CLASS TEST

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DC MACHINE

ELECTRICAL ENGINEERING

Date of Test : 06/07/2023

ANSWER KEY

1.	(b)	7.	(b)	13.	(b)	19.	(b)	25.	(b)
2.	(a)	8.	(b)	14.	(a)	20.	(c)	26.	(c)
3.	(b)	9.	(d)	15.	(d)	21.	(a)	27.	(b)
4.	(b)	10.	(b)	16.	(a)	22.	(a)	28.	(a)
5.	(d)	11.	(a)	17.	(c)	23.	(a)	29.	(a)
6.	(a)	12.	(c)	18.	(b)	24.	(a)	30.	(d)

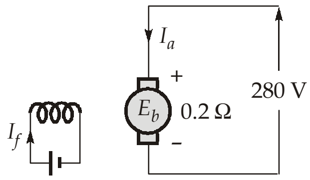
DETAILED EXPLANATIONS

1. (b)

Back emf is given by,

$$E_b = \frac{NP\phi Z}{A \times 60}$$

$$= \frac{1000 \times 0.15 \times 100}{60} = 250 \text{ V}$$



$$I_a = \frac{280 - 250}{0.2} = 150 \text{ A}$$

2. (a)

Let, induced emf $= x$

$$x + I_a r_a = 300 \text{ V} \quad \text{...(i)}$$

When load is reduced to half,

$$x + \frac{I_a r_a}{2} = 250 \text{ V} \quad \text{...(ii)}$$

Solving equation (i) and (ii), we get

Induced emf, $x = 200$ V

3. (b)

For maximum efficiency,

Constant loss = losses proportional to square of variable

Cu loss = I^2R

Brush loss $\propto$ I (so it is not included in constant losses)

So, Constant loss = $150 + 200 + P_i$

$150 + 200 + P_i = 400$

$P_i = 50$ W

4. (b)

The motor and generator are identical

DC supply given to motor,

$$V = 1 \text{ p.u.}$$

Current in both motor and generator

$$I_{am} = I_{ag} = 1 \text{ p.u.}$$

$$R_{am} = R_{ag} = 0.02 \text{ p.u.}$$

Back emf in motor, $E_m = V - I_{am} R_{am}$

$$E_m = 1 - 1 \times 0.02 = 0.98 \text{ p.u.}$$

Also $E_m I_m = E_g I_{ag}$

$\Rightarrow$ $E_m = E_g = 0.98$ p.u.

Terminal voltage of generator,

$$V_g = E_g - I_{ag} \cdot R_{ag}$$

$$= 0.98 - 1 \times 0.02 = 0.96 \text{ p.u.}$$

Load resistance $= \frac{V_g}{I_g} = \frac{0.96}{1.0} = 0.96$ p.u.

5. (d)

For series motor, $T \rightarrow$ Torque

$$T \propto I_a^2$$

or, $$I_a \propto \sqrt{T} \quad ...(i)$$

and also, $$E_b \propto N\phi$$

or $$E_b \propto NI_a \quad (\text{as } \phi \propto I_a)$$

$$N \propto \frac{E_b}{I_a}$$

From equation (i),

$$N \propto \frac{E_b}{\sqrt{T}}$$

6. (a)

$$T = K\phi I_a = 300$$

$$E = V - I_a R_a = K\phi\omega$$

$$600 - 0.5\, I_a = 2\pi \times \frac{1500}{60} \times \frac{300}{I_a}$$

$$0.5 I_a^2 - 600 I_a + 47123.8 = 0$$

$$I_a = 84.49 \text{ A}$$

$$K\phi = 3.55 \text{ Nm/A}$$

$$I_a' = \frac{T}{(K\phi)'} = \frac{300}{0.9 \times 3.55} = 93.89 \text{ A}$$

7. (b)

$$\text{Rotation speed} = 600 \text{ rpm}$$

$$N = \frac{600}{60} = 10 \text{ rev/sec}$$

Peripheral velocity of commutator,

$$V_p = \pi DN$$

$$= \pi \times 50 \times 10 \text{ cm/sec}$$

As we know, $$V_p \times t_c = \text{Brush width}$$

$\therefore$ Time of commutation, $$t_c = \frac{2}{\pi \times 50 \times 10} = 1.273 \text{ msec}$$

