Highlights your final answer

Try to avoid calculation mistake

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Leading Institute for ESE, GATE & PSUs

ESE 2025 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Electrical Engineering

Test-4 : Electrical Machines + Analog Electronics + Control Systems

Name : ....

Roll No :

Test Centres			Student's Signature
Delhi ☑	Bhopal ☐	Jaipur ☐	
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Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. There are Eight questions divided in TWO sections.
3. Candidate has to attempt FIVE questions in all in English only.
4. Question no. 1 and 5 are compulsory and out of the remaining THREE are to be attempted choosing at least ONE question from each section.
5. Use only black/blue pen.
6. The space limit for every part of the question is specified in this Question Cum Answer Booklet. Candidate should write the answer in the space provided.
7. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
8. There are few rough work sheets at the end of this booklet. Strike off these pages after completion of the examination.

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	36
Q.2	46
Q.3	
Q.4	39
Section-B	
Q.5	37
Q.6	
Q.7	51
Q.8	
Total Marks Obtained	209

Signature of Evaluator: Sourabh kumar

Cross Checked by: ....

IMPORTANT INSTRUCTIONS

CANDIDATES SHOULD READ THE UNDERMENTIONED INSTRUCTIONS CAREFULLY. VIOLATION OF ANY OF THE INSTRUCTIONS MAY LEAD TO PENALTY.

DONT'S

1. Do not write your name or registration number anywhere inside this Question-cum-Answer Booklet (QCAB).
2. Do not write anything other than the actual answers to the questions anywhere inside your QCAB.
3. Do not tear off any leaves from your QCAB, if you find any page missing do not fail to notify the supervisor/invigilator.
4. Do not leave behind your QCAB on your table unattended, it should be handed over to the invigilator after conclusion of the exam.

DO'S

1. Read the Instructions on the cover page and strictly follow them.
2. Write your registration number and other particulars, in the space provided on the cover of QCAB.
3. Write legibly and neatly.
4. For rough notes or calculation, the last two blank pages of this booklet should be used. The rough notes should be crossed through afterwards.
5. If you wish to cancel any work, draw your pen through it or write "Cancelled" across it, otherwise it may be evaluated.
6. Handover your QCAB personally to the invigilator before leaving the examination hall.

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Section A : Electrical Machines + Analog Electronics + Control Systems

Q.1 (a) A 4-pole, 3-ϕ Slip Ring Induction Motor (SRIM) is used as a frequency changer. Its stator is excited from 3-phase, 50 Hz supply. A load requiring 3-phase, 20 Hz supply is connected to the star-connected rotor through three slip rings of SRIM.

(i) At what two speeds the prime mover should drive the rotor of this SRIM?

(ii) Find the ratio of two voltages available at the slip rings at the two speeds.

[12 marks]

Given:- 4pole, 3ϕ SRIM $f_s = 50Hz$

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

(i) $f_r = 20Hz$

$$f_r = s f_s$$

$$20 = s_1 \cdot 50$$

$$s_1 = \frac{20}{50} = 0.4$$

(ii) speed of the prime mover -

$$N_1 = N_s(1-s)$$

$$= 1500(1-0.4)$$

$$\boxed{N_1 = 900\,rpm}$$

~~Another speed -~~

$$\cancel{N_2 = N_s(1+s)}$$

$$\cancel{= 1500(1+0.4)}$$

$$\cancel{\boxed{N_2 = 2100\,rpm}}$$

$$f_r = s f_s$$

$$50 = s_2\, 20$$

$$s_2 = 2.5$$

Another speed $N_2 = N_s(1-s)$

$$N_2 = 1500(1-2.5)$$

$$\boxed{N_2 = 2250\,rpm}$$

(ii) voltage available at the slip ring

$E_2 = sV_s$

∴ as two different slip is same

Hence, the ~~ratio of~~

$$\boxed{E_2 \propto s}$$

$$\frac{E_{21}}{E_{22}} = \frac{s_1}{s_2} = \frac{0.4}{2.5} = 0.16$$

$$\boxed{\frac{E_{21}}{E_{22}} = 0.16}$$

5

.1 (b) The open-loop transfer function of a unity feedback ac position control system is

$$G(s) = \frac{10K}{s(1+0.1s)}.$$

Find the minimum value of the amplifier gain K so that when the input shaft rotates at $\frac{1}{2}$ revolution per second, the steady-state velocity error is 0.2°. With that value of K, what will be the value of damping factor and natural frequency?

[12 marks]

$$G(s) = \frac{10k}{s(1+0.1s)}$$

For type-I system
steady state error —

$$k_v = \lim_{s\to 0} s\,G(s) = \lim_{s\to 0} s \cdot \frac{10k}{s(1+0.1s)}$$

$$k_v = 10k$$

steady state error

$$e_{ss} = \frac{1}{k_v} = \frac{1}{10k} \quad -(1)$$

For the given system

$$e_{ss} = \theta = 0.2° = \frac{0.2}{360} = \frac{1}{1800} \text{ rev}$$

$$N = 0.5 \text{ rpm}$$

$$= \cancel{0.5 \times \frac{2\pi}{60}} = \frac{1}{2} \text{ rpm}$$

$$= \cancel{0.0523 \text{ rad/s}}$$

$$\cancel{e_{ss} = \frac{\theta}{N} = \frac{0.2}{0.0523} = 3.81 \text{ deg/sec}} \quad -(11)$$

∴ equating (1) and (11) we get

$$\frac{1}{2} \times \frac{1}{10k} = \cancel{3.81\deg}\ \frac{1}{1800}$$

$$\boxed{K = 90}$$

$\boxed{\cancel{K \approx 0.0262}}$ $\boxed{K = 90}$

$\therefore$ Hence, minimum value of $K = 0.0262$

$$\therefore G(s) = \frac{10 \times \cancel{0.0262}\ 90}{s(1+0.1s)} = \frac{900}{s(1+0.1s)}$$

Characteristic equation -

$$1 + \frac{\cancel{0.262}\ 900}{s(1+0.1s)} = 0$$

$$s + 0.1s^2 + \cancel{0.262}\ 900 = 0$$

$$s^2 + 10s + \cancel{2.62}\ 9000 = 0$$

$\cancel{\omega_n^2 = 2.62}$ $\cancel{2\xi\omega_n = 10}$

$\cancel{\boxed{\omega_n = 1.618 r/s}}$ $\cancel{2 \times \xi \times 1.618 = 10}$

$\cancel{\boxed{\xi = 3.089}}$

$\omega_n^2 = 9000$

$\omega_n = 94.86 r/s$

$2 \times \xi\, \omega_n = 10$

$2 \times \xi \times 94.86 = 10$

$\xi = 0.0527$

Hence, $K = 90$

$\omega_n = 94.86 r/s$

$\xi = 0.0527$

11

Good Approach

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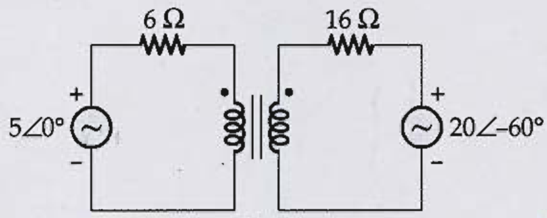
Q.1 (c) In the figure shown below:



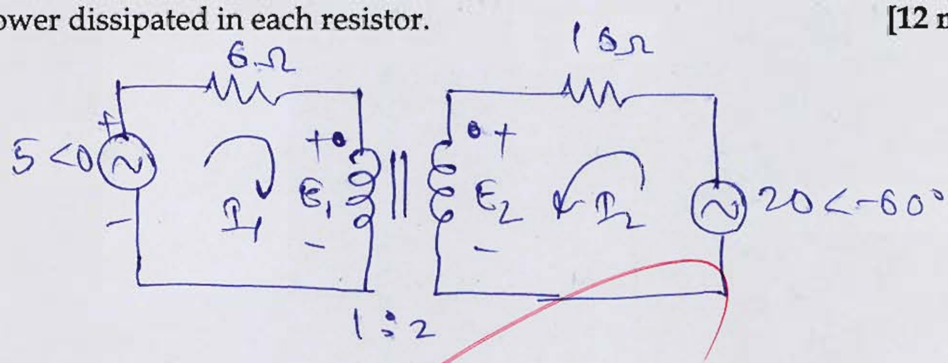
1 : 2

IDEAL TRANSFORMER

Calculate :

(i) The power delivered by each source.

