Homework 4 - SOLUTION KEY

EE-306 – Electromechanical Devices - Semester 162

Problem 1

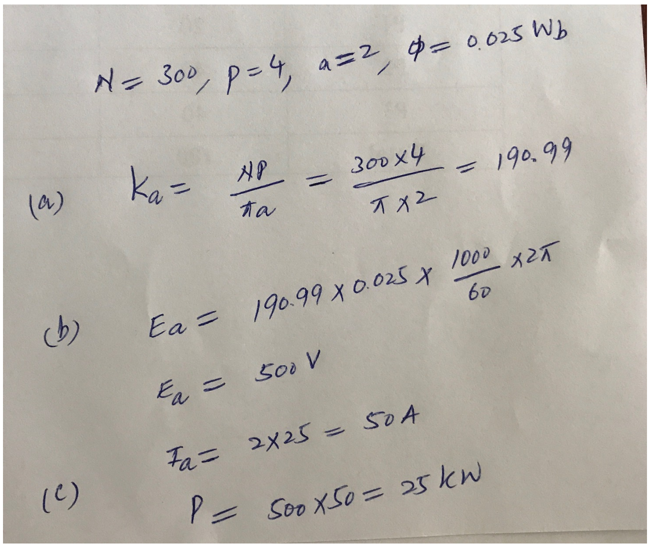
A four-pole DC machine has a wave winding of 300 turns. The flux per pole is 0.025 Wb. The DC machine rotates at 1000 rpm.

(a) Determine the machine constant,

(b) Determine the generated voltage,

(c) Determine the kW rating if the rated current through the turn is 25 A.

Solution



$N = 300, \; p = 4, \; a = 2, \; \phi = 0.025 \text{ Wb}$

(a) $K_a = \frac{Np}{\pi a} = \frac{300 \times 4}{\pi \times 2} = 190.99$

(b) $E_a = 190.99 \times 0.025 \times \frac{1000}{60} \times 2\pi$

$E_a = 500 \text{ V}$

(c) $I_a = 2 \times 25 = 50 \text{ A}$

$P = 500 \times 50 = 25 \text{ kW}$

Problem 2

A separately excited DC generator has six poles and is running at 1150 rpm. The armature has 120 slots with 8 conductors per slot and is connected as **wave winding**. The generated voltage in each conductor is 1.5 V and each conductor can carry a full load current of 4 A. Determine the following:

(a) The terminal voltage at no load,

(b) The output current at full load,

(c) The required flux per pole,

(d) The power developed by the armature on full load.

Solution

$P = 6$, $Z = 120 \times 8 = 960$

$E_g = 1.5\ V/\text{conductor}$

$I_{conductor} = 4A$, $N = 1150$ rpm

$a = 2$ (wave winding)

No. of conductors per path $= \frac{960}{2} = 480$

Induced emf per path $= 480 \times 1.5 = 720V$

(a) No-load terminal voltage $= 720V$

(b) The output current at fullload $= 8A$

(c) $\phi = \frac{E_a \times 60 \times a}{PZN} = \frac{720 \times 60 \times 2}{6 \times 960 \times 1150}$

$\phi = 13.04\ mWb$

(d) $P_d = E_a I_a = 720 \times 8$

$P_d = 5.76\ kW$

Problem 3

Part (a)

A self excited DC shunt generator (20 kW, 200 V, 1800 rpm) has $R_a = 0.1\ \Omega$, $R_{fw} = 150\ \Omega$. Assume that $E_a = V_t$ at no load. Data for the magnetization curve at 1800 rpm are:

I_f (A)	0.0	0.125	0.25	0.5	0.625	0.75	0.857	1.0	1.25	1.5
E_a (V)	5	33.5	67	134	160	175	190	200	214	223

(a) Determine the maximum generated voltage,

(b) At full-load condition, $V_t = V_t(rated)$, $I_a = I_a(rated)$, If $I_f = 1.25$ A. Determine the value of the field control resistance R_{fc},

(c) Determine the electromagnetic power and torque developed at full-load condition.

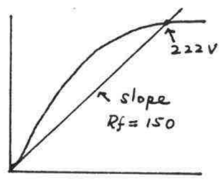
Solution

1(a) $E_a|_{max}$ will occur at $R_{fc} = 0$

Draw field resistance line for

$R_f = R_{fw} = 150\Omega$

$E_a(max) = 222V$

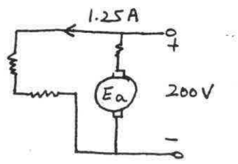


(b) $I_a(rated) = \frac{20,000}{200} = 100A$

$V_t(rated) = 200V$

$R_f = \frac{200}{1.25} = 160\Omega$

$R_{fc} = 160 - 150 = 10\Omega$



(c) $E_a = V_t + I_a R_a = 200 + 100 \times 0.1 = 210V$

$P_{dc} = E_a I_a = 210 \times 100 = 21000\ W$

$\omega_m = \frac{1800}{60} \times 2\pi = 188.5\ rad./sec.$

$T = \frac{E_a I_a}{\omega_m} = \frac{21000}{188.5} = 111.41\ N.m$

Part (b)

Supose that the shunt generator is now connected as a long-shunt compound generator. If the full-load terminal voltage, $V_t = 200V$, and resistance of the series field windings is 0.04 Ω.

