Ajay Kumar Garg Engineering College, Ghaziabad

Department of Electrical & Electronics Engineering

MODEL SOLUTION

Sessional Test - 2

Course: B.Tech
Session: 2017-18
Subject: Electric Drives
Max Marks: 50

Semester: VII
Branch: EN-1,2
Sub. Code: NEN-701
Time: 2 Hours.

Note: Attempt **all** the sections

SECTION-A

A. Attempt **all** the parts. **(5X2=10)**

1. What do you mean by Load equalization?

Ans: It is a process of smoothing the fluctuating load. The fluctuated load draws heavy current from supply during peak load which damages the equipment. In load equalization energy is stored at light load, and utilised when peak load occurs.

2. A motor of smaller rating can be selected for a short time duty. Why?

Ans: In this motors the time of operation is very low & the heating time is much lower than cooling time so, the motor cools off the ambient temperature before operating again. Hence, a smaller rating motor should be selected for this duty.

3. For a DC series motor which type of braking is not possible & why?

Ans: Regenerative Braking is not possible because in a series motor field & armature will be connected in series. In order to brake by this method 'Ia' should be made negative which in turn makes field flux also -ve which fails to brake as $\boxed{T \propto \phi I_a}$.

4. What are the methods of braking applicable to induction motor?

→ Regenerative Braking

→ Plugging

→ Dynamic Braking

5. State different classes of Motor Duty in detail with examples.

→ Continuous duty
→ Short time duty
→ Intermittent periodic duty
→ Intermittent periodic duty with starting
→ Intermittent periodic duty with starting & Braking
→ Continous duty with intermittent periodic loading
→ Continous duty with starting & Braking.

SECTION-B

B. Attempt **all** the parts. **(5X5=25)**

6. A motor has a heating time constant of 90 mins and a cooling time constant of 120 mins and final steady state temperature rise on full-load of 60°C. The motor has repeated load cycle of full load for 30 mins followed by stationary period of 30 mins. Determine the maximum and minimum temperatures. Also determine the overload on the motor that can be allowed on this cycle such that the maximum temperature rise does not exceed the permissible value of 60°C.

Solution: Given, Heating time constant

$\tau = 90min$

Cooling time constant

$\tau' = 120mins.$

$\theta_{ss} = 60°C.$ $t_h = 30mins$

$t_c = 30mins.$

Heating

$$\theta_2 = \theta_{ss}\left(1 - e^{-\frac{t_h}{\tau}}\right) + \theta_1 e^{-\frac{t_h}{\tau}}$$

$$\theta_2 = 60\left(1 - e^{-\frac{30}{90}}\right) + \theta_1 e^{-\frac{30}{90}}$$

$$\Rightarrow \theta_2 = 17 + \theta_1 \times 0.716 \longrightarrow (1)$$

Cooling $\theta_1 = \theta_2 e^{-\frac{30}{120}}$.

$\Rightarrow \theta_1 = \theta_2 \times 0.778 \rightarrow (2)$

From (1) & (2)

$\boxed{\theta_1 = 29.89^\circ C}$ $\boxed{\theta_2 = 38.42^\circ C}$

overload allowed can be $k = \sqrt{\frac{1-e^{-(t_h/\tau_h + t_c/\tau_1)}}{(1-e^{-t_h/\tau_h})}} = 1.287$

7. A Constant speed motor has the following duty cycle:
Load rising linearly from 200 to 500kW: 4min
Uniform Load of 400kW: 2min
Regenerative Power returned to supply linearly from 400kW to 0: 3 min
Remains idle: 4min
Determine power rating of the motor assuming loss to be proportional to $(\text{power})^2$.