8. (b)

Back emf, $$E_b = \frac{P\phi NZ}{60A} \quad (A = P \text{ for lap winding})$$

$$= \frac{0.6 \times 10^{-3} \times 750 \times 2000}{60} = 15 \text{ V}$$

9. (d)

We know that, emf generated,

$$E = \frac{P\phi NZ}{60A} = \phi \times 50 \times 18 \times \frac{9000}{60} \times \frac{4}{2}$$

$$357 = \phi \times 50 \times 18 \times \frac{9000}{60} \times \frac{4}{2}$$

Flux per pole, $\phi = 1.32$ mWb

10. (b)

Field current, $I_f = \frac{250}{125} = 2$ A

No load armature current, $I_{a0} = 16 - 2 = 14$ A;

Constant losses, $P_K = (250 \times 14 - (14)^2 \times 0.2) + 250 \times 2 = 3960.8$ W

$$I_a = 152 - 2 = 150 \text{ A}$$

$$P_L = I_a^2 R_a + P_K = (150)^2 \times 0.2 + 3960.8$$

$$= 8.461 \text{ kW}$$

$$P_{in} = 250 \times 152 = 38 \text{ kW}$$

$\therefore$ Efficiency, $\eta_n = \frac{38 - 8.461}{38} \times 100 = 77.73\%$

11. (a)

Series excited and should have polarity opposite to that of the next main pole in the direction of rotation of armature.

12. (c)

Compensating winding, AT/pole $= \text{armature AT/pole} \times \frac{\text{Pole arc}}{\text{Pole pitch}}$

$$= 19000 \times 0.7 = 13300$$

$$\text{Turn/pole} = \frac{AT_{cw}/\text{pole}}{\text{Armature current}} = \frac{13300}{1000} = 13.3 \approx 14$$

No. of compensating conductor per pole,

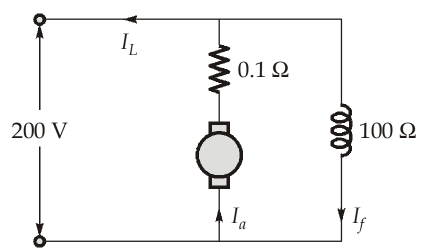
$$14 \times 2 = 28$$

$$\text{AT for airgap under interpole} = \frac{B_g}{\mu_0} l_g = \frac{0.3}{4\pi \times 10^{-7}} \times 1 \times 10^{-2} = 2387.324 \text{ ATs}$$

$$\text{Net AT for interpole} = 19000 + 2387.324 - 14000$$

$$\text{No. of turns in interpole} = \frac{19000 + 2387.324 - 14000}{1000} \approx 8$$

13. (b)



As generator:

Load current, $I_{L1} = \frac{60 \times 1000}{200} = 300$ A

Armature current, $I_{a1} = I_{L1} + I_f = 300 + \frac{200}{100} = 302 \text{ A}$

Generator induced emf, $E_{g1} = V_t + I_{a1}R_a + \text{brush drop}$

$$E_{g1} = 200 + 2 + 302 \times 0.1 = 232.2 \text{ V}$$

When belt breaks it will behave as motor then

$$I_{L2} = \frac{5000}{200} = 25 \text{ A}$$

Now,
$$I_{a2} = I_{L2} - I_f = 25 - 2 = 23 \text{ A}$$

$$E_{b2} = 200 - 2 - 23 \times 0.1 = 195.7 \text{ V}$$

as $E \propto N\phi$ or $E \propto N$ $\quad \phi \rightarrow$ constant

$$\frac{E_{b1}}{E_{b2}} = \frac{N_1}{N_2}$$

$$\Rightarrow \quad \frac{232.2}{195.7} = \frac{500}{N_2}$$

$\Rightarrow$ Speed, $N_2 = 421.4$ rpm

14. (a)

