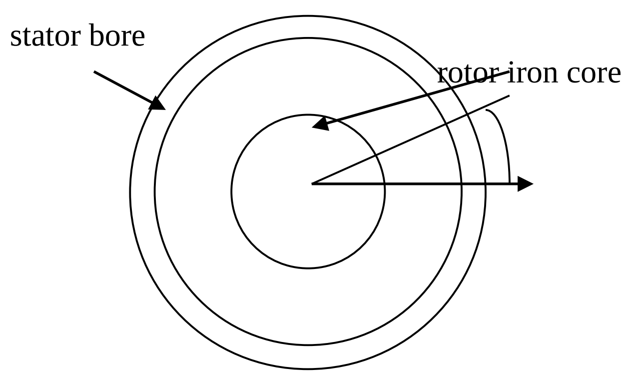
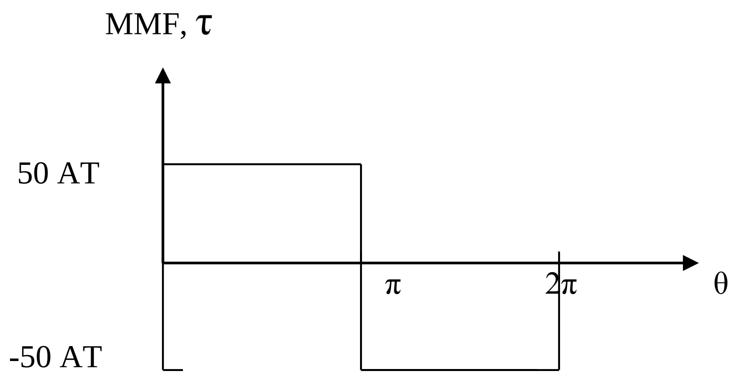


Fig. 5

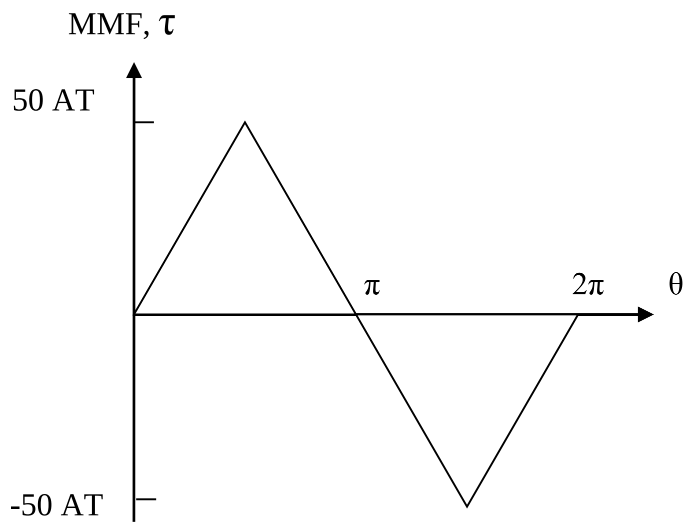
6. The figure shown below represents an AC machine in which the stator carries an electromagnet (located in slots on its inner radius) that produces the MMF distributions shown in the next page. For each MMF distribution deduce the shape of the coil used in this magnet. If the current flowing in the coil equals 10 A, and the turns of the coil are connected in series, estimate the number of turns in each case. Consider that both stator and rotor iron cores have infinite permeability.



(a)



(b)



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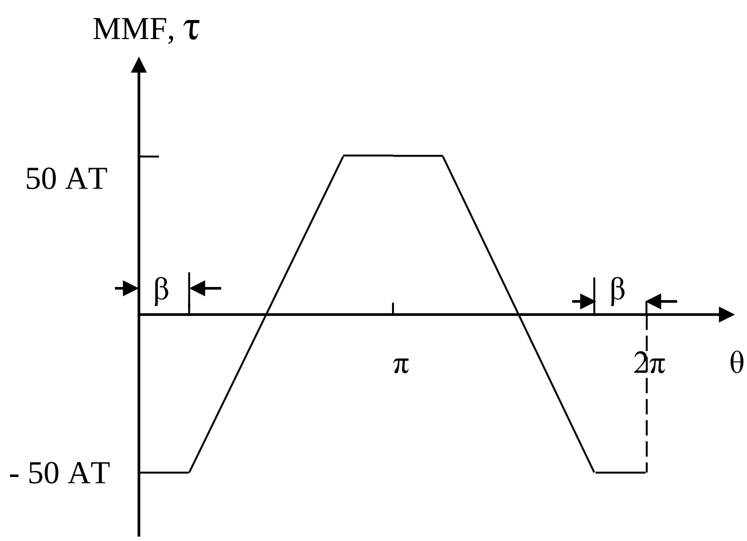