(ii) The power dissipated in each resistor. **[12 marks]**



Now, $\frac{E_1}{E_2} = \frac{1}{2}$ — ①

KVL in loop ①

$5 \angle 0^\circ = 6 I_1 + E_1$ — Ⓐ

KVL in loop 2

$20 \angle -60^\circ = 16 I_2 + E_2$ — Ⓑ

∴ $E_2 = 2 E_1$

and $\frac{I_1}{-I_2} = \frac{2}{1}$

⇒ $I_2 = -\frac{I_1}{2}$

$20 \angle -60 = 16 \times \left(-\frac{I_1}{2}\right) + 2 E_1$

$20 \angle -60^\circ = -8 I_1 + 2 E_1$ — Ⓑ

solving eq - (A) and (B) by cramer's rule

$$I_1 = \frac{\begin{vmatrix} 5\angle 0^\circ & 1 \\ 20\angle -60^\circ & 2 \end{vmatrix}}{\begin{vmatrix} 6 & 1 \\ -8 & 2 \end{vmatrix}} = \frac{10\angle 0^\circ - 20\angle -60^\circ}{12 + 8}$$

$$I_1 = 0.866\angle 90^\circ \text{ A}$$

Now, $I_2 = -\frac{I_1}{2} = -\frac{0.866}{2}\angle 90^\circ$

$$I_2 = 0.433\angle -90^\circ \text{ A}$$

11

(i) power delivered by $5\angle 0^\circ$ V source -

$S_1 = 5\angle 0^\circ \times 0.866\angle -90^\circ$

$= 4.33\angle -90^\circ$ VA

$\boxed{S_1 = -j4.33 \text{ VA}}$ $\boxed{P_1 = 0, \quad Q_1 = -4.33 \text{ VAR}}$

Good Approach

Power delivered by $20\angle -60^\circ$ V source

$S_2 = 20\angle -60^\circ \times 0.433\angle 90$

$\boxed{S_2 = (7.5 + j4.33) \text{ VA}}$ $\boxed{P_2 = 7.5 \text{ W}, \quad Q_2 = +4.33 \text{ VAR}}$

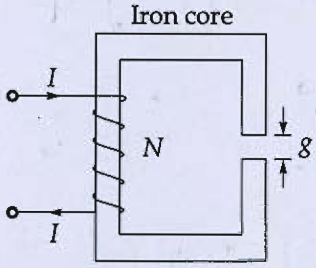
(ii) power dissipated in 6Ω resistor

$P_{6\Omega} = (0.866)^2 \times 6 = 4.5 \text{ W}$

Power dissipated in 16Ω resistor

$P_{16\Omega} = (0.433)^2 \times 16 = 3\ \Omega$

Q.1 (d) For the magnetic circuit shown below:



Length of iron path = 120 cm, g = 0.5 cm, area of cross-section of iron = 5 × 5 cm^2, μ_r = 1500, I = 2 A, N = 1000 turns.

Calculate and compare the field - energy stored and field energy density in iron as well as in air gap. Neglect fringing and leakage flux.

[12 marks]

Given :- for the core -

$l = 120$ cm $\quad A = 5 \times 5\,\text{cm}^2 = 25\,\text{cm}^2$

$\mu_r = 1500 \quad I = 2A \quad N = 1000$ turns

Reluctance of the iron core -

$$R_c = \frac{l_c}{\mu_0 \mu_r A} = \frac{120 \times 10^{-2}}{4\pi \times 10^{-7} \times 1500 \times 25 \times 10^{-4}}$$

$$R_c = 254648$$

Inductance of the core -

$$L_c = \frac{N^2}{R_c} = \frac{(1000)^2}{254648}$$

$$\boxed{L_c = 3.927\ H}$$

field energy density of core -

$$W_c = \frac{1}{2} L_c I^2 = \frac{1}{2} \times 3.927 \times (2)^2$$

$$\boxed{W_c = 7.854\ J/m3}$$

field energy stored

$$W_c = 7.854 \times 25 \times 10^{-4} \times 120 \times 10^{-2}$$

$$\boxed{W_c = 0.0235\ J}$$

Reluctance of the air gap

$$R_g = \frac{l_g}{\mu_0 A} = \frac{0.5 \times 10^{-2}}{4\pi \times 10^{-7} \times 25 \times 10^{-4}}$$

$$R_g = 1591549$$

Inductance of the air gap

$$L_g = \frac{N^2}{R_g} = \frac{(1000)^2}{1591549}$$

$$L_g = 0.6283 \text{ H}$$

energy density of air gap

$$w_g = \frac{1}{2} L_g i^2 = \frac{1}{2} \times 0.6283 \times (2)^2$$

$$\boxed{w_g = 1.256 \text{ J/m}^3}$$

Field energy stored

$$w_g = 1.256 \times 25 \times 10^{-4} \times 0.5 \times 10^{-2}$$

$$\boxed{w_g = 1.57 \times 10^{-5} \text{ J}}$$

4

Q.1 (e) The short-circuited tests on two single-phase transformer gave the following results:

200 kVA : 3% rated voltage ; rated current at 0.25 power factor lagging

500 kVA : 4% rated voltage ; rated current at 0.3 power factor lagging

These two transformers are connected in parallel. How do they share a load of 560 kW at 0.8 power factor lagging?

[12 marks]

Transformer 1. 200 kVA, 3% rated vtg
rated current, 0.25 pf lag

$\cos\phi = 0.25$

$\phi = 75.52^\circ$

$Z_1 = \frac{\%\text{ rated vtg}}{\text{rated current}} = 3\% = 0.03\text{ pu}$

$\boxed{Z_1 = 0.03 \angle 75.52^\circ \text{ pu}}$ at 200 kVA base

Transformer 2 500 kVA, 4% rated voltage
rated current, at 0.3 pf lag

$\cos\phi = 0.3$

$\phi = 72.54^\circ$

$Z_2 = \frac{\%\text{ rated vtg}}{\text{rated current}} = 4\% = 0.04\text{ pu}$

$\boxed{Z_2 = 0.04 \angle 72.54^\circ \text{ pu}}$ at 500 kVA base

Load :- 560 kW at 0.8 pf

$S = \frac{P}{\cos\phi} = \frac{560}{0.8} = 700\text{ kVA}$

Let $S_{base} = 700$ kVA

$Z_{1new} = 0.03 \angle 75.52 \times \frac{700}{200}$

$Z_{1new} = 0.105 \angle 75.52^\circ$ pu

$Z_{2new} = 0.04 \angle 72.54^\circ \times \frac{700}{500}$

$Z_{2new} = 0.056 \angle 72.54^\circ$ pu

KVA load shared by Transformer 1

$S_1 = S_{Load} \times \frac{Z_{2new}}{Z_{1new} + Z_{2new}}$

$S_1 = 700 \angle 36.87 \times \frac{0.056 \angle 72.54}{0.056 \angle 72.54 + 0.105 \angle 75.52}$

5

$S_1 = (199.68 + j139.44)$ KVA

$\boxed{P_1 = 199.68\ KW} \simeq 200$ KW

KVA load shared by Transformer 2 -

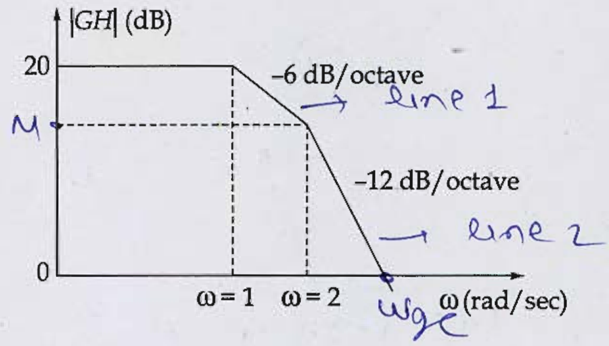
$S_2 = S_{Load} \times \frac{Z_{1new}}{Z_{1new} + Z_{2new}}$

$= 700 \angle 36.87 \times \frac{0.105 \angle 75.52}{0.105 \angle 75.52 + 0.056 \angle 72.54}$

$S_2 = (360.32 + j280.56)$ KVA

$\boxed{P_2 = 360.32\ KW \simeq 360\ KW}$

Q.2 (a) The asymptotic approximation to the log-magnitude versus frequency plot (Bode plot) of a unity feedback control system is shown in the figure. The system is a minimum phase system.



Determine :

(i) Gain crossover frequency in rad/sec.

(ii) Phase crossover frequency.

(iii) Gain margin in dB.

(iv) Phase margin in degrees. **[20 marks]**

(i) At $\omega = \omega_{gc}$ $|GH| = 0\,dB$

slope = $-12\,dB/oct = -40\,dB/dec$

~~40 dec~~

For line 1

$$-20 = \frac{M - 20}{\log 2 - \log 1}$$

$$\Rightarrow -20 = \frac{M-20}{\log 2}$$

$$M - 20 = -6$$

$$\boxed{M = 14\,dB}$$

For line 2

$$-40 = \frac{14 - 0}{\log 2 - \log \omega_{gc}}$$

$\Rightarrow$ $\log\left(\frac{\omega_{gc}}{2}\right)$ ~~= 2.82~~

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$$\log\left(\frac{2}{\omega_{gc}}\right) = -2.857$$

$$\frac{2}{\omega_{gc}} = 10^{-2.852} = 1.389 \times 10^{-3}$$

$$\boxed{\omega_{gc} = 1439.37\ r/s}$$

Hence, gain cross over frequency
$\omega_{gc} = 1439.37\ r/s$

(ii) Initial slope = 0 dB/dec

at $\omega = 1$ slope = -20 dB/dec

Hence at $\omega = 1$ pole is added

at $\omega = 2$ slope is -40 dB/dec

∴ Transfer function of the system

$$G(s)H(s) = \frac{K}{\left(1+\frac{s}{1}\right)\left(1+\frac{s}{2}\right)}$$

where $M = 20 \log K$

$M = 20$ dB

$20 \log K = 20$

$$\boxed{K = 10}$$

∴ Transfer function

$$G(s)H(s) = \frac{10}{(1+s)\left(1+\frac{s}{2}\right)} = \frac{20}{(s+1)(s+2)}$$

