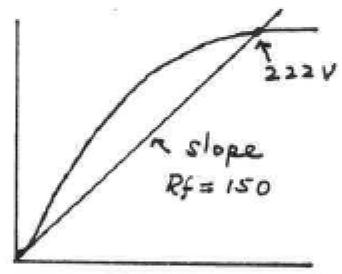
Q1)

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

Draw field resistance line for

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

$E_a\,(max) = 222\,V$

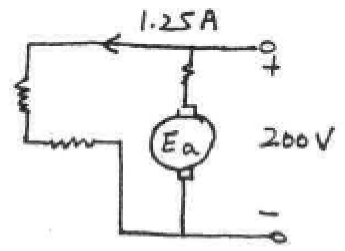


(b) $I_a\,(rated) = \dfrac{20{,}000}{200} = 100\,A$

$V_t\,(rated) = 200\,V$

$R_f = \dfrac{200}{1.25} = 160\,\Omega$

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



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

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

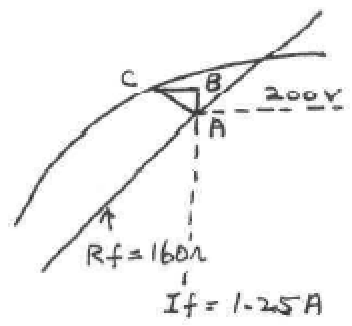
$\omega_m = \dfrac{1800}{60} \times 2\pi = 188.5$ rad./sec.

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

(d) Draw field resistance line at $R_f = 160\Omega$

At $V_t = 200V$, $I_f = 1.25A$ draw triangle ABC with a vertical line $AB = 10V$ and horizontal line BC where C is on magnetization curve

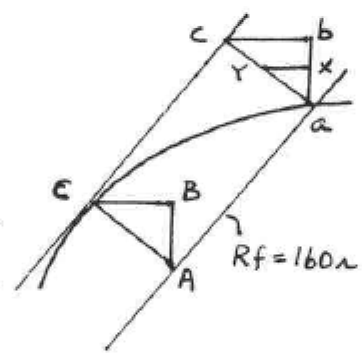
$BC = 0.09A = I_{f(AR)}$



(e) $AB = 25V$

$I_a = \frac{25}{0.1} = 250A$

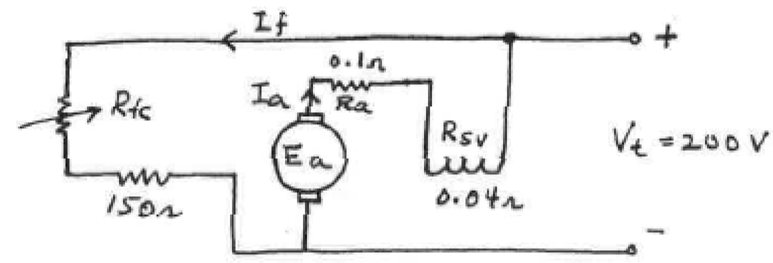
For full-load, construct triangle axY such that $ax = 10V$, $xY = 0.09A$. Draw C c parallel to A a such that Cc is tangent to magnetisation curve. Draw Δ abc. This is the largest Δ that will fit inside the magnetisation curve and field resistance line at C. Δ ABC is same as Δ abc



$AB = 25V = I_{a(max)} R_a$

$I_{a(max)} = \frac{25}{0.1} = 250A$

(2 a)



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

$= 200 + 100 (0.1 + 0.04)$

$= 214 V$

From the magnetization curve for $E_a = 214 V$

$$\bar{I}_f \text{ (eff)} = 1.25 \text{ A} = I_f + \frac{N_{sr} I_a}{N_f} - I_f \text{ (AR)}$$

Now $\bar{I}_f (AR) = 0.09$ A at full-load value of I_a (from part 1d)

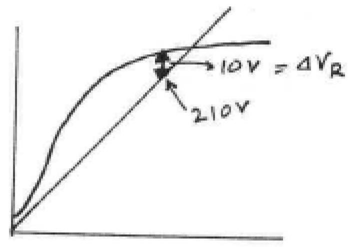
$V_t |_{NL} \simeq E_a = 200 V \longrightarrow$ from magnetization curve $I_f = 1$ A

Hence $1.25 = 1 + \dfrac{N_{sr} \times 100}{1200} - 0.09$

$\Rightarrow N_{sr} = 4.08$ turns / pole

Q2)

$\boxed{4.14}$ (a) $I_a\Big|_{rated} = \dfrac{20,000}{200} = 100\,A.$

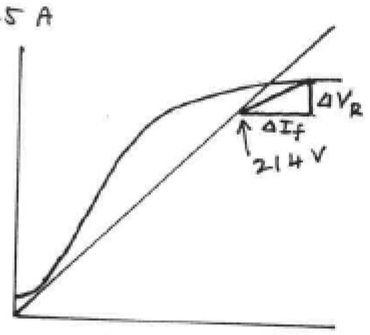


$\Delta V_R = I_a R_a = 100 \times 0.1 = 10V.$

$V_t = 210\,V.$

(b) $\Delta I_f = +\dfrac{N_{sr} I_a}{N_f} = \dfrac{3 \times 100}{1200} = +0.25\,A$

