CLASS TEST

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INDUCTION

ELECTRICAL ENGINEERING

Date of Test : 29/07/2024

ANSWER KEY

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

DETAILED EXPLANATIONS

1. (d)

We know that,

$$\frac{\text{Starting torque}}{\text{Full load torque}} = \frac{T_{st}}{T_{fl}} = x^2\left(\frac{I_{sc}}{I_{fl}}\right)^2 \times s_{fl}$$

or, $$0.4 = x^2 \times (5)^2 \times 0.035$$

or, $$x^2 = \frac{0.4}{25 \times 0.035}$$

$$x = \sqrt{\frac{0.4}{25 \times 0.035}} = 0.676$$

∴ The percentage of tapping is 67.6%.

2. (b)

$$N_s \text{ (stator field)} = \frac{120 \times 50}{4} = 1500 \text{ rpm;}$$

$$N_s \text{ (rotor field)} = \frac{120 \times 30}{4} = 900 \text{ rpm}$$

∴ $$N_r = 1500 \pm 900 = 2400 \text{ rpm, } 600 \text{ rpm}$$

3. (d)

Starting winding current $I_s = 3\angle{-15°}$ A $= (2.9 - j0.78)$ A

Running winding current $I_m = 5\angle{-40°}$ A $= (3.83 - j3.21)$ A

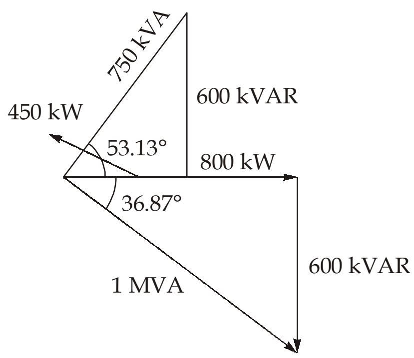
The component of running winding current that lags behind the supply voltage by 90°

= Reactive component of running winding current

= 3.21 A

4. (d)

The given condition can be explained with phasors,



Active power consumed by induction motor,

= 1 MVA × 0.8 = 800 kW

Reactive power consumed by induction motor,

= 800 kW × tan(36.87°)

= 600 kVAR

Active power consumed by synchronous condenser,

= 750 KVA × 0.6 = 450 kW

Reactive power delivered by synchronous condenser

$= 450 \text{ kW} \times \tan(53.13°)$

$= 600 \text{ kVAR}$

$Q_{net} = 0$ i.e. $\phi = 0°$

∴ The power factor of the total load is unity

$\cos\phi = 1$

5. (a)

$$\text{The rotor copper loss} = \frac{s}{1-s} \times \text{Gross mechanical power developed}$$

$$\text{Synchronous speed, } N_s = \frac{120f}{P} = \frac{120 \times 50}{6} = 1000 \text{ rpm}$$

$$\text{Slip, } s = \frac{N_s - N_r}{N_s} = \frac{1000-950}{1000} = 0.05$$

$$\text{The rotor copper loss} = \left(\frac{0.05}{1-0.05}\right) \times (4500+850)$$

$$= 281.58 \text{ W}$$

6. (d)

$$T_s = 1.5\, T_f$$

$$T_{max.} = 2\, T_f$$

$$\text{For maximum torque, } s_{mT} = \frac{r_2}{x_2}$$

$$\frac{T_s}{T_{max}} = \frac{1.5T_f}{2T_f} = \frac{2s_{mT}}{1+s_{mT}^2}$$

i.e. $1.5s_{mT}^2 - 4s_{mT} + 1.5 = 0$

∴ $s_{mT} = 0.45$

7. (a)

The slip at maximum torque is,

$$S_{max,T} = \frac{R_2}{X_2} = \frac{0.02}{0.08} = 0.25$$

$$\text{Synchronous speed, } N_s = \frac{120 \times 50}{8} = 750 \text{ rpm}$$

$$\omega_s = \frac{2\pi}{60} \times N_s = \frac{2\pi}{60} \times 750$$

$$= 78.54 \text{ rad/sec}$$

$$\text{Stator voltage, } V_1 = \frac{220}{\sqrt{3}} = 127 \text{ V}$$

Maximum torque developed by the motor,

$$T_{max} = \frac{3V_1^2}{2\omega_s \times X_2} = \frac{3 \times (127)^2}{2 \times 78.54 \times 0.08} = 3850.51 \text{ N-m}$$

8. (d)

Synchronous speed, $\omega_s = \frac{2}{P} \times 2\pi f = \frac{4 \times \pi \times 50}{6} = 104.72$ rad/sec