$$G(j\omega) = \frac{20}{(j\omega+1)(j\omega+2)}$$

$$\angle G(j\omega) = -\tan^{-1}(\omega) - \tan^{-1}\left(\frac{\omega}{2}\right)$$

at $\omega = \omega_{pc}$ $\quad \phi = -180$

$$-\tan^{-1}(\omega) - \tan^{-1}\left(\frac{\omega}{2}\right) = -180$$

$$\tan^{-1}(\omega) + \tan^{-1}\left(\frac{\omega}{2}\right) = 180$$

$$\tan^{-1}\left(\frac{\omega + \omega/2}{1 - \frac{\omega^2}{2}}\right) = 180$$

ω_{pc} ~~does not~~ exist

$$\boxed{\omega_{pc} = \infty}$$

(iii) at $\omega = \infty$ $\quad |G(j\omega)| = 0$

$$GM = 20\log\left|\frac{1}{G(j\omega)}\right| = \infty$$

$$\boxed{GM = \infty}$$

(iv) at $\omega = \omega_{gc}$

$$\phi = -\tan^{-1}(1439.37) - \tan^{-1}\left(\frac{1439.37}{2}\right)$$

$$= -179.88^\circ$$

$$PM = 180 + \phi$$

$$= 180 - 179.88$$

$$\boxed{PM = 0.12^\circ}$$

14

Q.2 (b) A 150 kVA, 2500/250 V, single-phase two winding transformer is to be used as an auto transformer for stepping up the voltage from 2500 V to 2750 V. At rated load, the two winding transformer has 2.5% loss, 3% voltage regulation and 4% impedance. For the auto transformer, determine the followings:

(i) Voltage and current rating.

(ii) kVA rating.

(iii) Efficiency.

(iv) Percentage impedance.

(v) Regulation, and

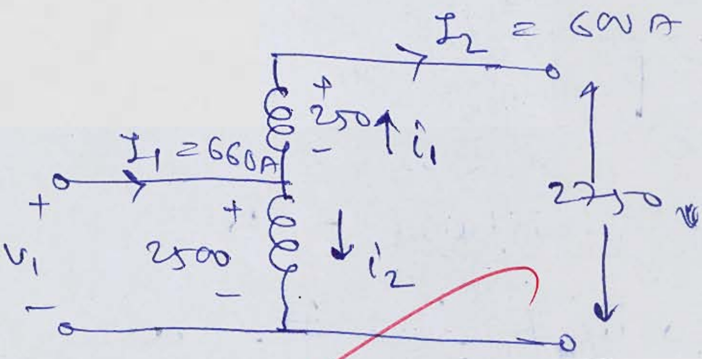
(vi) Short circuit current on each side. **[20 marks]**

For 2 winding transformer -

% Z = % 4

% R = % Cu loss = 2.5 %.

% VR = 3 %.



$i_1 = \frac{150 \times 10^3}{250} = 600\ A$

$i_2 = \frac{150 \times 10^3}{2500} = 60\ A$

(i) For auto transformer

primary voltage $V_1 = 2500V$

and primary current $I_1 = 600 + 60$

$I_1 = 660\ A$

secondary voltage $V_2 = 2750V$

and secondary current $I_2 = 600\ A$

(ii) KVA rating of Auto transformer

$S = V_1 I_1 = V_2 I_2$

$= 2500 \times 660$

$\boxed{S = 1650 \text{ KVA}}$

(iii) Auto transformer loss = 2 winding T/F loss

$\text{Loss} = \frac{2.5}{100} \times 1500 \times 10^3$

$\text{Loss} = 3750 \text{ W}$

Output = 1650 KVA

∴ At upf

$\text{efficiency} = \frac{\text{output}}{\text{output} + \text{losses}} \times 100$

$= \frac{1650 \times 10^3 \times 1}{1650 \times 10^3 \times 1 + 3750} \times 100$

$= 99.77\%$

$\boxed{\eta = 99.77\%}$

(iv) $K = \frac{V_1}{V_2} = \frac{2500}{2750} = 0.909$

$(\% \text{ Impedance})_{AT} = (1-k) \times \frac{(\% \text{ impedance})_{2\,wdg}}{\cancel{k}}$

$(\% Z)_{AT} = \frac{4}{\cancel{1-0.909}} \times (1 - 0.909)$

$\boxed{(\% Z)_{AT} = 0.363\%}$

(v) $(\%\,VR)_{AT} = (1-K)\,(\%\,VR)_{2\,wdg\,T/F}$

$(\%\,VR)_{AT} = (1-0.909) \times 3\,\%$

$\boxed{(\%\,VR)_{AT} = 0.273\,\%}$

(vi) Short circuit current

$= \dfrac{1}{(\%\,Z)_{AT}}$

$= \dfrac{100}{0.363}$

$\boxed{I_{SC} = 275\ pu}$

$\therefore$ ~~$(I_{SC}) = 275$~~

short circuit current on primary side —

$I_{SC_1} = 275 \times I_1 = 275 \times 660$

$= 181.82\,kA$

short circuit current on secondary side

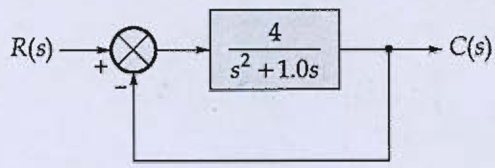
$I_{SC_2} = 275\,I_2 = 275 \times 600$

$= 165\,kA$

18

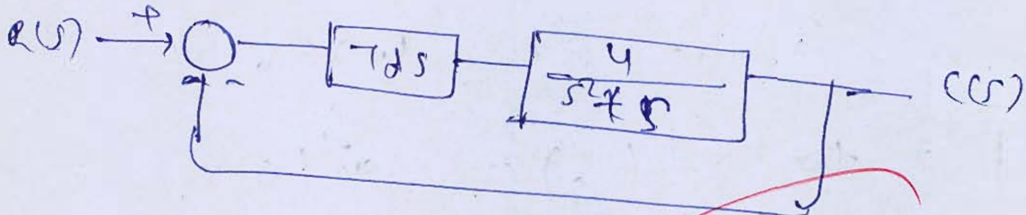
Good Approach

Q.2 (c) A closed-loop control system with unity feedback is shown in figure below. By using derivative control, the damping ratio is to be made 0.75. Determine the value of T_d. Also determine the rise time, peak time and peak overshoot without derivative control and with derivative control. The input to the system is a unit-step.



[20 marks]

with derivative controller $G_c(s) = T_d s$



closed - loop transfer function -

$$\frac{C(s)}{R(s)} = \frac{\dfrac{4T_d s}{s^2+s}}{1+\dfrac{4T_d s}{s^2+s}} = \frac{4T_d s}{s^2+s+4T_d s}$$

without derivative control -

characteristics eqn -

$$s^2+s+4=0$$

$\therefore \omega_n^2 = 4$ $\qquad 2\times\xi_p\,\omega_n = 1$

$\omega_n = 2\ r/s$ $\qquad 2\times\xi_p\times 2 = 1$

$$\boxed{\xi_p = 0.25}$$

$\therefore$ Now, with derivation control

$\omega_n = 2\ r/s$ $\qquad \xi_p' = 0.75$

$$2\times\xi_p\,\omega_n = 1+4T_d$$

$$\Rightarrow 2\times 0.75\times 2 = 1+4T_d$$

$1 + 4T_d = 3$

$\boxed{T_d = 0.5}$

without Derivative control

$\xi_p = 0.25 \quad \omega_n = 2 \text{ r/s}$

$\omega_d = \omega_n\sqrt{1-\xi_p^2}$

$= 2\sqrt{1-0.25^2} = 1.936 \text{ r/s}$

$\phi = \cos^{-1}(\xi_p) = \cos^{-1}(0.25)$

$= 75.52^\circ = 1.318 \text{ rad}$

Rise time

$t_r = \dfrac{\pi - \phi}{\omega_d} = \dfrac{\pi - 1.318}{1.936}$

$\boxed{t_r = 0.942 \text{ sec}}$

peak time

$t_p = \dfrac{\pi}{\omega_d} = \dfrac{\pi}{1.936}$

$\boxed{t_p = 1.623 \text{ sec}}$

peak overshoot

$\% M_p = e^{\frac{-\xi_p \pi}{\sqrt{1-\xi_p^2}}} \times 100$

$= e^{\frac{-0.25\pi}{\sqrt{1-0.25^2}}} \times 100$

$$\boxed{\% M_p = 44.43\%}$$

with derivative control

$\xi_e = 0.75 \quad \omega_n = 2 \, r/s$

$\omega_d = \omega_n \sqrt{1-\xi_e^2}$

$= 2\sqrt{1-0.75^2}$

$\omega_d = 1.323 \, r/s$

$\phi = \cos^{-1}(\xi_e) = \cos^{-1}(0.75)$

$= 41.41^\circ$ or 0.723 rad

Rise time

$t_r = \dfrac{\pi - \phi}{\omega_d} = \dfrac{\pi - 0.723}{1.323}$

$$\boxed{t_r = 1.828 \text{ sec}}$$

Peak time

$t_p = \dfrac{\pi}{\omega_d} = \dfrac{\pi}{1.323}$

$$\boxed{t_p = 2.374 \text{ sec}}$$

Peak overshoot

$\% M_p = e^{\frac{-\xi_e \pi}{\sqrt{1-\xi_e^2}}} \times 100$

$= e^{\frac{-0.75\pi}{\sqrt{1-0.75^2}}} \times 100$

$\boxed{\% \, M_p = 2.837\%}$

14

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Q.3 (a) When the primary of a transformer is energized at rated voltage of 11000 V and at rated frequency of 50 Hz, it takes 3.2 A and 2400 watt at no-load. Another transformer has all its core dimension $\sqrt{2}$ times the corresponding core dimension of the first transformer. Number of primary turns, type of core material and lamination thickness are the same in both the transformers. If the primary of the second transformer is energized from 22000 V, 50 Hz supply, calculate the no-load current and power drawn by it.

