EE3124 Tutorial 2 (Solution)
DC Machines

Name: **Student No.:**

Q1 - Four types of permanent magnets that have been widely used for electric motors.

- What are their names and chemical formulas?
- Which two rare-earth elements are being used for permanent magnets?
- Sketch their demagnetization characteristics. Which magnetic is the strongest? Why?

Solution

Four types of permanent magnets:

i) neodymium-iron-boron (Compound, $Nd_2Fe_{14}B$),

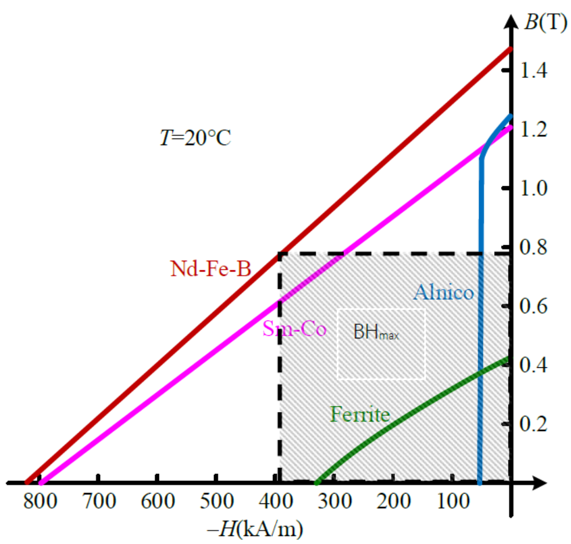
ii) samarium-cobalt (Compound, $SmCo_5$ / Sm_2Co_{17})

iii) aluminium-nickel-cobalt (Alloy, Al-Ni-Co or Alnico),

iv) ferrite, iron III oxide (Compound, Fe_2O_3)

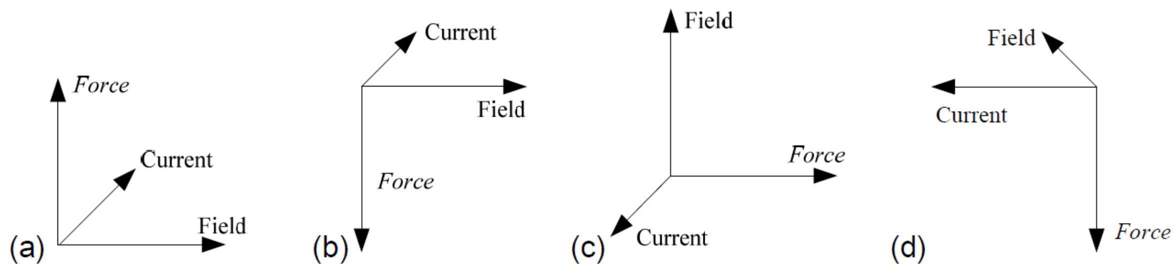
Two-rare-earth elements:

- neodymium (Nd),
- samarium (Sm)



Strongest: neodymium-iron-boron, Highest BH_{max}(largest rectangle that can be inscribed under the normal curve)

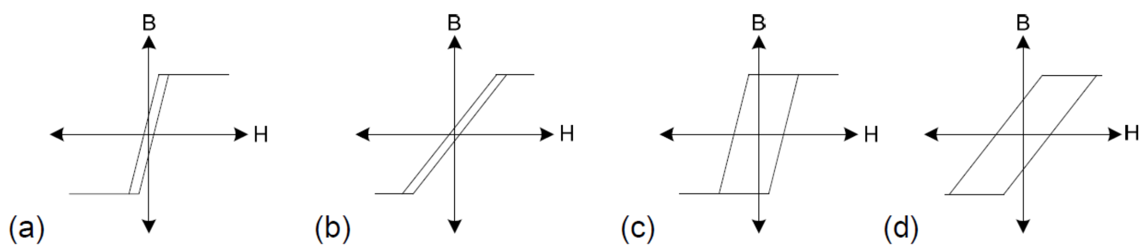
Q2 - Study the Fleming's rule for motor. Which of the following vector diagram represents the Fleming's rule of force creation in a machine.