7. For a 3-phase winding arrangement of a 2-pole machine, the number of slots per pole per phase equals 5, each slot has 10 conductors, each conductor carries 10 A. Sketch to scale the MMF distribution for the 3 phases. The conductors are connected such that full pitch coils are obtained.

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<u>Faraday's Law Applications</u>

1. Using Faraday's law, Lenz's law and magnetic circuit theories, show that the equivalent circuit of a transformer having an ideal characteristics with the exception that its core permeability is finite (i.e. $\mu \neq \infty$) may be represented as shown in Fig.6. Derive the value of X_m in this case.

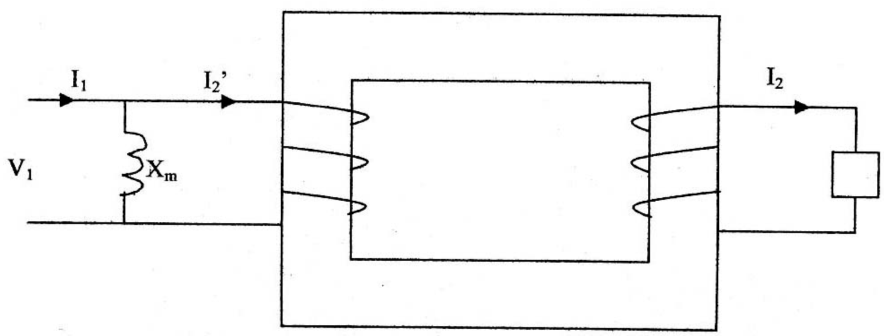


Fig. 1

2. The following data where obtained on a thin sheet of silicon steel of thickness 0.05 mm. Compute the hysteresis losses and the eddy current losses.

Frequency (Hz)	Flux Density (T)	Magnetic Loss (W/Kg)
25	1.1	0.4
25	1.5	0.8
60	1.1	1.2

3. The no-load test (primary is fed with rated voltage while the secondary is left o.c.) is performed on a 1-phase transformer at different frequencies for the purpose of separating its eddy and hysteresis losses. For the following reading determine both P_c and P_h.

f	10	20	30	40	50	60	70
P_{core}	104	216	336	464	600	744	896

4. A square loop (of side b) is mounted on a vertical shaft and rotated at angular velocity ω in a uniform magnetic field B perpendicular to the axis. Assume the initial angle θ_o equals zero.
   Derive an expression for:

   a. the instantaneous EMF,
   b. the current driven through an inductive load $Z\angle\Phi$, and
   c. the electromagnetic torque exerted on the loop.

Prove that the power supplied to the load equals input mechanical power.

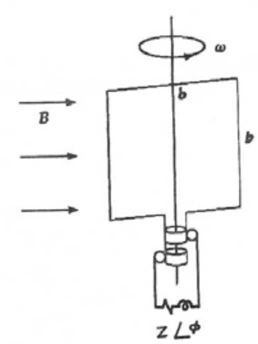
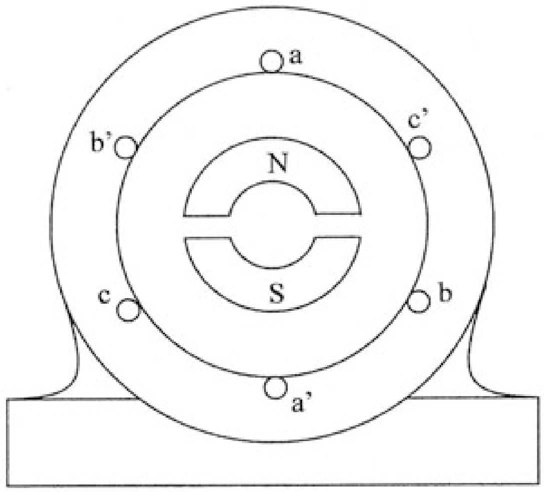
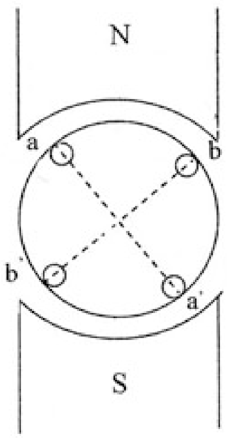