[20 marks]

Q.3 (b) A 460 V, 25 hp, 60 Hz, 4-pole, Y-connected wound rotor induction motor has the following impedances per phase referred to stator side is a :

$$R_1 = 0.641\ \Omega,\ R_2 = 0.332\ \Omega$$

$$X_1 = 1.106\ \Omega,\ X_2 = 0.464\ \Omega,\ X_m = 26.3\ \Omega$$

(i) What is maximum torque of this motor? At what slip and speed does it occur?

(ii) What is the starting torque of this motor?

(iii) When the rotor resistance is doubled, what is the speed at which the maximum torque now occurs? What is the new starting torque of the motor?

[20 marks]

Q.3 (c) A 440 V, 50 Hz, 6 pole, Y-connected induction motor running at 950 rpm has the following parameters referred to the stator : $R_s = 0.5\ \Omega$, $R'_r = 0.4\ \Omega$, $X_s = X'_r = 1.2\ \Omega$, $X_m = 50\ \Omega$. Motor is driving a fan load, the torque of which is given by $T_L = 0.0123\ \omega_m^2$. Now one phase of the motor falls, calculate the motor speed and current. Will it be safe to allow the motor to run for a long period? (Solve using approximate circuit)

[20 marks]

Q.4 (a) A 4-pole compound generator has armature, series-field and shunt-field resistance of 1 Ω, 0.5 Ω and 100 Ω respectively. This generator delivers 4 kW at a terminal voltage of 200 V. Allowing 1 V per brush for contact drop, calculate for both short-shunt and long-shunt connections.

(i) The generated emf, and

(ii) The flux per pole if the armature has 200 lap-connected conductors and is driven at 750 rpm.

[20 marks]

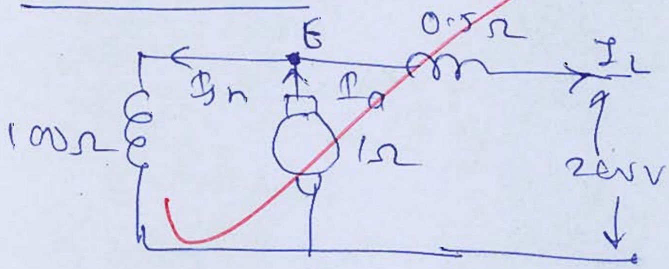
Given :- 4 pole compound generator

$R_a = 1\Omega \qquad R_{se} = 0.5\Omega$

$R_{sh} = 100\Omega$

(1)

short - shunt



$$I_L = \frac{4000}{200} = 20\,A$$

$$E = 200 + 0.5 \times 20 = 210\,V$$

$$I_{sh} = \frac{210}{100} = 2.1\,A$$

$$I_a = 20 + 2.1 = 22.1\,A$$

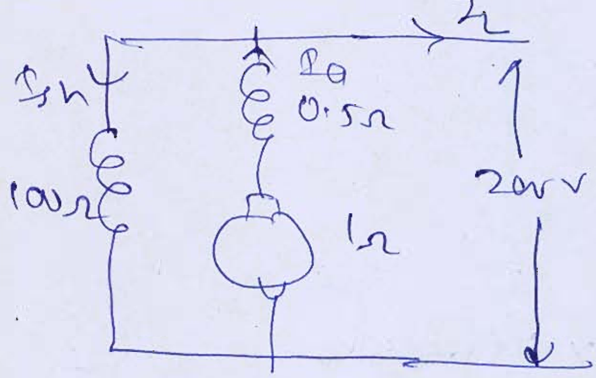
Generated emf –

$$E_g = 210 + 22.1 \times 1$$

+ Brush drop

$$\boxed{E_g = 232.1\,V}$$

Long - shunt



$I_L = \frac{4000}{200}$

$I_L = 20A$

$I_{sh} = \frac{200}{100}$

$I_{sh} = 2A$

$\therefore I_a = 20 + 2$

$= 22 A$

Generated emf =

$E_g = 200 + 22 \times (1 + 0.5)$ + Brus drop

$\boxed{E_g = 233 V}$

(ii) Short shunt

$E_g = 232.1 V$

$\therefore E_g = \frac{P \phi N Z}{60 A}$

$\Rightarrow 232.1 = \frac{4 \times \phi \times 750 \times 200}{60 \times 4}$

$\phi = 0.09288 \text{ wb}$

$\boxed{\phi = 92.88 \text{ mwb}}$

Long - shunt

$$E_g = 233\,V$$

$$E_g = \frac{P\phi N Z}{60\,A}$$

$$\Rightarrow 233 = \frac{4 \times \phi \times 750 \times 200}{60 \times A}$$

$$\phi = 0.0932\,Wb$$

$$\boxed{\phi = 93.2\,mWb}$$

15

Q.4 (b) Obtain the time response of the system described by

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -1 & -2 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 1 \\ -1 \end{bmatrix} u$$

with the initial conditions $\begin{bmatrix} x_1(0) \\ x_2(0) \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \end{bmatrix}, y = \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$.

[20 marks]

∴ ~~A =~~ $\dot{x}(t) = A\,x(t) + B\,u(t)$

$A = \begin{bmatrix} 0 & 1 \\ -1 & -2 \end{bmatrix} \qquad B = \begin{bmatrix} 1 \\ -1 \end{bmatrix}$

$y = C\,X(t)$

$C = [\,0 \quad 1\,]$

Now, for time response with initial condition — $\begin{bmatrix} x_1(0) \\ x_2(0) \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$

we need to find state transition matrix

$\phi(t) = \mathcal{L}^{-1}\left[(sI - A)^{-1}\right]$

$(sI - A) = \begin{bmatrix} s & 0 \\ 0 & s \end{bmatrix} - \begin{bmatrix} 0 & 1 \\ -1 & -2 \end{bmatrix}$

$= \begin{bmatrix} s & -1 \\ 1 & s+2 \end{bmatrix}$

$(sI - A)^{-1} = \dfrac{\begin{bmatrix} s+2 & 1 \\ -1 & s \end{bmatrix}}{s(s+2)+1}$

$$= \frac{\begin{bmatrix} s+2 & 1 \\ -1 & s \end{bmatrix}}{s^2+2s+1}$$

$$= \begin{bmatrix} \frac{s+2}{(s+1)^2} & \frac{1}{(s+1)^2} \\ \frac{-1}{(s+1)^2} & \frac{s}{(s+1)^2} \end{bmatrix}$$

$$= \begin{bmatrix} \frac{1}{s+1} + \frac{1}{(s+1)^2} & \frac{1}{(s+1)^2} \\ \frac{-1}{(s+1)^2} & \frac{1}{s+1} - \frac{1}{(s+1)^2} \end{bmatrix}$$

Taking inverse Laplace transform — we get —

$$\phi(t) = \begin{bmatrix} e^{-t} + te^{-t} & te^{-t} \\ -te^{-t} & e^{-t} - te^{-t} \end{bmatrix}$$

For $\begin{bmatrix} x_1(0) \\ x_2(0) \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$

$$\therefore \phi(t) = \begin{bmatrix} e^{-t} + te^{-t} & te^{-t} \\ -te^{-t} & e^{-t} - te^{-t} \end{bmatrix} \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

$$x(t) = \begin{bmatrix} te^{-t} \\ e^{-t} - te^{-t} \end{bmatrix}$$

$\therefore$ output $y(t)$

$$y(t) = [0\ 1]\, x(t)$$

$$= [0\ 1] \begin{bmatrix} t e^{-t} \\ e^{-t} - t e^{-t} \end{bmatrix}$$

$$\boxed{y(t) = e^{-t} - t e^{-t}}$$

Hence, for the ~~given~~ given initial condition, output response of the system is —

$$\boxed{y(t) = e^{-t} - t e^{-t}}$$

6

Q.4 (c) A 10 kVA, 380 V, 4-pole, 50 Hz, 3-ϕ, star-connected cylindrical rotor alternator has a stator resistance and synchronous reactance of 1 ohm and 15 ohms respectively. It supplies a load of 8 kW at rated voltage and 0.8 lagging power factor.

(i) Draw a phasor diagram of operation.