Solution:

Rated power = rms value of Power P_{rms}.
for interval (i)

$$P_1 = \sqrt{\frac{1}{4}\int_0^4 \left(\frac{500-200}{4}x\right)^2 dx} = 173.205\,kW$$

$$P_{rms} = \sqrt{\frac{(173.20)^2 \times 4 + 400^2 \times 2 + 400^2 \times 3}{13}}$$

$$P_{rms} = \sqrt{\frac{120000 + 320000 + 480000}{13}}$$

$$= \sqrt{\frac{92 \times 10^4}{13}}$$

$$\boxed{P_{rms} = 266.024\,KW}$$

8. A 220V, 970 rpm separately excited motor having an armature resistance of 0.05 Ω draws 100A from the source. The motor is braked by plugging from an initial speed of 1000rpm. Calculate: (i) The resistance to be connected in series with armature to limit the initial baking current to twice the rated current (ii) Initial Braking torque (iii) The braking torque when the speed has reduced to Zero.

Solution :

At 970 rpm,

$$E = 220 - 0.05 \times 100$$
$$= 215V$$

At 1000 rpm, $E = \frac{1000}{970} \times 215 = 221.65V$

(a) For plugging operation

$$R_B + R_a = \frac{E+V}{I_a} = \frac{221.65+220}{200}$$
$$= 2.21\Omega$$

$$R_B = 2.21 - 0.05 = \underline{\underline{2.16\Omega}}$$

(b) $T = \frac{E \times I_a}{\omega_m} = \frac{221.65 \times 200}{1000 \times \frac{2\pi}{60}} = \underline{\underline{423.3N\text{-}m}}$

(c) At Zero Speed $E = 0$

$$I_a = \frac{V}{R_B + R_a} = \frac{220}{2.21} = 99.55A$$

As $T \propto I_a$,

$$T = 423.3 \times \frac{99.55}{200}$$
$$= \underline{\underline{210.7N\text{-}m}}$$

9. A 3-ϕ, 440V, 50Hz, 6 pole, Y-connected induction motor has following parameters referred to the stator: $R_s = 0.5\ \Omega$, $R_r' = 0.6\ \Omega$, $X_s = X_r' = 1$. Stator to rotor turns ratio is 2. If the motor is used for the regenerative braking, Determine: (i) Maximum overhauling torque it can hold and the range of speed in which it can safely operate. (ii) The speed at which it will hold a load with a load torque of 160 N-m.

Solution :

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

(i) $\omega_{ms} = 104.72$ r/s

For regenerative braking

$$S_m = -\frac{R_r'}{\sqrt{R_s^2 + (X_s + X_r')^2}}$$

$$= -\frac{0.6}{\sqrt{0.5^2 + (1+1)^2}} = -0.291$$

$$I_r' = \frac{V}{\sqrt{\left(R_s + \frac{R_r'}{S}\right)^2 + (X_s + X_r')^2}}$$

$$= \frac{440/\sqrt{3}}{\sqrt{\left(0.5 - \frac{0.6}{0.291}\right)^2 + 2^2}}$$

$$\boxed{I_r' = 100.108\,A}$$

$$T_{max} = \frac{3 I_r'^2 R_r'/s}{\omega_{ms}} = \frac{3 \times (100.108)^2 \times \left(\frac{1}{-0.291}\right)}{104.72}$$

$$\boxed{T_{max} = } \; -986.588\ \text{N-m}$$

Max. over hauling torque $= \underline{986.58\,\text{Nm}}$

speed @ which torque is max.

$= (1 - S_m) \times$ synchronous speed

10. A drive has following equations for motor and load torques:

$T = (1+2\omega_m)$ and $T_l = 3\sqrt{\omega m}$ Obtain the equilibrium points and determine their steady state stability.