$$AT_{CW}/\text{Pole} = AT_a(\text{peak}) \times \frac{\text{Pole arc}}{\text{Pole pitch}}$$

$$= 20000 \times 0.8 = 16000$$

AT_a(peak) interpolar region $= 20000 - 16000 = 4000$

$$AT_i = AT_a(\text{peak}) + \frac{B_i}{\mu_0} l_{gl}$$

$$= 4000 + \left[\frac{0.3}{4\pi \times 10^{-7}} \times 1.2 \times 10^{-2}\right] = 6865 \text{ AT/P}$$

$$N_i = \frac{6865}{1000} \approx 7 \text{ turns}$$

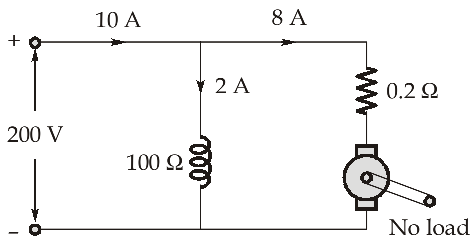
15. (d)

No load loss $= 200 \times 10 = 2000$ W

$$I_f = \frac{200}{100} = 2 \text{ A}$$

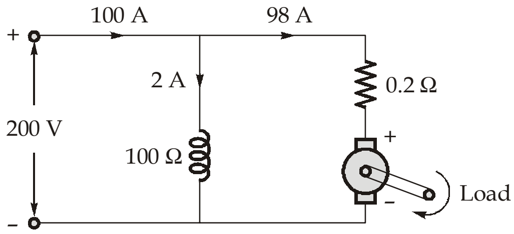
Core loss $= (200 \times 8) - (8^2 \times 0.2)$

$= 1587.2$ W



At load:

Stray load loss = 0.5 × 2000 = 1000 W

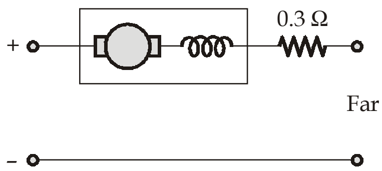


$$P_L = \left(I_a^2 R_a + V_{brush} I_a + P_{stray}\right) + \left(P_{core} + P_{shunt\ field}\right)$$

$$P_L = (98^2 \times 0.2) + (2 \times 98) + 1000 + 1587.2 + (200 \times 2)$$

$$P_L = 5.104 \text{ kW}$$

16. (a)



Load current = 200 A

Voltage rise due to booster= 50 V

Voltage drop in feeder = I_L × feeder resistance

= 200 × 0.3 = 60 V

Voltage difference between station bus-bar and far end of the feeder.

= 60 – 50 = 10 V

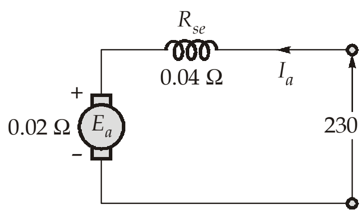
17. (c)

For an over compounded dc generator, percentage of compounding = voltage regulation

$$\%\in_R = \left(\frac{E_a - V}{V}\right) \times 100 = \left(\frac{I_a R_a}{V}\right) \times 100$$

$$= \left(\frac{800 \times 0.02}{500} \times 100\right) = \frac{16}{5} = 3.2\%$$

18. (b)



Armature power developed,

= shaft power + rotational losses

= 1.5 kW + 0.1 kW

$E_b I_a$ = 1.6 kW

Back emf is given by,

$$E_b = \frac{NP\phi Z}{A \times 60} = \frac{N \times 0.035 \times 500}{60} \qquad \text{(For lap } A = P\text{)}$$

and armature current, $I_a = \dfrac{230 - E_b}{0.06}$

$$E_b\left(\frac{230 - E_b}{0.06}\right) = 1600$$

$$230\, E_b - E_b^2 - 96 = 0$$

$$E_b = 229.58 \text{ V}$$

$$\text{Speed, } N = \frac{60E_b}{\phi Z} = \frac{60 \times 229.58}{0.035 \times 500}$$

$$N = 787.13 \text{ rpm}$$

19. (b)