(ii) Express the resistance and synchronous reactance in per unit values with the machine rating as the base.

(iii) Calculate the percentage regulation.

(iv) What is the terminal voltage if the load is suddenly removed (with the speed and excitation unaltered)?

[20 marks]

Given :- 10 kVA, 380 V, 4 pole, 50 Hz
3 ϕ, star-connected alternator

$r_a = 1\Omega$
$X_s = 15\Omega$

Load = 8 kW at 0.8 lag pf

(i) $V_{ph} = \frac{380}{\sqrt{3}} = 219.39 \text{ V}$

$I_a = \frac{8 \times 10^3}{\sqrt{3} \times 380 \times 0.8} = 15.19 \text{ A}$

$\bar{I}_a = 15.19 \angle -\cos^{-1}(0.8)$

$\bar{I}_a = 15.19 \angle -36.87^\circ \text{ A}$

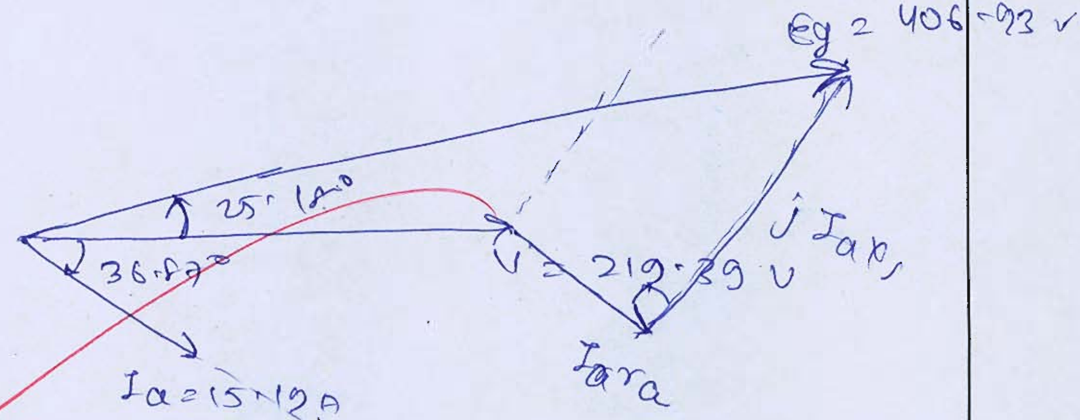
Generator emf -

$\bar{E}_g = \bar{V}_{ph} + \bar{I}_a (r_a + jX_s)$

$= 219.39 \angle 0^\circ + 15.19 \angle -36.87^\circ \times (1 + j15)$

$\boxed{\bar{E}_g = 406.93 \angle 25.18^\circ}$

Taking V as reference phasor



(ii)

$S_{base} = 10 kVA$

$V_{base} = 380 V$

$Z_{base} = \frac{V^2_{base}}{S_{base}} = \frac{(380)^2}{10 \times 1000} = 14.44 \Omega$

$\therefore$ resistance $r_a = \frac{1}{14.44} = 0.0692 pu$

reactance $X_s = \frac{15}{14.44} = 1.0387 pu$

(iii)

% vtg regulation $= (\text{pu } r)\cos\phi + (\text{pu } x)\sin\phi$

$= (0.0692 \times \cos 36.87 + 1.0387 \times \sin 36.87) \times 100$

$\boxed{\% VR = 67.85\%}$

18

(iv) If load is removed then —

terminal vtg $V_t = |E_g|$

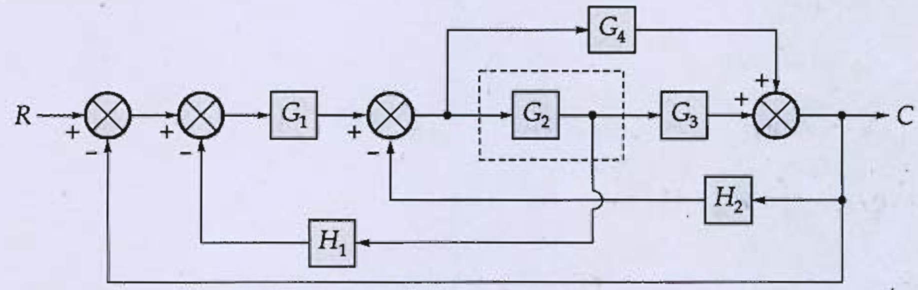
$(V_t)_{ph} = 406.93 V$

$\boxed{(V_t)_{l-l} = 704.82 V}$

Good Approach

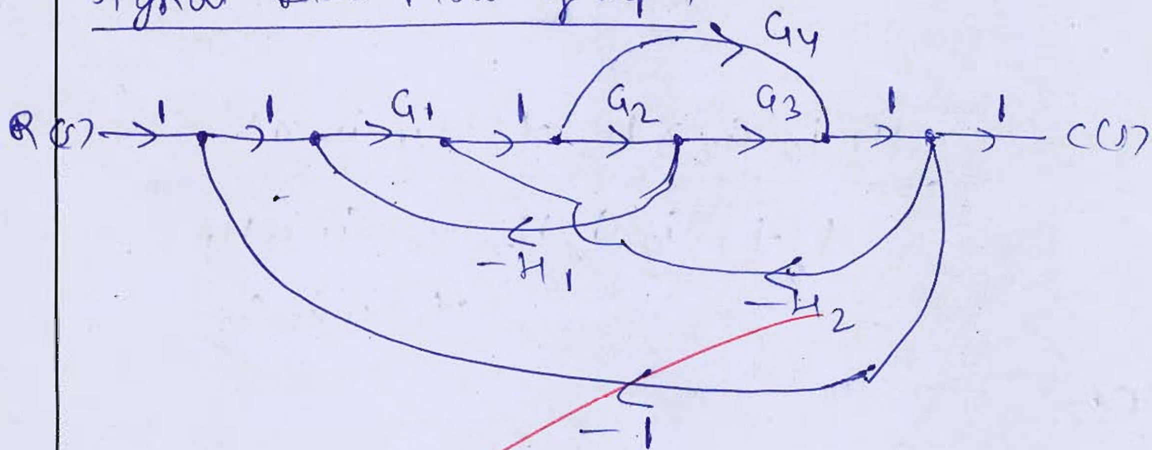
Section B : Electrical Machines + Analog Electronics + Control Systems

Q.5 (a) Obtain the transfer function of the feedback control system shown by using signal flow graph method.



[12 marks]

Signal flow graph



Forward Path

$P_1 = G_1 G_2 G_3$

$P_2 = G_1 G_4$

Individual loop

$L_1 = -G_2 G_3 H_2$ $\quad L_2 = -G_1 G_2 H_1$

$L_3 = -G_1 G_2 G_3$

There is no two-non-touching loop

$\therefore \Delta = 1 - (L_1 + L_2 + L_3)$
$+ (\text{two-non-touching loops})$

$\Delta = 1 - (-G_2 G_3 H_2 - G_1 G_2 H_1 - G_1 G_2 G_3)$

$\Delta = 1 + G_2 G_3 H_2 + G_1 G_2 H_1 + G_1 G_2 G_3$

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$\Delta_1 = 1$

$\Delta_2 = 1$

From Mason's gain formula –

Transfer function –

$$\frac{C(s)}{R(s)} = \frac{\sum_{k=1}^{2} P_K \Delta_K}{\Delta}$$

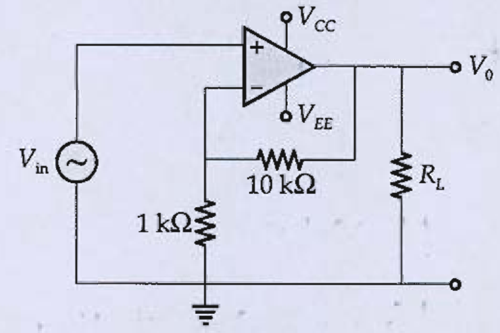
$$= \frac{G_1 G_2 G_3 \times 1 + G_1 G_4 \times 1}{1 + G_2 G_3 H_2 + G_1 G_2 H_1 + G_1 G_2 G_3}$$

$$\frac{C(s)}{R(s)} = \frac{G_1 G_2 G_3 + G_1 G_4}{1 + G_1 G_2 G_3 + G_1 G_2 H_1 + G_2 G_3 H_2}$$

$+ G_1 G_4 + G_4 H_2$

5

Q.5 (b) The 741 C Op-Amp having the following parameters is connected as shown in the figure.



A = 20000, R_i = 2 MΩ, R_0 = 75 Ω, f_0 = 5 Hz, supply voltage = ±15 V, output voltage swing = ±13 V. Identity the circuit.
Compute the values of A_F, R_{iF}, R_{OF} and V_{OUT}.