Starting torque, $T_{starting} = \frac{3}{\omega_s} \cdot \frac{E_2^2 r_2'}{(r_2')^2 + (x_2')^2}$

$$40 = \frac{3}{104.72} \times \frac{E_2^2 \times 0.32}{(0.32)^2 + (3.2)^2}$$

Rotor voltage at standstill,

$$E_2 = 212.43 \text{ V}$$

9. (a)

For same air gap flux, $\frac{V}{f}$ ratio should be constant

Flux, $\phi = \frac{V}{f} = \text{constant}$

$$\frac{V_2}{f_2} = \frac{V_1}{f_1}$$

$$V_2 = \frac{400}{50} \times 30 = 240 \text{ V}$$

Synchronous speed of motor for 50 Hz source

$$N_s = \frac{120 \times 50}{4} = 1500 \text{ rpm}$$

$$\text{Slip, } s_1 = \frac{1500 - 1440}{1500} = 0.04$$

At small value of slip, the electromagnetic torque is given by

$$T = \frac{3}{\omega_s} \times \frac{V^2 s}{r_2}$$

$$T \propto \frac{V^2}{f} \cdot s$$

For same torque, $\frac{V_2^2}{f_2} \cdot s_2 = \frac{V_1^2}{f_1} \cdot s_1$

$$\frac{(240)^2}{30} s_2 = \frac{400^2}{50} \times 0.04$$

$$\text{Slip, } s_2 = 0.067$$

Synchronous speed of motor at 30 Hz source,

$$N_{s2} = \frac{120 \times 30}{4} = 900 \text{ rpm}$$

$$\text{Rotor speed, } N = (1 - 0.067) \times 900$$

$$N = 840 \text{ rpm}$$

10. (d)

Ratio of full load torque to maximum torque is given by

$$\frac{T_{fl}}{T_m} = \frac{2}{\frac{s_m}{s} + \frac{s}{s_m}}$$

Slip at maximum torque,

$$s_m = \frac{R_2}{X_2} = \frac{0.25}{4} = 0.0625\ \Omega$$

Slip at full load torque, $s_{fl} = \frac{1500 - 1440}{1500} = 0.04$

Now,
$$\frac{T_{fl}}{T_m} = \frac{2}{\frac{0.0625}{0.04} + \frac{0.04}{0.0625}}$$

So,
$$\frac{T_m}{T_{fl}} = 1.10125$$

11. (d)

Given, Pole, $P = 6$

$$f = 50 \text{ Hz}$$

Synchronous speed, $N_s = \frac{120f}{P} = \frac{120 \times 50}{6} = 1000$ rpm

Slip, $s = \frac{1000 - 960}{1000} = 0.04$

Mechanical power developed

$$P_{mech} = 20000 + 1100 = 21100 \text{ W}$$

$$\text{Rotor copper loss} = \frac{s}{1-s} \times \text{mechanical power developed}$$

$$= \frac{0.04}{(1-0.04)} \times 21100 \qquad \text{...(i)}$$

$$\text{Also rotor copper loss} = 3I_2^2 \times R_2 + 300$$

$$= 3 \times (40)^2 \times R_2 + 300 \qquad \text{...(ii)}$$

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

$$4800 \times R_2 + 300 = \frac{0.04}{(1-0.04)} \times 21100$$

$$4800\, R_2 = 579.17$$

$$R_2 = 0.121\ \Omega$$

12. (b)

Electromagnetic torque for induction motor is given by,

$$T = \frac{3}{\omega_s} \cdot \frac{V^2 (R_2' / s)}{\left(\frac{R_2'}{s}\right)^2 + (X_2')^2}$$

At starting, $s = 1$

$$T = \frac{3}{\omega_s} \cdot \frac{V^2 R_2'}{(R_2')^2 + (X_2')^2}$$

and $$T \propto V^2$$

$$\frac{T_2}{T_1} = \frac{V_2^2}{V_1^2}$$

$$\frac{45}{60} = \frac{V_2^2}{(400)^2}$$

$$V_2 = \sqrt{\frac{400^2 \times 45}{60}} = 346.41 \text{ V}$$

13. (b)

For small slips, torque is

$$T_e \propto \frac{sV^2}{R_2 f}$$

$$\text{Slip, } s_1 = \frac{N_s - N_1}{N_s} = \frac{750 - 720}{750} = 0.04$$

$$\text{Slip, } s_2 = \frac{750 - 690}{750} = 0.08$$

For constant torque,

$$\frac{s_1}{(R_2')_{\text{old}}} = \frac{s_2}{(R_2')_{\text{new}}}$$

$$(R_2')_{\text{new}} = \frac{0.05 \times 0.08}{0.04}$$

$$(R_2')_{\text{new}} = 0.1$$

$$R_{\text{ext}} = 0.1 - 0.05$$

$$= 0.05\ \Omega$$

14. (a)