Load characteristic is

$$T_L \propto N^2$$

For dc series motor, torque-current relation is given by

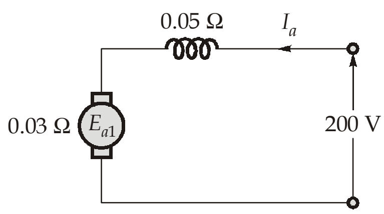
$$T_d \propto I_a^2$$

$$\therefore \quad \frac{I_{a2}}{I_{a1}} = \frac{N_2}{N_1}$$

$$\frac{I_{a2}}{15} = \frac{750}{1500}$$

$$I_{a2} = 7.5 \text{ A}$$

Case-I:



$$E_{a1} = 200 - 15 \times (0.03 + 0.05)$$

$$E_{a1} = 198.8 \text{ V}$$

Case-II:

When additional resistance added in series with the armature circuit,

$$I_{a2} = 7.5 \text{ A,}$$

$$N_2 = 750 \text{ rpm}$$

Now, $E_a \propto \phi\omega_m$

$$\frac{E_{a2}}{E_{a1}} = \frac{N_2\, I_{a2}}{N_1\, I_{a1}} \qquad \text{(In dc series motor } \phi \propto I_a\text{)}$$

$$\frac{E_{a2}}{198.8} = \frac{750 \times 7.5}{1500 \times 15}$$

$$E_{a2} = 49.7 \text{ V}$$

$$E_{a2} = 200 - 7.5(0.08 + R_{ext}) = 49.7$$

$$0.08 + R_{ext} = \frac{200 - 49.7}{7.5}$$

$$R_{ext} = 20.04 - 0.08$$

$$= 19.96\ \Omega$$

20. (c)

We know that,

Torque, $T \propto \phi I_a$

So, $$\frac{T_1}{T_2} = \frac{\phi_1 I_{a1}}{\phi_2 I_{a2}}$$

$$T_2 = \frac{\phi_2 I_{a2}}{\phi_1 I_{a1}} \times T_1$$

Given, $\phi_2 = 1.2\,\phi_1$, $I_{a1} = 40$ A, $I_{a2} = 60$ A

Torque developed, $$T_2 = 1.2 \times \frac{60}{40} \times 20 = 36 \text{ N-m}$$

21. (a)

Output power, $P_0 = 240 \times 100$
$= 24000$ W

Shunt field current, $I_f = 3$ A,

Armature current, $I_a = 100 + 3 = 103$ A

Series field current, $$I_{se} = \frac{0.04}{0.04 + 0.01} \times 100 = 80 \text{ A}$$

$I_d = 100 - 80 = 20$ A

$E_a = V_t + I_L R_{fe} + I_s R_s + I_a R_a$
$= 240 + 100 \times 0.03 + 80 \times 0.01 + 103 \times 0.05$
$= 248.95$ V

$V_f = E_a - I_a R_a$
$= 248.95 - 103 \times 0.05 = 243.8$ V

Hence, $$R_f = \frac{243.8}{3} = 81.267\ \Omega$$

Copper losses :

Armature : $I_a^2 R_a = 103^2 \times 0.05 = 530.45$ W

Series field : $I_s^2 R_s = 80^2 \times 0.01 = 64$ W

Shunt field : $I_f^2 R_f = 3^2 \times 81.267 = 731.4$ W

Diverter resistance: $I_d^2 R_d = 20^2 \times 0.04 = 16$ W

Feeder resistance: $I_L^2 R_{fe} = 100^2 \times 0.03 = 300$ W

Total copper loss : $P_{cu} = 530.45 + 64 + 731.4 + 16 + 300$
$= 1641.85$ W

Thus, the power developed is

$P_d = P_0 + P_{cu} = 24000 + 1641.85$
$= 25641.85$ W

The power input is,

$P_{in} = P_d + P_r$
$= 25641.85 + 2000$
$= 27641.85$ W

Hence, the efficiency is

$$\eta = \frac{P_0}{P_{in}} = \frac{24000}{27641.85} = 0.8682 \text{ (or) } 86.82\%$$