(a) Determine the generated voltage,

(a) Draw the long-shunt generator circuit diagram and label it.

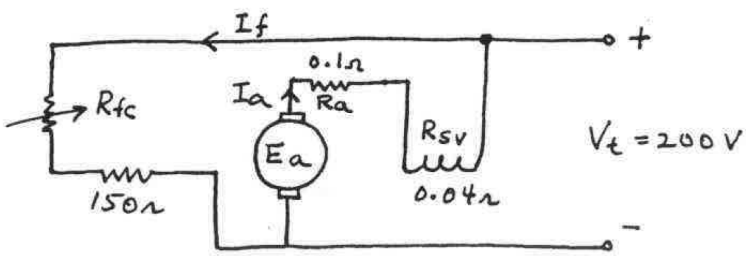
Solution
(a)

$E_a = V_t + I_a(R_a + R_{sr})$

$E_a = 200 + 100(0.1 + 0.04)$

$E_a = 214V$

(b)



Problem 4

A 240 V DC shunt motor has an armature resistance of 0.05 Ω. When the motor is connected to its supply, the armature current is 20 A, the field current is 12 A, and the speed is 1200 rpm. Now, a load is applied to the shaft, and the armature current increases to 300 A and the speed drops to 1150 rpm. Determine the following for the loaded condition,

(a) Rotational loss,

(b) Field circuit loss,

(c) Efficiency at the loaded condition.

Solution

(a) From no-load condition, rotational loss is:

$$P_{rot} = E_a I_a = (240 - 20 \times 0.5) \times 20 = 4780\ W$$

This can be assumed constant if the speed variation is small.

(b) $P_f = 240 \times 120 = 2880\ W$

(c) $P_a = E_a I_a = (240 - 300 \times 0.05) \times 300$

$$= 67500\ W$$

$$P_{out} = 67500 - 4780 = 62720\ W$$

$$P_a = 240 \times 300 = 72000\ W$$

$$P_{in} = P_a + P_f = 74880\ W$$

$$\eta = \frac{62720}{74880} \times 100$$

$$\eta = 83.8\ \%$$

Problem 5

A DC series motor (230 V, 12 hp, 1200 rpm) is connected to a 230 V supply, draws a current of 40 amperes, and rotates at 1200 rpm. $R_a = 0.25\ \Omega$ and $R_{sr} = 0.1\Omega$. Assume magnetic linearity.

(a) Determine the power and torque developed by the motor,

(b) Determine the speed, torque, and power if the motor draws 20 amperes.

Solution

(a) $E_a = 230 - 40\,(0.25 + 0.1) = 216$ V

$P = E_a I_a = 216 \times 40 = 8640$ W

$\omega_m = \frac{1200}{60} \times 2\pi = 125.66$ rad./sec.

$T = \frac{8640}{125.66} = 68.76$ N.m

(b) $E_a = k_{sr} I_a \omega_m = k I_a n$

$E_a = 230 - 20\,(0.25 + 0.1) = 223$ V

$\frac{216}{223} = \frac{40 \times 1200}{20 \times n}$

$n = 2478$ rpm $\quad \omega_m = 259.5$ rad./sec.

$P = 223 \times 20 = 4460$ W

$T = 4460 / 259.5 = 17.19$ N.m

Note: (a) 1200 rpm, 68.76 N.m → low speed high torque

(b) 2324.66 rpm, 17.19 N.m → high speed low torque

Problem 6

A 220 V shunt DC motor has an armature resistance of 0.2 Ω and a field resistance of 110 Ω. At no-load, the motor runs at 1000 rpm and it draws a current of 7 A. At full-load, the input to the motor is 11 kW.

(a) Determine the speed regulation of the motor at full-load conditions.