Ratio of full load torque to maximum torque is given by

$$\frac{T}{T_{\max}} = \frac{2}{\frac{s_m}{s} + \frac{s}{s_m}}$$

$$\frac{1}{4} = \frac{2}{\frac{0.25}{s} + \frac{s}{0.25}}$$

$$s^2 - 2s + 0.0625 = 0$$

$$\text{Slip, } s = 0.03175$$

As rotational losses are neglected

$$P_{\text{shaft}} = P_{\text{developed}}$$

$$\text{Copper loss} = \frac{(P_{dev}) \times s}{1 - s}$$

$$\text{Copper loss} = \frac{50000 \times 0.03175}{(1 - 0.03175)}$$

$$\text{Copper loss} = 1639.55 \text{ W}$$

15. (b)

At starting slip, $s = 1$

$$I = \frac{V}{\sqrt{R_2^2 + X_2^2}}$$

$$(X_2)_{50\text{ Hz}} = X_2$$

and $(X_2)_{25\text{ Hz}} = 0.5\, X_2$

$$\text{Current, } (I)_{50\text{ Hz}} = \frac{V}{X_2\sqrt{\left(\frac{R_2}{X_2}\right)^2 + 1}}$$

and $\text{Current, } (I)_{25\text{ Hz}} = \dfrac{V}{X_2\sqrt{\left(\frac{R_2}{X_2}\right)^2 + 0.25}}$

$$\frac{(I)_{25\text{ Hz}}}{(I)_{50\text{Hz}}} = \frac{\sqrt{s_m^2 + 1}}{\sqrt{s_m^2 + 0.25}} \qquad \left(\text{Given}, s_m = \frac{R_2}{X_2} = 0.4\right)$$

$$\frac{(I)_{25\text{ Hz}}}{(I)_{50\text{Hz}}} = \frac{\sqrt{0.4^2 + 1}}{\sqrt{0.4^2 + 0.25}} = 1.68$$

16. (a)

$$P_{\text{shaft}} = 25000 \text{ W}$$

$$P_{\text{dev}} = P_{\text{shaft}} + \text{Rotational loss}$$

$$= 25000 + 350$$

$$P_{\text{dev}} = 25350 \text{ W}$$

$$P_{\text{ag}} = \frac{25350}{1 - 0.04} = 26406.25 \text{ W}$$

$$P_{\text{in}} = P_{\text{ag}} + \text{stator loss}$$

$$= 26406.25 + 1500 + 800$$

$$P_{\text{in}} = 28706.25 \text{ W}$$

$$\text{Efficiency} = \frac{P_{\text{out}}}{P_{\text{in}}} \times 100 = \frac{25000}{28706.25} \times 100$$

$$\%\,\eta = 87.09\%$$

17. (b)

$$\text{Synchronous speed, } N_s = \frac{120\, f_1}{P} = \frac{120 \times 50}{6} = 1000 \text{ rpm}$$

$$\text{Slip, } s = \frac{f_2}{f_1} = \frac{1.5}{50} = 0.03 \quad \text{or} \quad 3\%$$

$$\text{Rotor speed, } N_r = (1 - s)\, N_s = (1 - 0.03) \times 1000 = 970 \text{ rpm}$$

$$\omega_r = \frac{2\pi N_r}{60} = \frac{2\pi \times 970}{60} = 101.58 \text{ mechanical rad/sec}$$

Shaft power output $P = T\,\omega_r$

$= 150 \times 101.58 = 15236 \text{ W} = 15.24 \text{ kW}$

18. (b)

The mmf distribution contains a fundamental and a family of space harmonics of order $h = 6\,m \pm 1$, where m is is positive number.

In a three phase machine, when sinusoidally varying currents flow through the winding, the space harmonic wave rotate at $(1/h)$ times the speed of the fundamental wave. The space harmonic waves rotate in the same direction as the fundamental wave if $h = 6\,m \pm 1$ and in the opposite direction if $h = 6\,m - 1$.

19. (c)

In order to avoid saturation in stator and rotor cores which would cause sharp increase in magnetizing current, the flux ϕ_r must be kept constant as 'f' is varied. To achieve this when 'f' is varied, 'V' must also be varied such that $\left(\frac{V}{f}\right)$ remains constant.