22. **(a)**

For series DC motor,

$$T \propto I^2$$

as torque is constant means current also remains constant

$$T = \frac{E_b I_a}{\omega}$$

as both T and I_a as constant

$$E_b \propto \omega$$

In case of series connection $E_b \approx V/2$

for parallel connection, $E_b \approx V$

So speed becomes double

23. **(a)**

The shunt field current is

$$I_f = \frac{120}{40} = 3\text{A}$$

For maximum efficiency,

$$I_{Lm}^2(\text{R}_a + \text{R}_s) = P_r + I_f^2(R_a + R_s + R_f)$$

$$I_{Lm}^2(0.05 + 0.02) = 3^2(0.05 + 0.02 + 40) + 2000$$

or, $I_{\text{Lm}} = 183.64$ A

Thus the power output at maximum efficiency is :

$$P_0 = 120 \times 183.64 = 22036.8 \text{ W}$$

The total copper loss is

$$P_{cu} = I_a^2(R_a + R_s) + I_f^2 R_f$$

$$= (183.64)^2 \times 0.07 + (3)^2 \times 40$$

$$= 2720.65 \text{ W}$$

The power developed at maximum efficiency is

$$P_d = P_0 + P_{\text{cu}}$$

$$= 22036.8 + 2720.65 = 24757.45 \text{ W}$$

The power input : $P_{\text{in}} = 24757.45 + 2000 = 26757.45$ W

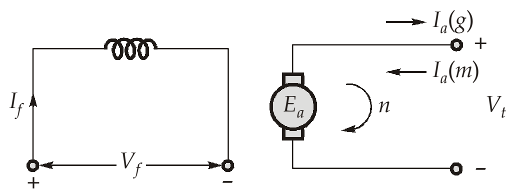
Hence, the maximum efficiency is :

$$\eta = \frac{22036.8}{26757.45} = 0.8235 \quad \text{(or)} \quad 82.35\%$$

24. **(a)**

Open circuit ($I_a = 0$), then

$$V_t = E_a = 250 \text{ V at } 3000 \text{ rpm}$$



Now, $V_t = 255$ V

As $V_t > E_a$, the machine is acting as a motor

$$I_a = \frac{V_t - E_a}{R_a} = \frac{255 - 250}{0.05} = 100 \text{ A}$$

The current flowing into the positive terminal in opposition to E_a, therefore

$$\text{Electromagnetic power} = E_a I_a = 250 \times 100$$
$$= 25 \text{ kW} = \text{mechanical power output}$$
$$\text{Speed} = 3000 \text{ rpm}$$

or, $$\frac{3000 \times 2\pi}{60} = 314.16 \text{ rad/s}$$

Electromagnetic torque,

$$T_{em} = \frac{E_a I_a}{\omega_m} = \frac{25 \times 10^3}{314.16} = 79.58 \text{ N-m}$$

25. (b)

$$AT_{cw/pole} = \frac{I_a Z}{2AP}\left(\frac{\text{Pole arc}}{\text{Pole pitch}}\right)$$

$$\therefore \quad N_{cw/pole} = \frac{Z}{2AP}\left(\frac{\text{Pole arc}}{\text{Pole pitch}}\right) = \frac{286}{2 \times 6 \times 6} \times 0.7 = 2.78$$

Compensating conductor/pole

$$= 2.78 \times 2 = 5.56 \approx 6 \text{ (nearest integer)}$$

26. (c)

$$\text{Firing angle, } \alpha = 0°$$
$$\frac{3\sqrt{2}V_l}{\pi}\cos\alpha = 230$$
$$V_l = 170.31 \text{ V}$$