Solution

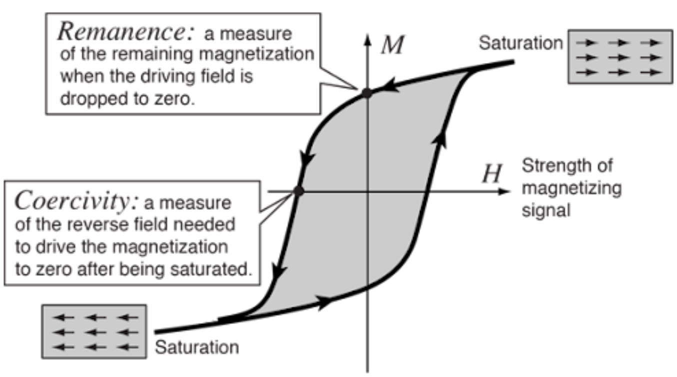
(b)/(d)

Q3 - Which of the following figure represents the BH curve of a good permanent magnetic?



Solution

(c) – higher remanence



Q4 - Use the correct word from the word bank to complete the sentence.

Increase	field	small	rotor	reduce	brush
high	transformer	dc-motor	commutator	reversing	rectifying

i) ____________ permeability ferromagnetic materials should be used to ____________ the flux density in the transformer core.

ii) The air gap between the stator and rotor should kept as _____________ as possible to ____________ the reluctance.

iii) The induced back-emf of a permanent magnetic dc-motor depends on the magnetic ____________ intensity and ____________ speed.

iv) To reduce the eddy current loss, ______________ and induction motor (both stator and rotor) are made of laminated stainless steel.

v) In a DC- motor the ____________ applies electric current to the windings. By ____________ the current direction in the rotating windings each half turn, a steady rotating force (torque) is produced.

Solution

i) _High_ permeability ferromagnetic materials should be used to _increase_ the flux density in the transformer core.

Explanation: $B = \mu H$, when μ increases, same H (same current) will induces larger B (flux density)

ii) The air gap between the stator and rotor should kept as _small_ as possible to _reduce_ the reluctance.

Explanation: Intuitively, it can't be larger. Reluctance, akin to resistance in electrical circuit, is the "resistance" in a magnetic circuit. $R = \frac{l}{\mu A} = \frac{l}{\mu_0 \mu_r A}$. The smaller the air gap, of course the small "resistance" for the magnetic field flow between the stator and rotor. From the equation, the smaller l. We want the gap to have more steel, less air.

iii) The induced back-emf of a permanent magnetic dc-motor depends on the magnetic _field_ intensity and _rotor_ speed.

Explanation: $E = K_e \Phi \omega_n$ and $\Phi = \int_A BdA$, where K_e is the parameter determined by the Electrical Machine, $H = \frac{B}{\mu}$ is the magnetic field intensity and ω_n is the rotor speed.

iv) To reduce the eddy current loss, _transformer_ and induction motor (both stator and rotor) are made of laminated stainless steel.

Explanation: Eddy currents (also called Foucault's currents) are loops of electrical current induced within conductors by a changing magnetic field in the conductor according to Faraday's law of induction. Eddy currents flow in closed loops within conductors, in planes perpendicular to the magnetic field.