[12 marks]

Feedback factor

$$\beta = \frac{1\,k\Omega}{1\,k\Omega + 10\,k\Omega} = \frac{1}{11}$$

$$A_f = \frac{A}{1+A\beta} = \frac{20000}{1+20000 \times \frac{1}{11}}$$

$$A_f = 10.994$$

$$\boxed{A_f \simeq 11}$$

It is voltage series feedback

$$R_{if} = R_i(1+A\beta)$$
$$= 2 \times 10^6 \left(1 + 20000 \times \frac{1}{11}\right)$$

$$\boxed{R_{if} = 3638.36\,M\Omega}$$

$$R_{of} = \frac{R_o}{1+A\beta}$$
$$= \frac{75}{1+20000 \times \frac{1}{11}}$$

$$\boxed{R_{of} = 0.0412\,\Omega \text{ or } 41.22\,m\Omega}$$

$$A_{CF} = \frac{v_{out}}{v_{in}} = 11$$

$$\Rightarrow v_{out} = 11 \times 15$$

$$= 165v > +13v$$

since it is greater than saturation voltage -

$$\therefore \boxed{v_{out} = +13v}$$

5

Q.5 (c) The open-loop transfer function of a unity feedback control system is given by

$$G(s) = \frac{K}{s(1+sT)}.$$

(i) By what factor the amplifier gain K should be multiplied so that the damping ratio is increased from 0.2 to 0.8?

(ii) By what factor the time constant T should be multiplied so that the damping ratio is reduced from 0.9 to 0.3?

[12 marks]

$$G(s) = \frac{K}{s(1+sT)}$$

(i) characteristic equation –

$$1 + \frac{K}{s(1+sT)} = 0$$

$$s(1+sT) + K = 0$$

$$s^2T + s + K = 0$$

$$s^2 + \frac{s}{T} + \frac{K}{T} = 0$$

comparing the above eq-n with standard characteristic eq-n – we get –

$$\omega_n^2 = \frac{K}{T} \qquad 2\xi\omega_n = \frac{1}{T}$$

$$\omega_n = \sqrt{\frac{K}{T}} \qquad 2 \times \xi_p \times \sqrt{\frac{K}{T}} = \frac{1}{T}$$

$$\xi_p = \frac{1}{T} \times \frac{1}{2}\sqrt{\frac{T}{K}}$$

$$\boxed{\xi_p = \frac{1}{2\sqrt{KT}}}$$

For ~~$\xi_p = 0.2$~~ $K = K_1$ $\quad \xi_p = 0.2$

$$\frac{1}{2\sqrt{K_1T}} = 0.2 \qquad \text{— (I)}$$

$K = K_2 \quad \xi_p = 0.8$

$$\frac{1}{2\sqrt{K_2T}} = 0.8 \qquad \text{— (II)}$$

Dividing (I) and (II) we get -

$$\sqrt{\frac{k_2}{k_1}} = \frac{1}{4}$$

$$K_2 = \frac{K_1}{16} = 0.0625\, k_1$$

$$\boxed{K_2 = 0.0625\, k_1}$$

Hence, ∴ gain k should by multiply by 0.0625 to increased the damping ratio from 0.2 to 0.8.

(ii) For $T = T_1$, $\xi = 0.9$

$$\frac{1}{2\sqrt{kT_1}} = 0.9 \quad \text{— (III)}$$

$T = T_2$, $\xi = 0.3$

$$\frac{1}{2\sqrt{kT_2}} = 0.3 \quad \text{— (IV)}$$

dividing (III) by (IV) we get -

$$\sqrt{\frac{T_2}{T_1}} = 3$$

$$\boxed{T_2 = 9T_1}$$

11

Good Approach

Hence, time constant T should multiply by 9 ~~to~~ so that damping ratio is reduced from 0.9 to 0.3

Q.5 (d) Consider a negative feedback system having the characteristic equation,

$$1+\frac{K}{(1+s)(1.5+s)(2+s)}=0.$$

It is desired that all the roots of the characteristic equation have real parts less than –1. Extend the Nyquist stability criterion to find the largest value of K satisfying the condition.

[12 marks]

characteristics eqn –

$$1+\frac{K}{(1+s)(1.5+s)(2+s)}=0$$

open loop transfer –

$$G(s)H(s)=\frac{K}{(1+s)(1.5+s)(2+s)}$$

$$G(j\omega)H(j\omega)=\frac{K}{(1+j\omega)(1.5+j\omega)(2+j\omega)}$$

$$M=\frac{K}{\sqrt{\omega^2+1}\sqrt{1.5^2+\omega^2}\sqrt{4+\omega^2}}$$

$$\phi=-\tan^{-1}(\omega)-\tan^{-1}\left(\frac{\omega}{1.5}\right)-\tan^{-1}\left(\frac{\omega}{2}\right)$$

at $\omega=0$ $M=\frac{K}{1\times1.5\times2}=\frac{K}{3}$ $\phi=0$

at $\omega=\infty$ $M=0$ $\phi=-270$

$\phi=-180°$

$\Rightarrow$ $-\tan^{-1}(\omega)-\tan^{-1}\left(\frac{\omega}{1.5}\right)-\tan^{-1}\left(\frac{\omega}{2}\right)=-180$

$$\tan^{-1}\left(\frac{\omega}{1.5}\right)+\tan^{-1}\left(\frac{\omega}{2}\right)=180-\tan^{-1}(\omega)$$

$$\Rightarrow\tan^{-1}\left(\frac{\frac{\omega}{1.5}+\frac{\omega}{2}}{1-\frac{\omega^2}{3}}\right)=180-\tan^{-1}(\omega)$$

$$\Rightarrow\frac{3.5\omega}{3-\omega^2}=-\omega$$

$3 - \omega^2 = -3.5$

$\omega^2 = 6.5$

$\boxed{\omega = 2.55 \text{ r/s}}$

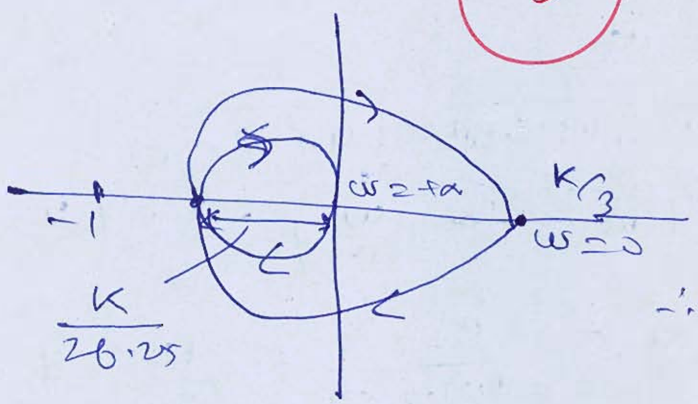
At $\omega = 2.55$ $M = \dfrac{K}{\sqrt{2.55^2+1}\,\sqrt{1.8^2+2.55^2}\,\sqrt{4+2.55^2}}$

$M = \dfrac{K}{2.739 \times 2.958 \times 3.24}$

$M = \dfrac{K}{26.25}$

Nyquist plot

5



For stability

$N = P - Z$

$N = 0$

$P = 0$

$\therefore \dfrac{K}{26.25} < 1$

$\boxed{K < 26.25}$

$\therefore$ Maximum value of K

$\boxed{K_{max} = 26.25}$

Q.5 (e) Sketch the polar plots of the transfer function $G(s) = \dfrac{1}{s(1+s)(1+2s)}$. Determine whether the polar plots cross the real axis. If so, determine the frequency at which the plots cross the real axis and the corresponding magnitude $|G(j\omega)|$.

[12 marks]

$$G(s) = \frac{1}{s(s+1)(2s+1)}$$

$$G(j\omega) = \frac{1}{j\omega(j\omega+1)(2j\omega+1)}$$

$$|G(j\omega)| = M = \frac{1}{\omega\sqrt{\omega^2+1}\,\sqrt{4\omega^2+1}}$$

$$\angle G(j\omega) = \phi = -90 - \tan^{-1}(\omega) - \tan^{-1}(2\omega)$$

$\omega = 0$ $M = \infty$ $\phi = -90^\circ$

$\omega = \infty$ $M = 0$ $\phi = -270^\circ$

$\therefore$ To cross the -ve real axis

$\phi = -180^\circ$

$\Rightarrow -90 - \tan^{-1}(\omega) - \tan^{-1}(2\omega) = -180^\circ$

$\tan^{-1}(\omega) + \tan^{-1}(2\omega) = 90^\circ$

$\Rightarrow \tan^{-1}\left(\dfrac{\omega+2\omega}{1-\omega\cdot 2\omega}\right) = 90$

$\tan 90 = \infty$

$\therefore 1 - 2\omega^2 = 0$

$2\omega^2 = 1$

$\omega = \dfrac{1}{\sqrt{2}} = 0.707$ r/s

Hence at $\boxed{\omega = 0.707 \text{ r/s}}$ the polar plot cross -ve real axis.