At $$\text{Speed, } N = 1500 \text{ rpm}$$
$$\text{Back emf, } E_1 = 230 - 20 \times 0.6 = 218 \text{ V}$$

At half rated torque,

$$\text{Current, } I_2 = \frac{1}{2} \times 20 = 10 \text{ A}$$
$$\text{Back emf, } E_2 = -\frac{900}{1500} \times 218 = -130.8 \text{ V}$$
$$\frac{3\sqrt{2}}{\pi}V_l\cos\alpha = -130.8 + 10 \times 0.6$$
$$\alpha = 122.86°$$

27. (b)

$$T = K\phi I_a$$
$$K\phi = \frac{10}{10} = 1 \text{ Nm/A}$$

Now, $$T = 25 \text{ Nm}$$
$$K\phi I_a = 25$$
$$I_a = 25 \text{ A}$$
$$V = E + I_a R_a$$

$$200 = K\phi\omega + 25 \times 0.2$$
$$\omega \times 1 = 195$$
$$\frac{2\pi N}{60} = 195$$
$$N = 1862.11 \text{ rpm}$$

28. **(a)**

At no load;

Back emf, $E_{b0} = V_t - I_{a0}(R_a)$

$$E_{b0} = 220 - 3(0.5)$$
$$E_{b0} = 218.5 \text{ V}$$

At full load;

Back emf, $E_{b\,fl} = V_t - I_{a\,fl}(R_a)$

$$= 220 - 45\ (0.5)$$
$$E_{b\,fl} = 197.5 \text{ V}$$

As flux is given constant;

then, we can write; $E_b \propto N$

or,
$$\frac{E_{b\,fl}}{E_{b0}} = \frac{N_{fl}}{N_0}$$

$$N_{fl} = \left(\frac{197.5}{218.5}\right) \times 1500$$
$$= 1355.83 \approx 1356 \text{ rpm}$$

29. **(a)**

The motor and generator are identical.

DC supply given to motor

$$V = 1 \text{ p.u.}$$

Current in both motor and generator

$$I_{am} = I_{ag} = 1 \text{ p.u.}$$

Armature resistance, $R_{am} = R_{ag} = 0.015$ p.u.

Back emf in motor, $E_m = V - I_{am} \cdot R_{am}$

$$E_m = 1 - (1 \times 0.015)$$
$$= 0.985 \text{ p.u.}$$

As rotational losses are negligible,

Power output of motor = Power input to generator

or, $E_m I_{am} = E_g \cdot I_{ag}$

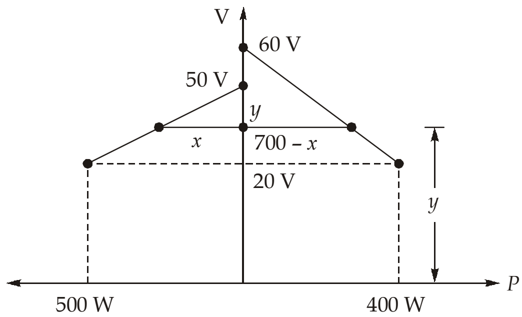
or, $E_m = E_g = 0.985$ p.u.

Terminal voltage of generator

$$V_g = E_g - I_{ag} \cdot R_{ag} = 0.985 - (1 \times 0.015) = 0.97 \text{ p.u.}$$

$$\text{Load resistance} = \frac{V_g}{I_g} = \frac{0.97}{1.0} = 0.97 \text{ p.u.}$$

30. (d)



From similarity of triangles for generator 1,

$$\frac{50-y}{x} = \frac{50-20}{500}$$

$$50 - y = 0.06\,x$$

$$0.06\,x + y = 50 \quad \text{...(i)}$$

For second triangle,

$$\frac{60-y}{700-x} = \frac{60-20}{400}$$

$$60 - y = 70 - 0.1\,x$$

$$0.1\,x - y = 10 \quad \text{...(ii)}$$

Solving the equations (i) and (ii), we get

$$y = 27.5 \text{ V}$$

$$\text{Voltage} = 27.5 \text{ V}$$

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