Solution: At, Equilibrium

$$T = T_L$$

$$(1+2\omega_m) = 3\sqrt{\omega_m}$$

$$(1+2\omega_m)^2 = 9\omega_m$$

$$1+4\omega_m^2+4\omega_m = 9\omega_m$$

$$\Rightarrow 4\omega_m^2 - 5\omega_m + 1 = 0$$

$$\omega_m = \frac{+5 \pm \sqrt{25-16}}{8}$$

$$= \frac{5 \pm 3}{8} = \frac{8}{8}, \frac{2}{8}$$

$$\boxed{\omega_m = 1, \tfrac{1}{4} \text{ r/s}}$$

$$\frac{dT}{d\omega_m} = 2$$

$$\frac{dT_L}{d\omega_m} = \frac{3}{2\sqrt{\omega_m}}$$

$$\left.\frac{dT}{d\omega_m}\right|_{@\omega_m = 1, 1/4} = 2$$

$$\left.\frac{dT_L}{d\omega_m}\right|_{@\omega_m = 1/4} = 3$$

$T @ \omega_m = 1 \Rightarrow 3 = T$ $\boxed{T = T_L}$

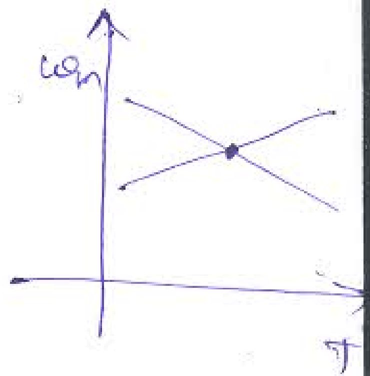
$T_L @ \omega_m = 1 \Rightarrow T_L = 3$ Nm

@ $\omega_m = 1$ r/s

$$\frac{dT_L}{d\omega_m} = \frac{3}{2} = 1.5 \text{ N-m}$$

$T @ \omega_m = 1/4 \Rightarrow T = 1 + 2 \times \frac{1}{4}{}_{2} = 1.5$ N-m

$T_L @ \omega_m = 1/4 \Rightarrow T_L = 1.5$ N-m



$\therefore$ At $\omega = 1$, $\frac{dT}{d\omega_m} > \frac{dT_L}{d\omega_m}$ unstable

$\omega = 1/4$, $\frac{dT}{d\omega_m} < \frac{dT_L}{d\omega_m}$ stable

Q9 Solution Continuation

$= (1+0.291) \times 1000$

$= 1291 rpm$

Speed range is from 1000 to 1291 rpm

Stable operation during regenerative braking occurs from synchronous speed @ which the torque is maximum. Thus range of speed for safe operation will be from 1000 to 1291 rpm

(ii) At steady state operation $T = T_L$

$$\frac{3}{\omega_{ms}} \times \frac{V^2 R_r'/s}{\left(R_s + \frac{R_r'}{s}\right)^2 + (X_s + X_r')^2} = T_L$$

$$\Rightarrow \frac{3}{104.72} \times \frac{(440)^2 \times \frac{0.6}{s}}{\left(0.5 + \frac{0.6}{s}\right)^2 + (1+1)^2} = -160$$

$$\Rightarrow \frac{\frac{1109.24}{s}}{\left(0.5 + \frac{0.6}{s}\right)^2 + 2^2} = -160$$

$$\Rightarrow \frac{1109.24}{s} = -160\left[\left(0.5 + \frac{0.6}{s}\right)^2 + 4\right]$$

$$= -160\left[0.25 + \frac{0.36}{s^2} + \frac{0.6}{s} + 4\right]$$

$$\Rightarrow \frac{1109.24}{s} = -40 - \frac{57.6}{s^2} - \frac{96}{s} - 640$$

$$\Rightarrow \frac{1109.24}{s} = \frac{-40s^2 - 57.6 - 96s - 640s^2}{s^2}$$

$$\Rightarrow 1109.24s = -680s^2 - 96s - 57.6$$

$\Rightarrow 680s^2 + 96s + 57.6 + 1109.24s = 0$

$\Rightarrow 680s^2 + 1205.24s + 57.6 = 0$

$s = -0.0491$

$s = 4.723$

$s = -1.723$

gives unstable operation

$s = -0.0491$ is the Solution.

Motor speed $= 1000(1+0.0491)$

$= 1049.1 rpm$

$\therefore$ speed @ which motor will hold a load @ 160N-m is 1049 rpm

SECTION-C

C. Attempt **all** the parts. **(2X7.5=15)**

11. Explain the thermal model of motor for heating and cooling and hence prove that both heating and cooling time constants depend on the velocity of air.

Answer:

Let the machine which is assumed to be homogenous body, & the cooling medium has following parameters @ time 't'

P_1 = Heat developed, watts

P_2 = Heat dissipated to cooling medium

W = weight of active parts of m/c, kg

h = specific heat, Joules per kg per °C

A = cooling surface, m^2

d = coefficient of heat transfer.