20. (d)

Given, motor is at standstill. The respective induced emf in stator and rotor will be

$$E_1 = \sqrt{2}\pi f_1 K_{w1} N_1 \phi$$

$$E_2 = \sqrt{2}\pi f_2 K_{w2} N_2 \phi$$

After taking ratio,

$$\frac{E_1}{E_2} = \frac{K_{w1} N_1}{K_{w2} N_2} = \frac{N_1'}{N_2'} \qquad (\text{as } f_1 = f_2 \text{ at stand still})$$

Where, N_1' = Effective stator turns per phase

N_2' = Effective rotor turns per phase

N_1 = Stator turns per phase

N_2 = Rotor turns per phase

Thus, $$\frac{5 \times 4}{K_{w2}} = 2$$

$\therefore$ $$K_{w2} = \frac{5 \times 4}{2} = 10$$

21. (b)

$$\text{Synchronous speed, } N_s = \frac{120 \times 50}{6} = 1000 \text{ rpm}$$

Stalling speed = 900 rpm

$$\text{Slip at stalling torque, } s = \frac{1000 - 900}{1000} = 0.1$$

$$\text{Slip at maximum torque; } S_{mT} = \frac{R_2}{X_2} = \frac{0.01}{X_2}$$

$\because$ $$0.1 = \frac{0.01}{X_2}$$

$$X_2 = 0.1\ \Omega$$

To obtain maximum torque at starting,

Let rotor resistance $= R_2'$

at starting, $s = 1$

$$S_{mT} = \frac{R_2'}{X_2}$$

$$\Rightarrow \quad 1 = \frac{R_2'}{0.1}$$

$$\Rightarrow \quad R_2' = 0.1\ \Omega/\text{phase}$$

The external resistance to be added,

$$R_{ext} = 0.1 - 0.01$$
$$= 0.09\ \Omega/\text{phase}$$

22. (c)

For $f_2 = 15$ Hz, the slip is

$$s = \pm\frac{f_2}{f_1} = \pm\frac{15}{60} = \pm\frac{1}{4}$$

The synchronous speed, $N_s = \dfrac{120 \times f}{P} = \dfrac{120 \times 60}{6} = 1200$ rpm

The speed of the system for f_2 =15 Hz

$$N_r = (1 \pm s)N_s = (1 \pm 0.25)1200$$
$$= 900 \text{ and } 1500 \text{ rpm}$$

∴ hence option (c) is correct.

We can check for $f_2 = 120$ Hz

$$s = \pm\frac{120}{60} = \pm 2$$

$$N_r = (1 \pm 2)\ 1200$$
$$= -1200 \text{ and } 3600 \text{ rpm}$$

23. (b)

Full load shaft power = 15 × 746 = 11190 W

Mechanical power developed =11190 + 750 = 11940 W

$$\text{Air gap power} = \frac{\text{Mechanical power developed}}{1 - s}$$

$$\text{Slip, } s = \frac{N_s - N_r}{N_s},$$

$$N_s = \frac{120 f}{P} = \frac{120 \times 60}{4} = 1800 \text{ rpm}$$

$$s = \frac{1800 - 1728}{1800} = 0.04$$

$$P_{ag} = \frac{11940}{1 - 0.04} = 12437.5 \text{ W}$$

Rotor copper loss $= sP_{ag} = 0.04 \times 12437.5$
$= 497.5$ W

24. (d)

We know, $P_{Cu} = sP_g$ ...(copper loss in terms of air gap power)

$$\Rightarrow \quad P_g = \frac{P_{Cu}}{s} = \frac{300}{0.04} = 7500 \text{ W}$$

Now $P_m = P_g(1 - s) = 7500\ (1 - 0.04) = 7200$ W

Here synchronous speed, $N_s = \frac{120f}{P} = \frac{120 \times 50}{4} = 1500$ rpm

$$\text{Torque developed} = \frac{P_g}{\omega_s} = \frac{7500}{2\pi \times \frac{1500}{60}} = 47.75 \text{ N-m}$$

Alternatively, torque can be calculated as

$$T = \frac{P_m}{\omega_s(1-s)} = \frac{7200}{2\pi \times \frac{1500}{60}(1-0.04)}$$

$$= 47.75 \text{ N-m}$$

25. (d)

$$\frac{T_{st}}{T_{fl}} = \left(\frac{I_{st}}{I_{fl}}\right)^2 s_{fl}$$

For $T_{st} = T_{fl}$

$$\frac{I_{st}}{I_{fl}} = \sqrt{\frac{1}{s_{fl}}} = \frac{1}{\sqrt{0.01}} = 10$$

26. (a)