Fig. 2

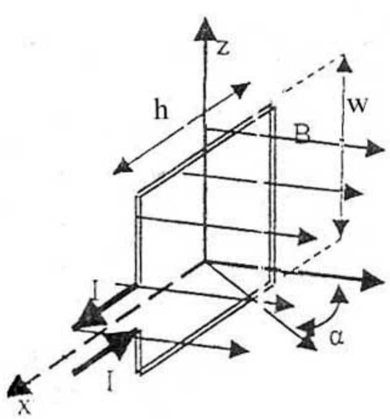
5. Derive the induced voltage equations for the two phase generator shown in Fig. 3.

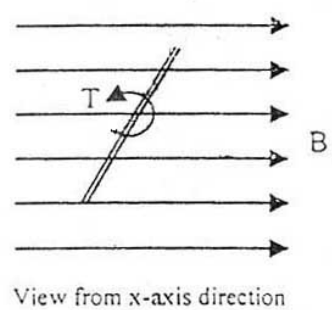
6. Derive the induced voltage equations for the three phase generator shown in Fig. 4.





7. In the elementary machine illustrated below, a current I sent through the loop in a uniform magnetic field B produces a torque that makes the loop rotates. As the loop rotates, the amount of the magnetic flux linking with the loop changes, giving rise to induced emf. Energy must be expended by an external electric source to counter this emf and establish the current in the loop. Prove that this electrical power is equal to the mechanical power exerted on the rotating loop.





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Maxwell's Equations – Poynting's Theorem

1. Compare the magnitudes of conduction current and displacement current for the frequencies 60 Hz, 1 k Hz, 1 MHz, and 1 GHz for the materials copper ($\sigma = 5.75 \times 10^7$, $\varepsilon = \varepsilon_o$), lead ($\sigma = 0.5 \times 10^7$, $\varepsilon = \varepsilon_o$), seawater ($\sigma \approx 4$, $\varepsilon = 81\varepsilon_o$), and earth ($\sigma \approx 10^{-3}$, $\varepsilon = 10\,\varepsilon_o$).

2. Calculate the loss after one kilometer for a plane wave propagating in dry earth. The frequency is 1 MHz, dry soil has a conductivity of $\sigma = 10^{-5}$ S/m and a relative permittivity of $\varepsilon_r = 3$. Repeat for sea water ($\sigma \approx 4$, $\varepsilon = 81\varepsilon_o$).

3. Assuming that a dc voltage V_o applied between the inner conductor (of radius a) and the outer sheath (of inner radius b) of a lossless coaxial cable causes a current I to flow to a load resistance, verify that the integration of the Poynting vector over the cross-sectional area of the dielectric medium equals the power V_oI that is transmitted to the load.

4. The inner conductor of a coaxial cable is made of homogeneous, linear conducting material (conductivity σ_o), while the outer conductor can be regarded as a perfectly conducting sheet. The cable is short-circuited at one end and is connected a DC source at the other (assumed circularly symmetric). Find:

a. The E and H fields in the air space between the two conductors.
b. The surface integral of Poynting's vector over a cross section of the cable.
c. Poynting's vector inside the inner conductor.
d. The flux of Poynting's vector into the inner conductor per unit length of cable.
e. The power dissipated in the inner conductor per unit length.
f. Compare the results of (d) and (e) in light of Poynting's theorem.

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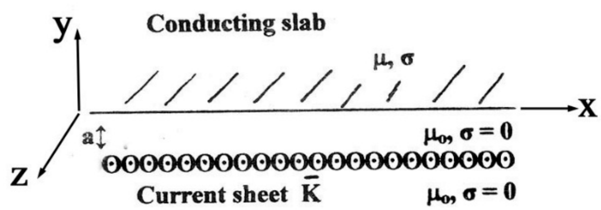
Magnetic Diffusion Equation Applications

1. Consider the simplified induction heating problem shown in Fig.1. The heating coil is represented by an infinitely wide, infinitely long current sheet:

$$\underline{K} = K_o \cos\omega t \, \underline{u}_z \;\; A/m$$

The heated body is assumed to be a semi-infinite slab extending for infinity in the x and z directions.