θ = mean temperature rise, °C

During a time dt, m/c temp rise be dθ,

Heat absorbed in m/c = (Heat developed inside m/c − Heat dissipated to cooling med)

$$Wh\,d\theta = P_1 dt - P_2 dt \rightarrow (1)$$

$$P_2 = \theta d A \rightarrow (2)$$

Sub eqn (1) & re arranging

$$C\frac{d\theta}{dt} = P_1 - D\theta \rightarrow (3)$$

$$\& \; C = Wh \rightarrow (4)$$

$$D = dA \rightarrow (5)$$

First order diff eqn has a solution

$$\theta = \theta_{ss} + k e^{-t/\tau} \rightarrow (6)$$

where $\theta_{ss} = \frac{P_1}{D}$ $\rightarrow$ (7)

$$\tau = \frac{C}{D} \rightarrow (8)$$

when initial temp. rise is θ_1,

$$\theta = \theta_{ss}(1-e^{-t/\tau}) + \theta_1 e^{-t/\tau} \rightarrow (9)$$

$$\& \; C\frac{d\theta}{dt} = P_1' - D'\theta \rightarrow (10)$$

Now Initial condns, $\theta = \theta_2$ @ $t=0$,

gives $\theta = \theta_{ss}'(1-e^{-t/\tau'}) + \theta_2 e^{-t/\tau'}$

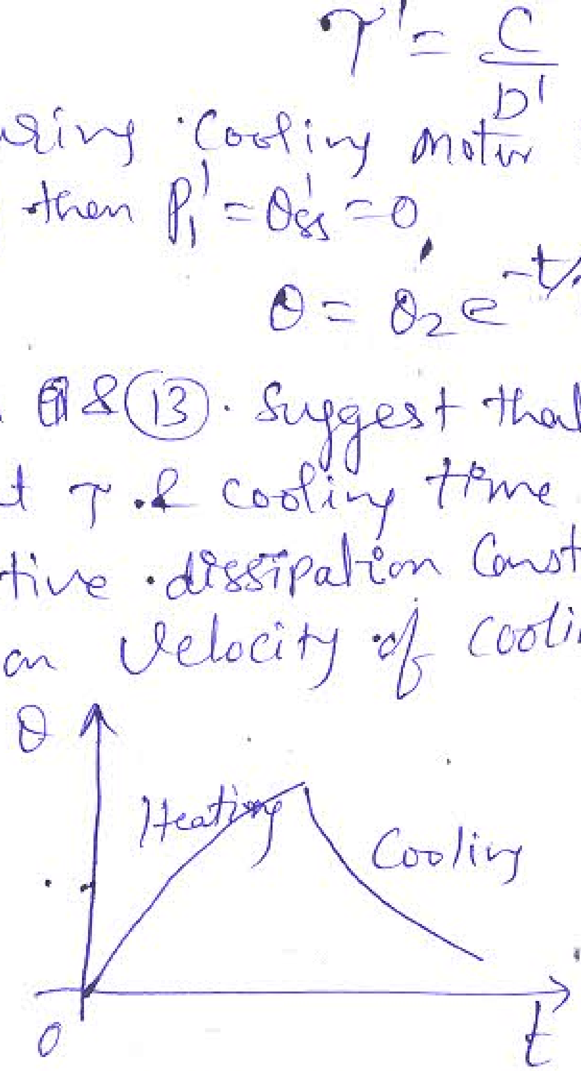
$$\theta_{ss}' = \frac{P_1'}{D'} \rightarrow (11)$$

$$\tau' = \frac{C}{D'} \rightarrow (12)$$

During cooling motor is disconnected from supply then $P_1' = \theta_{ss}' = 0$,

$$\theta = \theta_2 e^{-t/\tau'} \rightarrow (13)$$

Eqn (9) & (13) suggest that both heating time constant τ & cooling time constant τ' depend on respective dissipation constants D & D' which in turn depend on velocity of cooling air



Heating & Cooling Curves.