Power output, P_0 = 10 kW

Frequency, f = 50 Hz

Poles, P = 6

Slip, S = 0.04

Friction and windage losses = 0.4 kW

Mechanical power developed = 10.4 kW

$$\text{Air gap power, } P_g = \frac{\text{Mechanical power developed}}{1-s} = \frac{10.4}{1-0.04} = 10.83 \text{ kW}$$

$$\text{Synchronous speed} = \frac{120 \times 50}{6} = 1000 \text{ rpm or } 104.72 \text{ rad/sec}$$

Full load electromagnetic torque,

$$T_e = \frac{P_g}{\omega_s} = \frac{10.83 \times 10^3}{104.72} = 103.42 \text{ N-m}$$

27. (b)

Given, $I_{st} = 6 \times I_{fL}$

$$I_{fL} = \frac{\text{Power in kVA}}{\sqrt{3} \times V_L} = \frac{50 \times 10^3}{\sqrt{3} \times 440} = 65.608 \text{ A}$$

Current drawn by auto transformer from the mains at starting,

$$I_{st} = x^2 I_{st(motor)} = x^2 \times 6 \times I_{fl}$$
$$= (0.5)^2 \times 6 \times 65.608$$
$$= 98.412 \text{ A}$$

Starting kVA drawn by the auto transformer

$$= \sqrt{3} V_L I_{st(auto)}$$
$$= \sqrt{3} \times 440 \times 98.412$$
$$= 75 \text{ kVA}$$

28. (a)

We know that,

$$\text{Torque, } T = \frac{3}{\omega_{sm}} \times \frac{V^2}{R_2'} s \text{ (for low slip)}$$

Now, T = constant $\quad T \propto V^2 s$

(or) $\quad V_2^2 s_2 = V_1^2 s_1$

(or) $\quad s_2 = \left(\frac{V_1}{V_2}\right)^2 s_1$

(or) $\quad s_2 = 4s_1$,

hence slip increases 4 times,

Also, $\quad T = \frac{3I_2'^2}{\omega_{sm}} \times \frac{R_2'}{s} = \text{const.}$

(or) $\quad I_2'^2 \propto s$

$$\frac{I_2'}{I_1'} = \sqrt{\frac{s_2}{s_1}} = \sqrt{\frac{4}{1}} = 2$$

Hence, current increases by 2 times.

29. (b)

$$\text{Synchronous speed, } N_s = \frac{120 \times 50}{6} = 1000 \text{ rpm}$$

$$\text{Stalling speed} = 900 \text{ rpm}$$

$$\text{Slip at stalling torque, } s = \frac{1000 - 900}{1000} = 0.1$$

Slip at maximum torque; $\quad S_{mT} = \frac{R_2}{X_2} = \frac{0.01}{X_2}$

$\because \quad 0.1 = \frac{0.01}{X_2}$

$$X_2 = 0.1\ \Omega$$

To obtain maximum torque at starting,

Let rotor resistance $= R_2'$

At starting, $\quad$ slip, $s = 1$

$$S_{mT} = \frac{R_2'}{X_2}$$

$$\Rightarrow \quad 1 = \frac{R_2'}{0.1}$$

$$\Rightarrow \quad R_2' = 0.1 \ \Omega/\text{phase}$$

The external resistance to be added,

$$R_{ext} = 0.1 - 0.01$$
$$= 0.09 \ \Omega/\text{phase}$$

30. (b)

Given, $\eta = 0.9$

Let, P = Stator copper loss

= Rotor copper loss = Iron loss

No load losses = P_{NL}

Mechanical loss = P_{mL}

No load losses = Iron loss + Mechanical losses

$$P_{NL} = P + P_{mL}$$

$$3\ P_{mL} = P + P_{mL}$$

$$P_{mL} = \frac{P}{2}$$

$$\text{Efficiency, } \eta = \frac{\text{Output Power}}{\text{Output power} + \text{losses}} = \frac{37}{37 + P + P + P + \frac{P}{2}}$$

$$0.90 = \frac{37}{37 + 3.5P}$$

$$P = 1.1746 \approx 1.175 \text{ kW}$$

Airgap power = P_{output} + Mechanical losses + Rotor copper losses

$$\text{Now slip, } s = \frac{\text{Rotor copper losses}}{\text{Air gap power}}$$

$$= \frac{1.175}{37 + \frac{1.175}{2} + 1.175} = 0.03$$

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