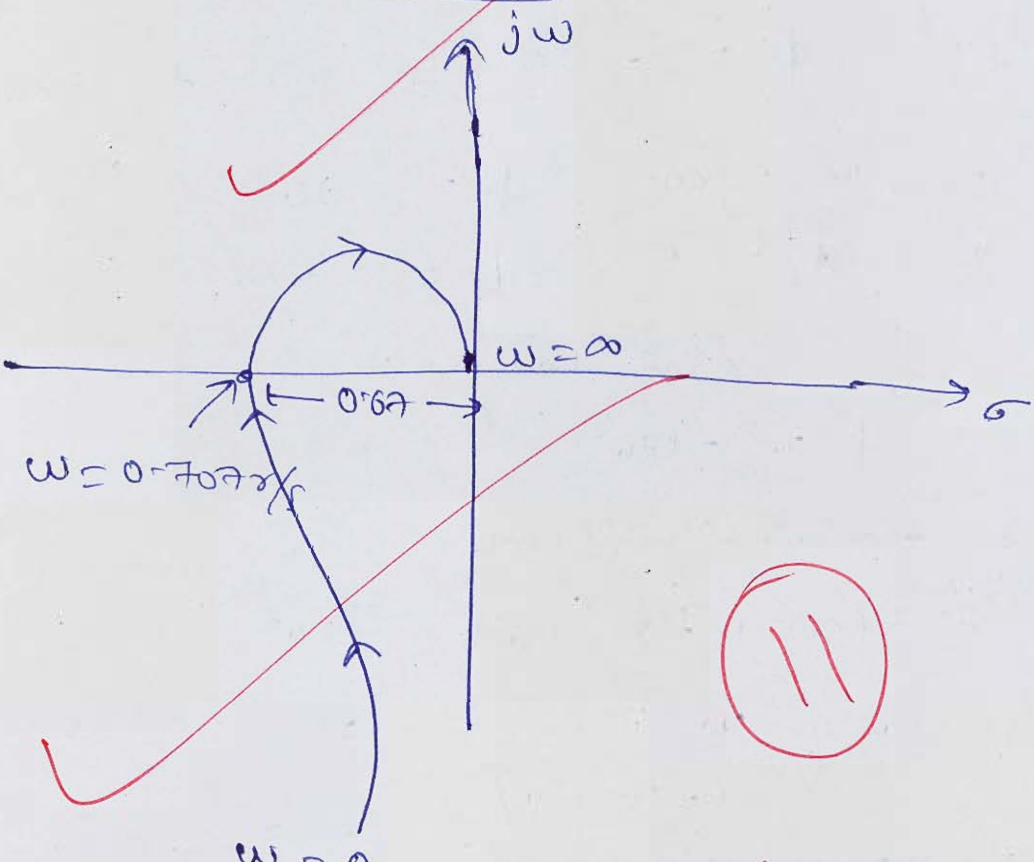
at $\omega = \frac{1}{\sqrt{2}}$

$$M = |G(j\omega)|_{\omega = \frac{1}{\sqrt{2}}} = \frac{1}{\frac{1}{\sqrt{2}}\sqrt{\frac{1}{2}+1}\sqrt{\frac{4\times 1}{2}+1}}$$

$$= \frac{1}{\frac{1}{\sqrt{2}} \times \sqrt{\frac{3}{2}} \times \sqrt{3}} = \frac{2}{3} = 0.67$$

$\therefore$ at $\omega = \frac{1}{\sqrt{2}} = 0.707$ r/s

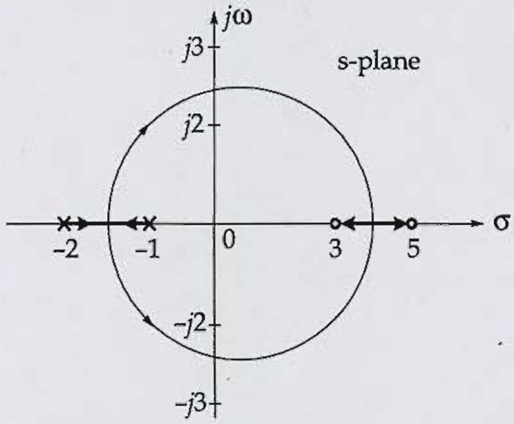
$$\boxed{M = 0.67}$$



11

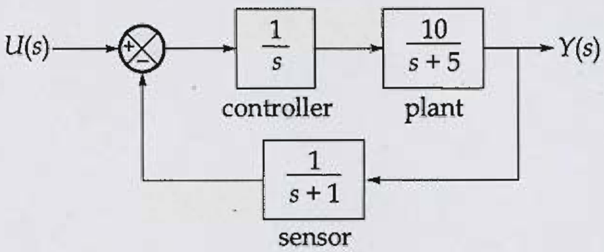
Good Approach

Q.6 (a) (i) The root locus plot for the certain control system is shown below:



Find the break-away and break-in points for the above root locus plot.

(ii) Obtain a state-space model of the system shown in figure below:



[10 + 10 marks]

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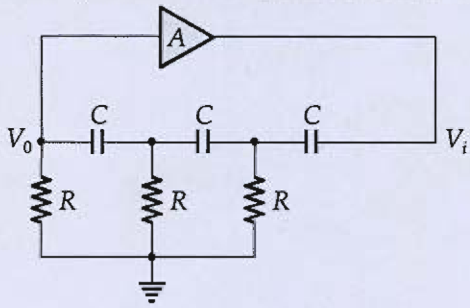
Q.6 (b) Derive the condition of oscillation and the expression for the frequency of oscillations for the circuit shown. (Use mesh analysis and Barkhausen's criteria). Draw actual oscillator circuit with one operational amplifier and minimum number of RC elements.



[20 marks]

Q.6 (c) (i) Using the Routh criterion, check whether the system represented by the following characteristic equation is stable or not. Comment on the location of the roots. Determine the frequency of sustained oscillations if any,

$$s^4 + 2s^3 + 6s^2 + 8s + 8 = 0$$

[10 marks]

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Q.6 (c) (ii) A control system with open loop transfer function is represented by $G(s)H(s) = \dfrac{K}{(s+2)^2(s+3)}$. Determine the range of value of K for which value of gain margin $(GM) \geq 4$ and position error constant is $K_p > 2$ when unit step input is applied.

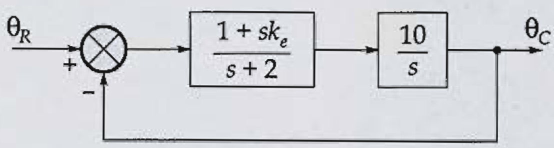
[10 marks]

Q.7 (a) The control system shown in figure employs proportional plus error rate control. Determine the value of error rate constant K_e so that the damping ratio is 0.6.

(i) Determine the value of setting time and maximum overshoot.

Find the steady-state error if the input is a unit-ramp.

(ii) What will be the those values (as calculated in part-i) without error rate control?



[20 marks]

