8-2. Assuming no armature reaction, what is the speed of the motor at full load? What is the speed regulation of the motor?

SOLUTION At full load, the armature current is

$$I_A = I_L - I_F = I_L - \frac{V_T}{R_{adj} + R_F} = 110 \text{ A} - \frac{240 \text{ V}}{250 \ \Omega} = 109 \text{ A}$$

The internal generated voltage E_A is

$$E_A = V_T - I_A R_A = 240 \text{ V} - (109 \text{ A})(0.19 \ \Omega) = 219.3 \text{ V}$$

The field current is the same as before, and there is no armature reaction, so E_{Ao} is still 241 V at a speed n_o of 1200 r/min. Therefore,

$$n = \left(\frac{E_A}{E_{Ao}}\right) n_o = \left(\frac{219.3 \text{ V}}{241 \text{ V}}\right)(1200 \text{ r/min}) = 1092 \text{ r/min}$$

The speed regulation is

$$SR = \frac{n_{nl} - n_{fl}}{n_{fl}} \times 100\% = \frac{1195 \text{ r/min} - 1092 \text{ r/min}}{1092 \text{ r/min}} \times 100\% = 9.4\%$$

8-3. If the motor is operating at full load and if its variable resistance R_{adj} is increased to 250 Ω, what is the new speed of the motor? Compare the full-load speed of the motor with R_{adj} = 175 Ω to the full-load speed with R_{adj} = 250 Ω. (Assume no armature reaction, as in the previous problem.)

SOLUTION If R_{adj} is set to 250 Ω, the field current is now

$$I_F = \frac{V_T}{R_{adj} + R_F} = \frac{240 \text{ V}}{250 \ \Omega + 75 \ \Omega} = \frac{240 \text{ V}}{325 \ \Omega} = 0.739 \text{ A}$$

Since the motor is still at full load, E_A is still 218.3 V. From the magnetization curve (Figure P8-1), the new field current I_F would produce a voltage E_{Ao} of 212 V at a speed n_o of 1200 r/min. Therefore,

$$n = \left(\frac{E_A}{E_{Ao}}\right) n_o = \left(\frac{218.3 \text{ V}}{212 \text{ V}}\right)(1200 \text{ r/min}) = 1236 \text{ r/min}$$

Note that R_{adj} has increased, and as a result the speed of the motor n increased.

8-13. A 7.5-hp 120-V series dc motor has an armature resistance of 0.1 Ω and a series field resistance of 0.08 Ω. At full load, the current input is 56 A, and the rated speed is 1050 r/min. Its magnetization curve is shown in Figure P8-5. The core losses are 220 W, and the mechanical losses are 230 W at full load. Assume that the mechanical losses vary as the cube of the speed of the motor and that the core losses are constant.