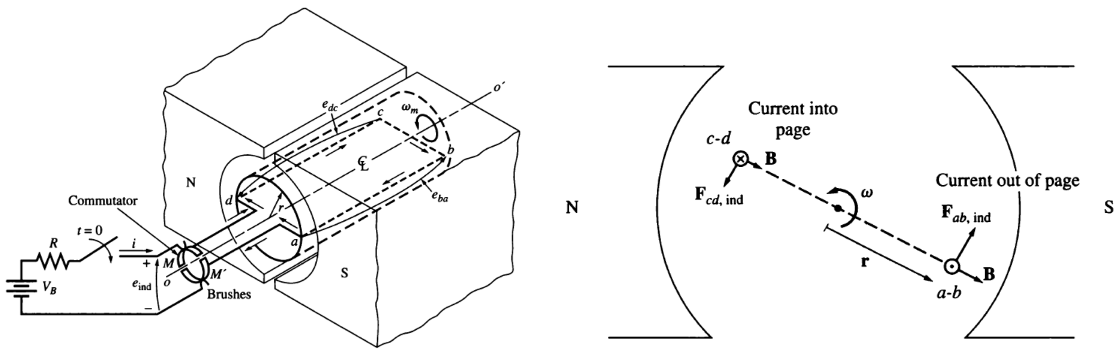
Q5 - The following figure shows a simple rotating loop between curved pole faces connected to a battery and a resistor through a switch. The resistor shows the total resistance of the battery and the wire in the machine. The physical dimensions and characteristics of this machine are

$r = 0.5$ m $l = 1.0$ m $R = 0.3\ \Omega$ $B = 0.25$ T $V_B = 120$ V

(a) What happens when the switch is closed?

(b) What is the machine's maximum starting current? What is its steady-state angular velocity at no load?

(c) Suppose a load is attached to the loop, and the resulting load torque is 10 N • m. What would the new steady-state speed be? How much power is supplied to the shaft of the machine? How much power is being supplied by the battery? Is this machine a motor or a generator?



Solution

(a)

the loop is initially stationary, $e_{ind} = 0$. Therefore, the current will be given by

$$i = \frac{V_B - e_{\text{ind}}}{R} = \frac{V_B}{R}$$

This current flows through the rotor loop, producing a torque

$$\tau_{\text{ind}} = \frac{2}{\pi}\phi i \qquad \text{CCW}$$

This induced torque produces an angular acceleration in a counterclockwise direction, so the rotor of the machine begins to turn. But as the rotor begins to turn, an induced voltage is produced in the motor, given by

$$e_{\text{ind}} = \frac{2}{\pi}\phi\omega_m$$

so the current i falls. As the current falls, $\tau_{\text{ind}} = (2/\pi)\phi i\downarrow$ decreases, and the machine winds up in steady state with $\tau_{\text{ind}} = 0$, and the battery voltage $V_B = e_{\text{ind}}$.

This is the same sort of starting behavior seen earlier in the linear dc machine.

(*b*) At *starting conditions,* the machine's current is

$$i = \frac{V_B}{R} = \frac{120\ \text{V}}{0.3\ \Omega} = 400\ \text{A}$$

At *no-load steady-state conditions,* the induced torque τ_{ind} must be zero. But $\tau_{\text{ind}} = 0$ implies that current i must equal zero, since $\tau_{\text{ind}} = (2/\pi)\phi i$, and the flux is nonzero. The fact that $i = 0$ A means that the battery voltage $V_B = e_{\text{ind}}$. Therefore, the speed of the rotor is

$$V_B = e_{\text{ind}} = \frac{2}{\pi}\phi\omega_m$$

$$\omega = \frac{V_B}{(2/\pi)\phi} = \frac{V_B}{2rlB}$$

$$= \frac{120\ \text{V}}{2(0.5\ \text{m})(1.0\ \text{m})(0.25\ \text{T})} = 480\ \text{rad/s}$$

(*c*) If a load torque of 10 N • m is applied to the shaft of the machine, it will begin to slow down. But as ω decreases, $e_{\text{ind}} = (2/\pi)\phi\,\omega\!\downarrow$ decreases and the rotor current increases $[i = (V_B - e_{\text{ind}}\!\downarrow)/R]$. As the rotor current increases, $|\tau_{\text{ind}}|$ increases too, until $|\tau_{\text{ind}}| = |\tau_{\text{load}}|$ at a lower speed ω.