$\Delta V_R = 100\,(0.1 + 0.03) = 13\,V.$



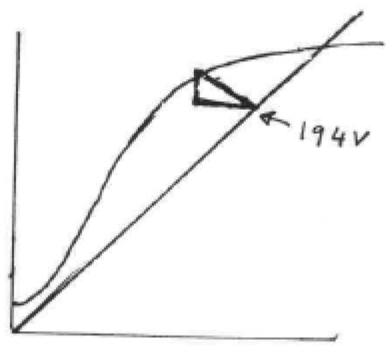
The right-angle triangle with sides $\Delta V_R = 13\,V$ and $\Delta I_f = 0.25\,A$ with points on the resistance line and magnetization curve gives

$V_t \simeq 214\,V.$

(c) $\Delta I_f = -\,0.25\,A.$

$\Delta V_R = 13\,V.$

$V_t \simeq 194\,V.$



Q3)

$E_a|_{1100} = 500 - 100 \times 0.25 = 475\ \mathrm{V}$

$E_a|_{900} = 475 \times \frac{900}{1100} = 388.6\ \mathrm{V}$

$I_a|_{1100} = 100\ \mathrm{A}$

$I_a|_{900} = 100 \times \frac{900}{1100} = 81.8\ \mathrm{A}$

$IR = V - E_a = 500 - 388.6 = 111.4\ \mathrm{V}$

$R = \frac{111.4}{81.8} = 1.36\ \Omega$

$R_{series} = 1.36 - 0.25 = 1.11\ \Omega$

Q4)

(a) If $R_{adj} = 100\ \Omega$, the total field resistance is 140 Ω, and the resulting field current is

$$I_F = \frac{V_T}{R_F + R_{adj}} = \frac{120\ \text{V}}{100\ \Omega\ +\ 40\ \Omega} = 0.857\ \text{A}$$

This field current would produce a voltage E_{Ao} of 82.8 V at a speed of n_o = 1000 r/min. The actual E_A is

$$E_A = V_T - I_A R_A = 120\ \text{V}\ -\ (70\ \text{A})(0.12\ \Omega) = 111.6\ \text{V}$$

so the actual speed will be

$$n = \frac{E_A}{E_{Ao}} n_o = \frac{111.6\ \text{V}}{82.8\ \text{V}} (1000\ \text{r/min}) = 1348\ \text{r/min}$$

(b) The output power is 10 hp and the output speed is 1000 r/min at rated conditions, therefore, the torque is

$$\tau_{out} = \frac{P_{out}}{\omega_m} = \frac{(10\ \text{hp})(746\ \text{W/hp})}{(1000\ \text{r/min})\left(\frac{2\pi\ \text{rad}}{1\ \text{r}}\right)\left(\frac{1\ \text{min}}{60\ \text{s}}\right)} = 71.2\ \text{N}\cdot\text{m}$$

(c) The copper losses are

$$P_{CU} = I_A^2 R_A + V_F I_F = (70\ \text{A})^2 (0.12\ \Omega) + (120\ \text{V})(0.857\ \text{A}) = 691\ \text{W}$$

The power converted from electrical to mechanical form is

$$P_{conv} = E_A I_A = (111.6\ \text{V})(70\ \text{A}) = 7812\ \text{W}$$

The output power is

$$P_{OUT} = (10\ \text{hp})(746\ \text{W/hp}) = 7460\ \text{W}$$

Therefore, the rotational losses are

$$P_{rot} = P_{conv} - P_{OUT} = 7812\ \text{W} -\ 7460\ \text{W} = 352\ \text{W}$$

(d) The input power to this motor is

$$P_{IN} = V_T (I_A + I_F) = (120\ \text{V})(70\ \text{A}\ +\ 0.857\ \text{A}) = 8503\ \text{W}$$

Therefore, the efficiency is

$$\eta = \frac{P_{OUT}}{P_{IN}} \times 100\% = \frac{7460\ \text{W}}{8503\ \text{W}} \times 100\% = 87.7\%$$

(e) The no-load E_A will be 120 V, so the no-load speed will be

$$n = \frac{E_A}{E_{Ao}} n_o = \frac{120 \text{ V}}{82.8 \text{ V}} (1000 \text{ r/min}) = 1450 \text{ r/min}$$

(f) If the field circuit opens, the field current would go to zero $\Rightarrow \phi$ drops to $\phi_{\text{res}} \Rightarrow E_A \downarrow \Rightarrow I_A \uparrow \Rightarrow \tau_{\text{ind}} \uparrow \Rightarrow n \uparrow$ to a *very* high speed. If $I_F = 0$ A, $E_{Ao} = 8.5$ V at 1800 r/min, so

$$n = \frac{E_A}{E_{Ao}} n_o = \frac{230 \text{ V}}{5 \text{ V}} (1000 \text{ r/min}) = 46{,}000 \text{ r/min}$$

(In reality, the motor speed would be limited by rotational losses, or else the motor will destroy itself first.)