12. Explain energy losses during starting and braking of a DC motor.

Ans :

Energy losses in motors & in resistors in motor armature ckt, power losses given by

$$V i_a = R_a i_a^2 + L_a i_a \frac{di_a}{dt} + K_e \phi \omega_m i_a \rightarrow (1)$$

Considering viscous friction torque to be a part of load torque T_L,

$$\frac{J d\omega_m}{dt} = T - T_L \rightarrow (2)$$

$$\& \int V_a i_a dt = \int R_a i_a^2 dt + \int L_a i_a di_a + \int J d\omega_m \omega_m + \int T_L \omega_m \rightarrow (3)$$

Starting of motor with a constant speed & applied voltage V & a load Torque T_L.

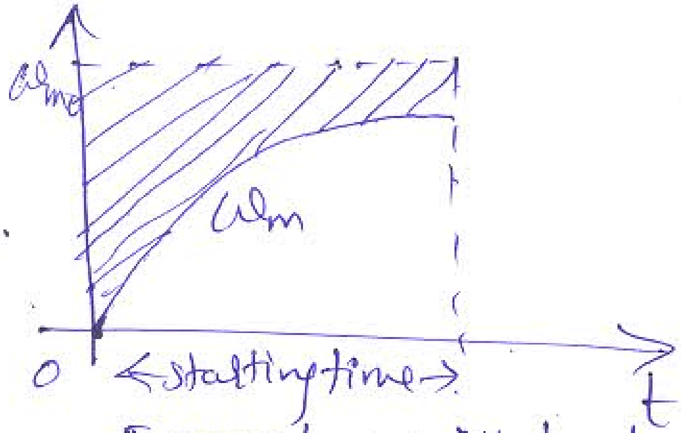
Since,
$$V_a i_a dt = (K_e \phi \omega_{mo}) i_a dt$$
$$= T \omega_{mo} dt$$
$$= \left(T_L + \frac{J d\omega_m}{dt}\right) \omega_{mo} dt$$
$$= \omega_{mo} T_L dt + J \omega_{mo} d\omega_m \rightarrow (4)$$

from (3) & (4)

$$\int R_a i_a^2 dt = \int J(\omega_{mo} - \omega_m) d\omega_m + \int T_L (\omega_{mo} - \omega_m) dt \rightarrow (5)$$

Hence energy loss @ no load E_0 is

$$E_0 = \int_0^{\omega_{mo}} J(\omega_{mo} - \omega_m) d\omega_m = \frac{1}{2} J \omega_{mo}^2 \rightarrow (6)$$



Energy loss with load during starting of sep excited dc motor.

$$E_m = J \int_{\frac{\omega_{mo}}{n}(n-1)}^{\frac{\omega_{mo}}{n}(m)} \left[\frac{\omega_{mo}}{n}(m) - \omega_m \right] d\omega_m$$

$$= \frac{1}{2} J \frac{\omega_{mo}^2}{n^2} \rightarrow (7)$$

Total Noload cu loss during starting becomes

$$E_0' = \frac{1}{2} J \frac{\omega_{mo}^2}{n} \rightarrow (8)$$

Comparing with (6) shows no load cu loss reduced by a factor 'n'.

For Rheostatic / Dynamic braking, $V=0$ neglecting L_a & assume T_L be constant equal to T_L,

$$\int i_a^2 R_a \, dt = -\int_{\omega_{mL}}^{0} J \omega_m \frac{d\omega_m}{dt} - \int T_L \omega_m dt \rightarrow (9)$$

It has been assumed that prior to braking motor was operating in steady state against a passive load torque T_L @ a speed ω_{mL}.

$$\int i_a^2 R_a \, dt = \frac{1}{2} J \omega_{mL}^2 - \int T_L \omega_m dt \rightarrow (10)$$

For plugging substituting $-V$ in place V & $L_a = 0$

we get $$\int i_a^2 R_a dt = -\int_{\omega_{mL}}^{0} J(\omega_{mo} + \omega_m) d\omega_m - \int T_L (\omega_{mo} + \omega_m) d\omega_m$$

$$= \frac{3}{2} J \omega_{mL}^2 - \int T_L (\omega_{mo} + \omega_m) dt \rightarrow (11)$$