At steady state, $|\tau_{\text{load}}| = |\tau_{\text{ind}}| = (2/\pi)\phi i$. Therefore,

$$i = \frac{\tau_{\text{ind}}}{(2/\pi)\phi} = \frac{\tau_{\text{ind}}}{2rlB}$$

$$= \frac{10\ \text{N} \bullet \text{m}}{(2)(0.5\ \text{m})(1.0\ \text{m})(0.25\ \text{T})} = 40\ \text{A}$$

By Kirchhoff's voltage law, $e_{\text{ind}} = V_B - iR$, so

$$e_{\text{ind}} = 120\ \text{V} - (40\ \text{A})(0.3\ \Omega) = 108\ \text{V}$$

Finally, the speed of the shaft is

$$\omega = \frac{e_{\text{ind}}}{(2/\pi)\phi} = \frac{e_{\text{ind}}}{2rlB}$$

$$= \frac{108\ \text{V}}{(2)(0.5\ \text{m})(1.0\ \text{m})(0.25\ \text{T})} = 432\ \text{rad/s}$$

The power supplied to the shaft is

$$P = \tau\omega_m$$

$$= (10\ \text{N} \bullet \text{m})(432\ \text{rad/s}) = 4320\ \text{W}$$

The power out of the battery is

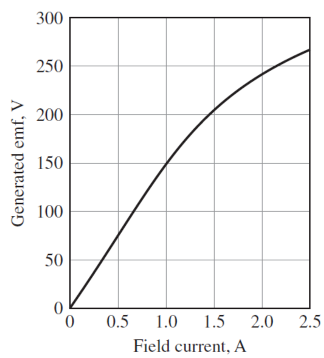
$$P = V_B i = (120\ \text{V})(40\ \text{A}) = 4800\ \text{W}$$

This machine is operating as a *motor,* converting electric power to mechanical power.

Q6 – The constant-speed magnetization curve for a 35-kW, 250-V dc machine at a speed of 1500 r/min is shown as follows. This machine is separately excited and has an armature resistance of 95 mΩ. This machine is to be operated as a dc generator while driven from a synchronous motor at constant speed.

1) What is the rated armature current of this machine?
2) With the generator speed held at 1500 r/min and if the armature current is limited to its rated value, calculate the maximum power output of the generator and the corresponding armature voltage for constant field currents of (i) 1.0 A, (ii) 2.0 A and (iii) 2.5 A.
3) Repeat part (b) if the speed of the synchronous generator is reduced to 1250 r/min.

(Hints: 3-DC machines Lecture slide page 13, voltage difference between motor and generator, E_a is linear to rotating speed.)



1500 r/min magnetization curve for the dc generator.

Part (a): Rated armature current = 35 kW/250-V = 140 A.

Part (b): At 1500 r/min, E_a can be determined directly from the magnetization curve of Fig. 7.32. The armature voltage can be calculated as

$$V_a = E_a - I_a R_a$$

and the power output as $P_{out} = V_a I_a$. With $I_a = 140$ A

I_f [A]	E_a [V]	V_a [V]	P_{out} [kW]
1.0	150	137	19.1
2.0	240	227	31.7
2.5	270	257	35.9

Part (c): The solution proceeds as in part (b) but with the generated voltage equal to 1250/1500 = 0.833 times that of part (b)

I_f [A]	E_a [V]	V_a [V]	P_{out} [kW]
1.0	125	112	15.6
2.0	200	187	26.1
2.5	225	212	29.6

Q7 – A 25 kW, 250 V DC shunt generator has armature and field resistances of 0.06 Ω and 100 Ω, respectively. Determine the total armature power developed when working

(i) As a generator delivering 25 kW output and

(ii) As a motor taking 25 kW input.

Solution

As Generator:

Output current $= \frac{25000}{250} = 100A; I_{sh} = \frac{250}{100} = 2.5A; I_a = 102.5A$

Generated e.m.f. $= 250 + I_a R_a = 250 + 6.15 = 256.15V$

Power developed in armature $= E_a I_a = 256.15 \times 102.5 = 26.25kW$

As Motor:

Motor input current $= 100A; I_{sh} = 2.5\ A; I_a = 97.5A$

$E_a = 250 - (97.5 \times 0.06) = 250 - 5.85 = 244.15V$

Power developed in armature $= E_a I_a = 244.15 \times 97.5 = 23.8kW$