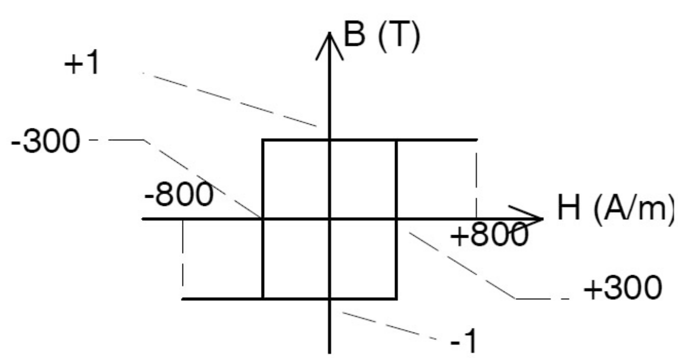
   a. Find the induced current in the slab.
   b. Find the active and reactive powers absorbed by the slab per unit surface area.



2. Using the Poynting vector approach, find the eddy current loss per unit length of a transformer lamination having a thickness 2d, width 2h (where h/d >>1) and permeability μ placed in a long coil having n turns/meter and supplied by a peak current I.

   For n= 100, d= 0.1 mm, h= 0.45 m, I_{max}= 8 A, f= 50 Hz, $\sigma = 0.17\text{x}10^6 \; \Omega^{-1}.\text{cm}^{-1}$ and μ_r = 5000. Find the power dissipated/unit length.

3. Find the total loss per unit length of a transformer lamination, having a thickness 0.2 mm, width 0.9 m and conductivity of $10^7 \; \Omega^{-1}$/m, placed in AC field having 800 A/m peak value and 50 Hz frequency. This computation should be performed taking into account the following BH characteristics.



4. Consider an infinite flat rectangular bus bar with rectangular cross section 2h x 2d (where h/d >>1) carrying an AC current of peak value I_m A. Using the Poynting vector approach, prove that the ratio between the AC and DC resistance of the bus bar is as follows:

$$\frac{Rac}{Rdc} = \frac{\alpha}{2}\frac{\sinh\alpha + \sin\alpha}{\cosh\alpha - \cos\alpha} \qquad \alpha = \frac{2d}{\delta} \qquad \delta = \sqrt{\frac{2}{\varpi\sigma\mu}}$$

5. A transmission line consists of two parallel long rectangular cross section conductors (width=2d, height=2h with h/d >>1) separated by a distance D in free space. If the transmission line carries a peak AC current I A. Find the ac resistance and total inductance of the line per unit length.

6. It is required to minimize the field inside a region 6 m wide using electromagnetic shielding. Using copper walls having conductivity of about $10^7\ \Omega^{-1}.m^{-1}$. Compute the wall thickness for 50 Hz fields if:
(a) Field magnitude inside is to be reduced to 1/4 of its value outside.
(b) Field magnitude inside is to be reduced to 1/8 of its value outside.

7. Consider the linear induction machine shown in Fig. 2 with motion in the z-direction. The geometry is assumed to be infinitely extended in the x and z direction. The current sheet is given by

$$\underline{K} = K_o \cos(\omega t - kz)\, \underline{u}_x \ A/m.$$

Find the levitation and traction forces per unit surface area.

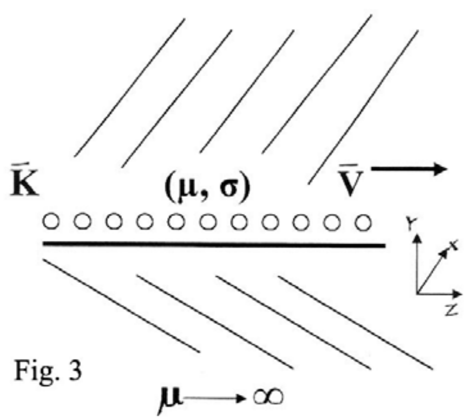


Fig. 3