~~closed~~ $G(s)H(s) = \dfrac{10(1+sk_e)}{s(s+2)}$

characteristic eq^n –

$$1 + \frac{10(1+sk_e)}{s(s+2)} = 0$$

$$\Rightarrow s^2 + 2s + 10 + 10sk_e = 0$$

$$s^2 + (2+10k_e)s + 10 = 0$$

comparing the above eq^n with

$s^2 + 2\xi_e\omega_n s + \omega_n^2$ — we get –

$\omega_n^2 = 10$

$\omega_n = \sqrt{10}$

$\omega_n = 3.16\ r/s$

$2\xi_e\omega_n = 2 + 10k_e$

$\xi_e = 0.6$

$\Rightarrow 2 \times 0.6 \times 3.16 = 2 + 10k_e$

$2 + 10k_e = 3.794$

$\boxed{k_e = 0.18}$

Hence, error rate constant

$\boxed{k_e = 0.18}$

(i) $\xi_e = 0.6 \quad \omega_n = 3.16\ r/s$

settling time

$$t_s = \frac{4}{\xi_e \omega_n} = \frac{4}{0.6 \times 3.16}$$

$$\boxed{t_s = 2.109\,sec}$$

maximum overshoot

$$\% M_p = e^{\frac{-\xi_e \pi}{\sqrt{1-\xi_e^2}}} \times 100$$

$$= e^{\frac{-0.6\pi}{\sqrt{1-0.6^2}}} \times 100$$

$$\boxed{\% M_p = 9.48\,\%}$$

for type-1 system

$$e_{ss} = \frac{1}{K_v}$$

where $K_v = \lim_{s \to 0} s\,G(s)H(s)$

$$= \lim_{s \to 0} s \cdot \frac{10(1+sK_e)}{s(s+2)}$$

$$= \frac{10}{2} = 5$$

$$e_{ss} = \frac{1}{5} = 0.2$$

$$\boxed{e_{ss} = 0.2}$$

(ii) without error controller

$$G(s)H(s) = \frac{10}{s(s+2)}$$

characteristics eq^n

$$1 + \frac{10}{s(s+2)} = 0$$

$$\Rightarrow s^2 + 2s + 10 = 0$$

$\omega_n^2 = 10$ $\qquad$ $2 \times \xi_p \times 3.16 = 2$

$\omega_n = 3.16\, r/s$ $\qquad$ $\xi_p = 0.316$

settling time

$$t_s = \frac{4}{\xi_p \omega_n} = \frac{4}{1} = 4\,sec$$

Maximum overshoot

$$\% M_p = e^{\frac{-\xi_p \pi}{\sqrt{1-\xi_p^2}}} \times 100$$

$$= e^{-\frac{0.316\pi}{\sqrt{1-0.316^2}}} \times 100$$

$$\boxed{\% M = 35.12\%}$$

18

Good Approach

Steady state error

$$e_{ss} = \frac{1}{k_v}$$

$$k_v = \lim_{s \to 0} s \cdot \frac{10}{s(s+2)} = 5$$

$$e_{ss} = \frac{1}{5} = 0.2$$

$$\boxed{e_{ss} = 0.2}$$

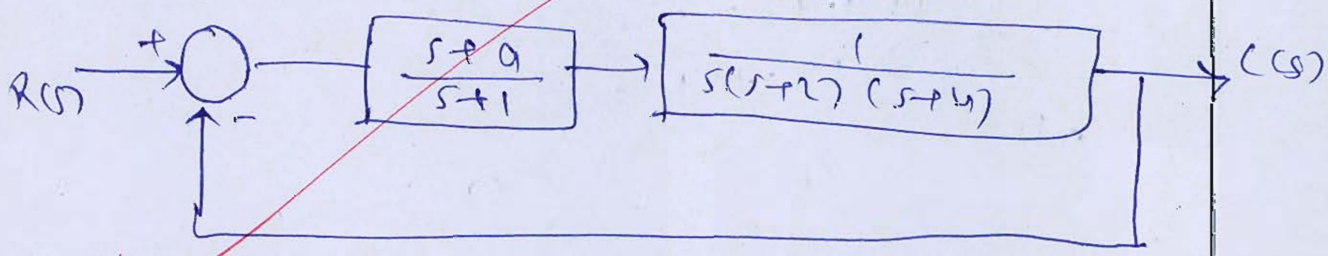
.7 (b) A negative unity feedback control system is provided with compensator in cascade with system, for system to be stable. The transfer function of plant and compensator are respectively $\frac{1}{s(s+2)(s+4)}$ and $\frac{(s+a)}{s+1}$. Calculate the range of value of 'a' for system to be stable and also represent complete system in form of block diagram. At critical stability condition, what will be the nature of compensator?

[20 marks]

$$G_p(s) = \frac{1}{s(s+2)(s+4)}$$

$$G_c(s) = \frac{(s+a)}{(s+1)}$$

Block diagram



open-loop transfer function

$$G_c(s)\,G_p(s) = \frac{s+a}{s(s+1)(s+2)(s+4)}$$

characteristic eqn -

$$1 + \frac{s+a}{s(s+1)(s+2)(s+4)} = 0$$

$$\Rightarrow s(s+1)(s+2)(s+4) + s + a = 0$$

$$\Rightarrow s(s^2+3s+2)(s+4) + s + a = 0$$

$$\Rightarrow s(s^3+4s^2+3s^2+12s+2s+8) + s + a = 0$$

$$\Rightarrow s^4 + 7s^3 + 14s^2 + 9s + a = 0$$

CE $\Rightarrow$ $s^4 + 7s^3 + 14s^2 + 9s + a = 0$

R-H table

s^4	1	14	a
s^3	7	9	0
s^2	12.714	a	0
s^1	$\frac{114.43 - 7a}{12.714}$	0	0
s^0	a	0	0

For the system to be stable –

$a > 0$

$\frac{114.43 - 7a}{12.714} > 0$

$114.43 - 7a > 0$

$a < 16.345$

$\therefore$ Hence, for the system to be stable –

$\boxed{0 < a < 16.345}$

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At critical value of $a = 16.345$

controller transfer

$$G_c(s) = \frac{s + 16.345}{s + 1}$$

as pole is nearer to ~~ori~~ origin than zero. Hence, the ~~or~~ $G_c(s)$ is lag compensator

18

Good Approach

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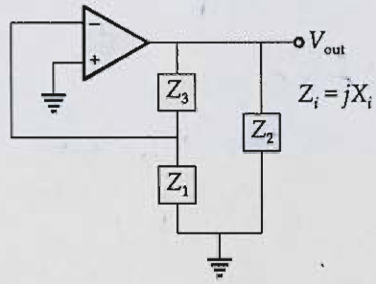
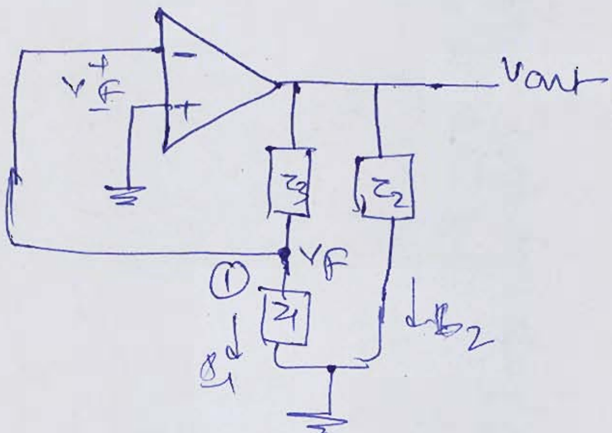
Q.7 (c) In the figure shown below:



The op-amp in the circuit has a finite open loop gain (A_v), finite output resistance ($R_0 > 0$) and it is ideal in all other aspects. Z_1, Z_2 and Z_3 are purely reactive elements with magnitudes $|X_1|, |X_2|$ and $|X_3|$. Prove that X_1 and X_2 must be of the same type of reactance (i.e., both must be either capacitive or inductive) to produce sustained oscillations.

[20 marks]



open loop gain = Av = finite

finite output resistance = R_0

$Z_1 = |X_1| \angle \pm 90^\circ$

$Z_2 = |X_2| \angle \pm 90^\circ$

$Z_3 = |X_3| \angle \pm 90^\circ$

as the nature of Z_1, Z_2 and Z_3 may be inductive or capacitive.

KCL at node ①

$$\frac{V_f - 0}{Z_1} + \frac{V_f - V_{out}}{Z_3} = 0$$

$$V_f\left(\frac{1}{Z_1} + \frac{1}{Z_3}\right) = \frac{V_{out}}{Z_3}$$

$$V_{out} = V_f\left(\frac{Z_3}{Z_1} + 1\right)$$

$$I_1 + I_2 = 0$$

$$\frac{V_f}{Z_1} + \frac{V_{out}}{Z_2} = 0$$

$$\frac{V_f}{Z_1} + \frac{V_f}{Z_2}\left(\frac{Z_3}{Z_1} + 1\right) = 0$$

$$\frac{1}{Z_1} + \frac{Z_3}{Z_2 Z_1} + \frac{1}{Z_2} = 0$$

$$\frac{Z_1 + Z_2 + Z_3}{Z_1 Z_2} = 0$$

$$\boxed{Z_1 + Z_2 + Z_3 = 0}$$

For sustained oscillation Z_1 and Z_2 must be of same nature

let Z_1 & Z_2 = inductive

$$Z_1 = |X_1| \angle 90^\circ = j|X_1|$$
$$Z_2 = |X_2| \angle 90^\circ = j|X_2|$$

$$j|X_1| + j|X_2| + Z_3 = 0$$

$$Z_3 = -j(|X_1| + |X_3|)$$

Z_3 – capacitive in nature

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let Z_1 and Z_2 = capacitive

~~Z_1 & Z_2~~ $Z_1 = |X_1| \angle -90° = -j|X_1|$

$Z_2 = |X_2| \angle -90° = -j|X_2|$

$-j|X_1| - j|X_2| + Z_3 = 0$

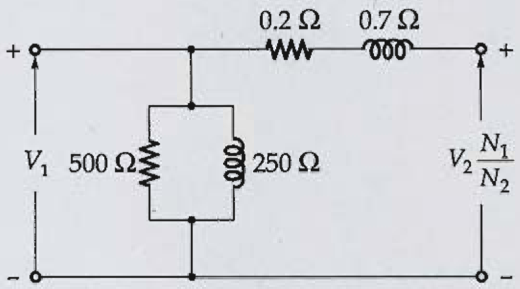
$Z_3 = j(|X_1| + |X_2|)$

Z_3 = inductive in nature.

Hence, for sustained oscillation nature of Z_1 and Z_2 must be same (either capacitive or inductive) and in opposite with Z_3.

15

Q.8 (a) The equivalent circuit referred to the low-tension side of a 250/2500 V single phase transformer is shown in figure.



The load impedance connected to the high-tension terminals is $380 + j230\ \Omega$. For a primary voltage of 250 V,

Find:

(i) The secondary terminal voltage.

(ii) Primary current and power factor, and

(iii) Power output and efficiency.

[20 marks]

8 (b) Given the transfer function,

$$\frac{Y(s)}{U(s)} = \frac{1}{(s+5)(s+4)}$$

Obtain the state equation using :

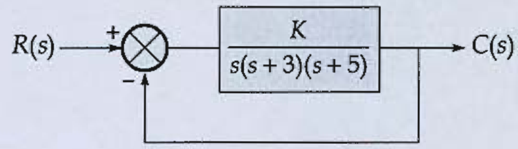
(i) Cascade decomposition

(ii) Direct decomposition

It is desired that the closed loop poles are to be placed at $s = (-1 \pm j2)$. Determine the feedback gain matrix K for part (i) and (ii).

[20 marks]

Q.8 (c) Using the Nyquist criterion, find the range of K for stability for the system shown in figure. Also find the value of gain K and frequency of oscillation for marginal stability.



[20 marks]

OOOO

Space for Rough Work

Space for Rough Work

Space for Rough Work

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