

EE3124 Test 1 (Solution)

Name:

Student No.:

Q1 – What are Electric machines? And briefly list the machine requirements for modern electric vehicles. (10 pts)

Solution:

An electrical machine is a device which converts mechanical energy into electrical energy or vice versa.

Electrical machines also include transformers, which do not actually make conversion between mechanical and electrical form but they convert AC current from one voltage level to another voltage level.

EV machine requirements are much more stringent than that of industrial machines: (any 4 or more items can get full points)

High torque and power densities.

High torque capability for electric launching and hill climbing.

High efficiency over wide torque and speed ranges.

Wide-speed operating range for low-speed creeping and high-speed cruising.

Wide constant-power operating capability.

High intermittent overload capability for overtaking.

High reliability and robustness for vehicular environment.

Publicly acceptable cost.

– What is magnetizing intensity? What is magnetic flux density? How are they related? (5 pts)

Solution (any reasonable answers can get full points)

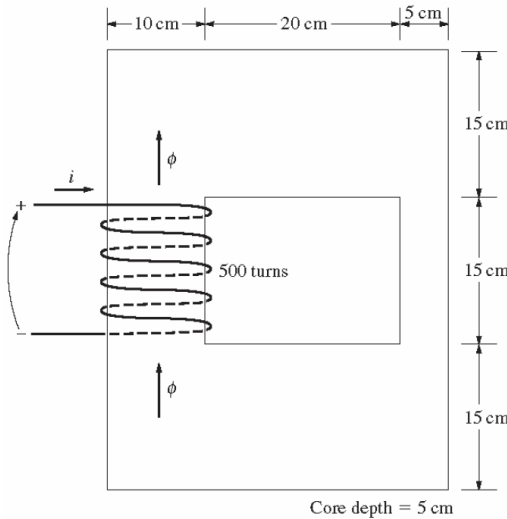
Magnetic Flux Density and Permeability

- The magnetic field intensity H is in a sense a measure of the effort that a current is putting into the establishment of a magnetic field. The strength of the magnetic field flux produced in a core also depends on the material of the core.
- The relationship between the magnetic field intensity H and the resulting magnetic flux density B produced within a material is given by

$$B = \mu H$$

Q2 – A ferromagnetic core is shown as follows. The depth of the core is 5 cm. The other dimensions of the core are as shown in the figure.

- 1) Find the value of the current that will produce a flux of 0.005 Wb. (20 pts)
- 2) With this current, what is the flux density at the top of the core? (5 pts)
- 3) What is the flux density at the right side of the core? Assume that the relative permeability of the core is 800. (5 pts)



SOLUTION There are three regions in this core. The top and bottom form one region, the left side forms a second region, and the right side forms a third region. If we assume that the mean path length of the flux is in the center of each leg of the core, and if we ignore spreading at the corners of the core, then the path lengths are $l_1 = 2(27.5 \text{ cm}) = 55 \text{ cm}$, $l_2 = 30 \text{ cm}$, and $l_3 = 30 \text{ cm}$. The reluctances of these regions are:

$$\mathcal{R}_1 = \frac{l}{\mu A} = \frac{l}{\mu_r \mu_o A} = \frac{0.55 \text{ m}}{(800)(4\pi \times 10^{-7} \text{ H/m})(0.05 \text{ m})(0.15 \text{ m})} = 72.9 \text{ kA} \cdot \text{t/Wb}$$

$$\mathcal{R}_2 = \frac{l}{\mu A} = \frac{l}{\mu_r \mu_o A} = \frac{0.30 \text{ m}}{(800)(4\pi \times 10^{-7} \text{ H/m})(0.05 \text{ m})(0.10 \text{ m})} = 59.7 \text{ kA} \cdot \text{t/Wb}$$

$$\mathcal{R}_3 = \frac{l}{\mu A} = \frac{l}{\mu_r \mu_o A} = \frac{0.30 \text{ m}}{(800)(4\pi \times 10^{-7} \text{ H/m})(0.05 \text{ m})(0.05 \text{ m})} = 119.4 \text{ kA} \cdot \text{t/Wb}$$

The total reluctance is thus

$$\mathcal{R}_{\text{TOT}} = \mathcal{R}_1 + \mathcal{R}_2 + \mathcal{R}_3 = 72.9 + 59.7 + 119.4 = 252 \text{ kA} \cdot \text{t/Wb}$$

and the magnetomotive force required to produce a flux of 0.005 Wb is

$$\mathcal{F} = \phi \mathcal{R} = (0.005 \text{ Wb})(252 \text{ kA} \cdot \text{t/Wb}) = 1260 \text{ A} \cdot \text{t}$$

and the required current is

$$i = \frac{\mathcal{F}}{N} = \frac{1260 \text{ A} \cdot \text{t}}{500 \text{ t}} = 2.5 \text{ A}$$

The flux density on the top of the core is

$$B = \frac{\phi}{A} = \frac{0.005 \text{ Wb}}{(0.15 \text{ m})(0.05 \text{ m})} = 0.67 \text{ T}$$

The flux density on the right side of the core is

$$B = \frac{\phi}{A} = \frac{0.005 \text{ Wb}}{(0.05 \text{ m})(0.05 \text{ m})} = 2.0 \text{ T}$$

Q3 – 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 (10 pts)
- (ii) As a motor taking 25 kW input. (10 pts)

Solution

As Generator:

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

$$\text{Generated e. m. f.} = 250 + I_a R_a = 250 + 6.15 = 256.15 \text{ V}$$

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

As Motor:

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

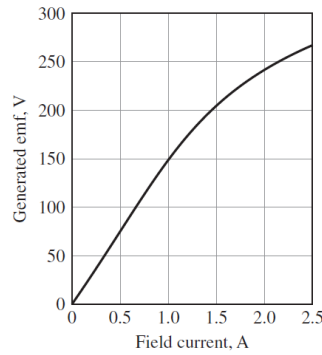
$$E_a = 250 - (97.5 \times 0.06) = 250 - 5.85 = 244.15 \text{ V}$$

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

Q4 – 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 m Ω . 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? (5 pts)
- 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. (15 pts)
- 3) Repeat part (b) if the speed of the synchronous generator is reduced to 1250 r/min. (15 pts)

(Hints: 3-DC machines Lecture slide page 13, voltage difference between motor and generator.)



1500 r/min magnetization curve for the dc generator.

Part (a): Rated armature current = $35 \text{ kW} / 250\text{-V} = 140 \text{ A}$.

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 $P_{\text{out}} = V_a I_a$. With $I_a = 140 \text{ A}$

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