Solution

Given :- $V_t = 220V$ DC Shunt motor

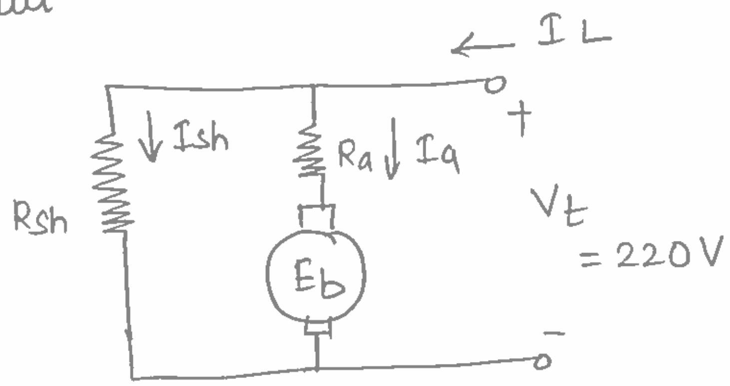
$R_a = 0.2\Omega$ $R_{sh} = 110\Omega$

No-load Data :- $n_{m,NL} = 1000$ rpm

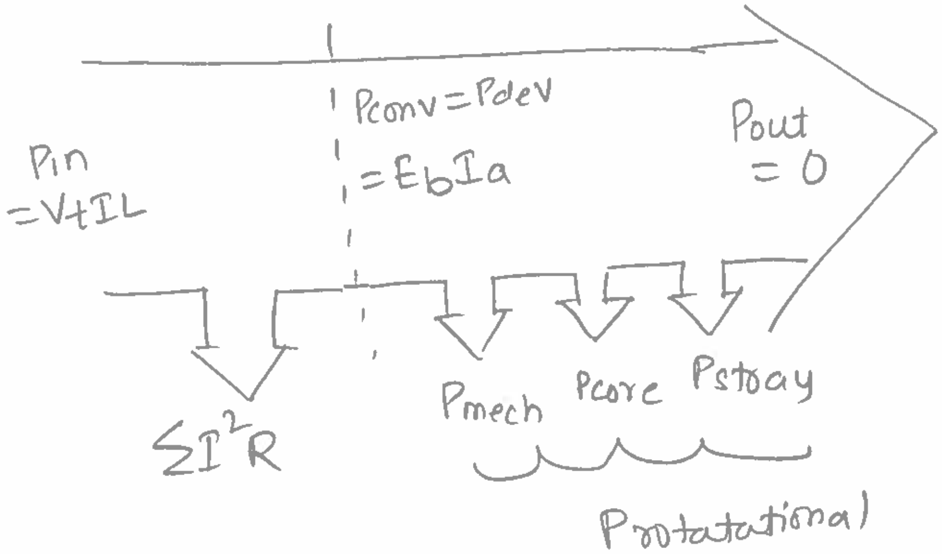
$I_{L,NL} = 7A$.

Full-load Data :- $P_{in,FL} = 11kW$

Equivalent circuit



Power-flow diagram under No-load



From the Power-flow diagram,

$$P_{rotational} = P_{in,NL} - \Sigma I^2R \text{ losses} \quad \text{(OR)}$$

$$P_{rotational} = P_{conv} = P_{dev} = E_{b,NL}\, I_{a,NL}$$

To find $E_{b,NL}$

$$I_{L,NL} = 7A$$

$$I_{sh,NL} = \frac{V_t}{R_{sh}} = \frac{220}{110} = 2A$$

$$I_{a,NL} = I_{L,NL} - I_{sh,NL} = 7-2 = 5A.$$

Now by KVL,

$$E_{b,NL} = V_t - I_{a,NL} R_a - V_{Br1} - V_{Br2}$$

$$= 220 - 5(0.2) - 0$$

$$\boxed{E_{b\,NL} = 219\,V}$$

Now $P_{rotational} = E_{b,NL} \cdot I_{a,NL}$

$$= 219 \times 5$$

$$\boxed{P_{rotational} = 1095\ W}$$

To find Speed under full-load condition

At <u>Full-load</u> :- given $P_{in,FL} = 11kW$

From, $I_{L,FL} = \frac{P_{in,FL}}{V_t}$

$$I_{L,FL} = \frac{11 \times 10^3}{220} = 50 A$$

$$I_{sh,FL} = \frac{V_t}{R_{sh}} = \frac{220}{110} = 2 A$$

$$I_{a,FL} = I_{L,FL} - I_{sh,FL} = 50 - 2 = 48 A$$

Now,

$$E_{b,FL} = V_t - I_{a,FL} \cdot R_a - V_{Br1} - V_{Br2}$$

$$= 220 - 48 \times 0.2 - 0$$

$$E_{b,FL} = 210.4 V$$

From the induced emf equation,

$$E_b = K_a \phi \omega_m$$

For no-load condition, $E_{b,NL} = K_a \phi_{NL} \omega_{m,NL}$

For full-load condition, $E_{b,FL} = K_a \phi_{FL} \omega_{m,FL}$

In a DC shunt machine, since the field current remains constant thereby the flux in the machine also remain constant.

$$\therefore \phi_{NL} = \phi_{FL}$$

Now,

$$\frac{E_{b,FL}}{E_{b,NL}} = \frac{\omega_{m,FL}}{\omega_{m,NL}}$$

$$\Rightarrow \omega_{m,FL} = \omega_{m,NL} \cdot \frac{E_{b,FL}}{E_{b,NL}}$$

$$= 1000 \times \frac{210.4}{219}$$

$$\boxed{n_{m,FL} = 960.73 \text{ rpm}}$$

Now, Speed regulation,

$$= \frac{n_{m,NL} - n_{m,FL}}{n_{m,FL}} \times 100$$

$$= \frac{1000 - 960.73}{960.73} \times 100$$

$$\boxed{SR = 4.1\%}$$

!End of Homework Solutions!