(g) The maximum value of $R_{\text{adj}} = 200\ \Omega$, so

$$I_F = \frac{V_T}{R_F + R_{\text{adj}}} = \frac{120 \text{ V}}{200\ \Omega\ +\ 40\ \Omega} = 0.500 \text{ A}$$

This field current would produce a voltage E_{Ao} of 50.6 V at a speed of n_o = 1000 r/min. The actual E_A is 120 V, so the actual speed will be

$$n = \frac{E_A}{E_{Ao}} n_o = \frac{120 \text{ V}}{50.6 \text{ V}} (1000 \text{ r/min}) = 2372 \text{ r/min}$$

The minimum value of $R_{\text{adj}} = 0\ \Omega$, so

$$I_F = \frac{V_T}{R_F + R_{\text{adj}}} = \frac{120 \text{ V}}{0\ \Omega\ +\ 40\ \Omega} = 3.0 \text{ A}$$

This field current would produce a voltage E_{Ao} of about 126.4 V at a speed of n_o = 1000 r/min. The actual E_A is 120 V, so the actual speed will be

$$n = \frac{E_A}{E_{Ao}} n_o = \frac{120 \text{ V}}{126.4 \text{ V}} (1000 \text{ r/min}) = 949 \text{ r/min}$$

Q5)

(a) If the generator is operating with no load at 1800 r/min, then the terminal voltage will equal the internal generated voltage E_A. The maximum possible field current occurs when R_{adj} = 0 Ω. The current is

$$I_{F,\max} = \frac{V_F}{R_F + R_{adj}} = \frac{120\ \text{V}}{20\ \Omega + 0\ \Omega} = 6\ \text{A}$$

From the magnetization curve, the voltage E_{Ao} at 1800 r/min is 135 V. Since the actual speed is 1800 r/min, the maximum no-load voltage is 135 V.

The minimum possible field current occurs when R_{adj} = 40 Ω. The current is

$$I_{F,\max} = \frac{V_F}{R_F + R_{adj}} = \frac{120\ \text{V}}{20\ \Omega + 40\ \Omega} = 2.0\ \text{A}$$

From the magnetization curve, the voltage E_{Ao} at 1800 r/min is 79.5 V. Since the actual speed is 1800 r/min, the minimum no-load voltage is 79.5 V.

(b) The maximum voltage will occur at the highest current and speed, and the minimum voltage will occur at the lowest current and speed. The maximum possible field current occurs when R_{adj} = 0 Ω. The current is

$$I_{F,\max} = \frac{V_F}{R_F + R_{adj}} = \frac{120\ \text{V}}{20\ \Omega + 0\ \Omega} = 6\ \text{A}$$

From the magnetization curve, the voltage E_{Ao} at 1800 r/min is 135 V. Since the actual speed is 2000 r/min, the maximum no-load voltage is

$$\frac{E_A}{E_{Ao}} = \frac{n}{n_o}$$

$$E_A = \frac{n}{n_o} E_{Ao} = \frac{2000\ \text{r/min}}{1800\ \text{r/min}}(135\ \text{V}) = 150\ \text{V}$$

The minimum possible field current occurs and minimum speed and field current. The maximum adjustable resistance is $R_{\text{adj}} = 30\ \Omega$. The current is

$$I_{F,\max} = \frac{V_F}{R_F + R_{\text{adj}}} = \frac{120\text{ V}}{20\ \Omega + 30\ \Omega} = 2.4\text{ A}$$

From the magnetization curve, the voltage E_{Ao} at 1800 r/min is 93.1 V. Since the actual speed is 1500 r/min, the maximum no-load voltage is

$$\frac{E_A}{E_{Ao}} = \frac{n}{n_o}$$

$$E_A = \frac{n}{n_o} E_{Ao} = \frac{1500\text{ r/min}}{1800\text{ r/min}}(93.1\text{ V}) = 77.6\text{ V}$$

Q6)

SOLUTION When I_F is 5 A and the armature current is 50 A, the magnetomotive force in the generator is

$$\mathcal{F}_{\text{net}} = NI_F - \mathcal{F}_{\text{AR}} = (1000\text{ turns})(5\text{ A}) - 400\text{ A}\cdot\text{turns} = 4600\text{ A}\cdot\text{turns}$$

or $\quad I_F^* = \mathcal{F}_{\text{net}} / N_F = 4600\text{ A}\cdot\text{turns} / 1000\text{ turns} = 4.6\text{ A}$

The equivalent internal generated voltage E_{Ao} of the generator at 1800 r/min would be 126 V. The actual voltage at 1700 r/min would be

$$E_A = \frac{n}{n_o} E_{Ao} = \frac{1700\text{ r/min}}{1800\text{ r/min}}(126\text{ V}) = 119\text{ V}$$

Therefore, the terminal voltage would be

$$V_T = E_A - I_A R_A = 119\text{ V} - (50\text{ A})(0.18\ \Omega) = 110\text{ V}$$