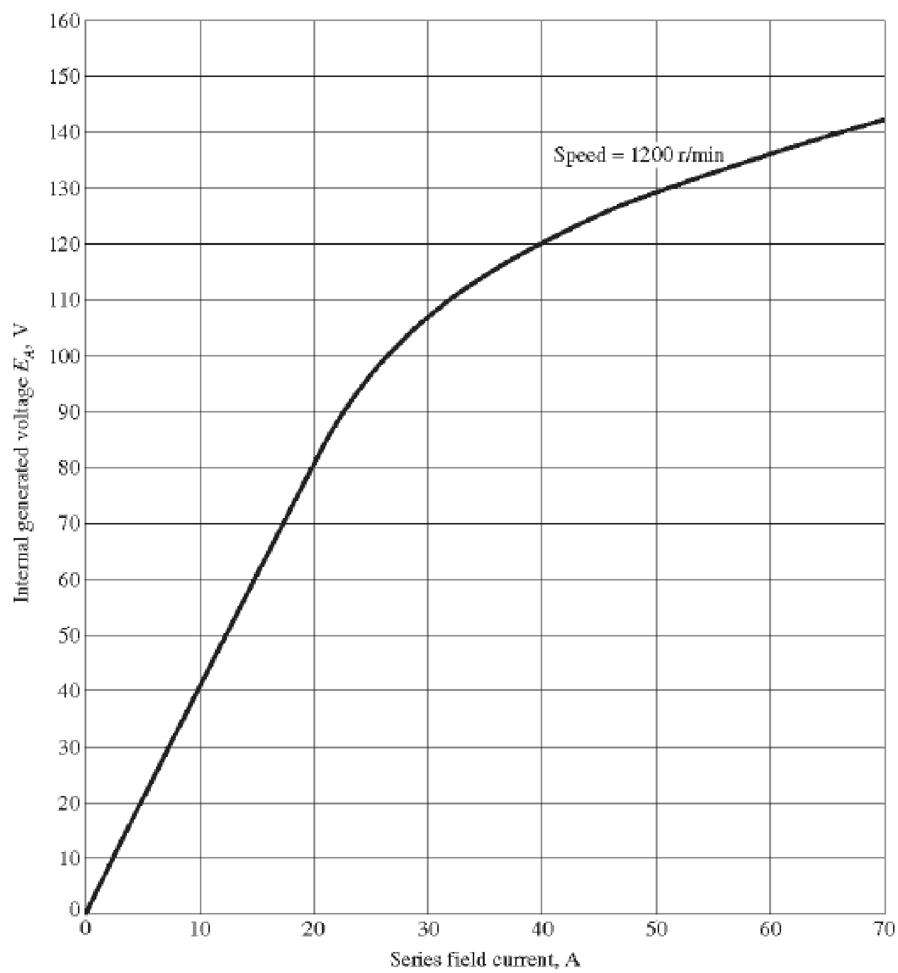

FIGURE P8–5
The magnetization curve for the series motor in Problem 8–13. This curve was taken at a constant speed of 1200 r/min.

(a) What is the efficiency of the motor at full load?

(b) What are the speed and efficiency of the motor if it is operating at an armature current of 40 A?

SOLUTION

(a) The output power of this motor at full load is

$$P_{\text{OUT}} = (7.5 \text{ hp})(746 \text{ W/hp}) = 5595 \text{ W}$$

The input power is

$$P_{\text{IN}} = V_T I_L = (120 \text{ V})(56 \text{ A}) = 6720 \text{ W}$$

Therefore the efficiency is

$$\eta = \frac{P_{\text{OUT}}}{P_{\text{IN}}} \times 100\% = \frac{5595 \text{ W}}{6720 \text{ W}} \times 100\% = 83.3\%$$

(b) If the armature current is 40 A, then the input power to the motor will be

$$P_{IN} = V_T I_L = (120 \text{ V})(40 \text{ A}) = 4800 \text{ W}$$

The internal generated voltage at this condition is

$$E_{A2} = V_T - I_A(R_A + R_S) = 120 \text{ V} - (40 \text{ A})(0.10\ \Omega + 0.08\ \Omega) = 112.8 \text{ V}$$

and the internal generated voltage at rated conditions is

$$E_{A2} = V_T - I_A(R_A + R_S) = 120 \text{ V} - (56 \text{ A})(0.10\ \Omega + 0.08\ \Omega) = 109.9 \text{ V}$$

The final speed is given by the equation

$$\frac{E_{A2}}{E_{A1}} = \frac{K\ \phi_2\ \omega_2}{K\ \phi_2\ \omega_2} = \frac{E_{Ao,2}\ n_2}{E_{Ao,1}\ n_1}$$

since the ratio $E_{Ao,2} / E_{Ao,1}$ is the same as the ratio ϕ_2 / ϕ_1. Therefore, the final speed is

$$n_2 = \frac{E_{A2}}{E_{A1}} \frac{E_{Ao,1}}{E_{Ao,2}} n_1$$

From Figure P8-5, the internal generated voltage $E_{Ao,2}$ for a current of 40 A and a speed of n_o = 1200 r/min is $E_{Ao,2}$ = 120 V, and the internal generated voltage $E_{Ao,1}$ for a current of 56 A and a speed of n_o = 1200 r/min is $E_{Ao,1}$ = 133 V.

$$n_2 = \frac{E_{A2}}{E_{A1}} \frac{E_{Ao,1}}{E_{Ao,2}} n_1 = \left(\frac{112.8 \text{ V}}{109.9 \text{ V}}\right)\left(\frac{133 \text{ V}}{120 \text{ V}}\right)(1050 \text{ r/min}) = 1195 \text{ r/min}$$

The power converted from electrical to mechanical form is

$$P_{conv} = E_A I_A = (112.8 \text{ V})(40 \text{ A}) = 4512 \text{ W}$$

The core losses in the motor are 220 W, and the mechanical losses in the motor are 230 W at a speed of 1050 r/min. The mechanical losses in the motor scale proportionally to the cube of the rotational speedm so the mechanical losses at 1326 r/min are

$$P_{mech} = \left(\frac{n_2}{n_1}\right)^3 (230 \text{ W}) = \left(\frac{1195 \text{ r/min}}{1050 \text{ r/min}}\right)^3 (230 \text{ W}) = 339 \text{ W}$$

Therefore, the output power is

$$P_{OUT} = P_{conv} - P_{mech} - P_{core} = 4512 \text{ W} - 339 \text{ W} - 220 \text{ W} = 3953 \text{ W}$$

and the efficiency is

$$\eta = \frac{P_{OUT}}{P_{IN}} \times 100\% = \frac{3953 \text{ W}}{4800 \text{ W}} \times 100\% = 82.4\%$$

8-16. The motor described above is connected in *shunt*.

(a) What is the no-load speed of this motor when R_{adj} = 120 Ω?

(b) What is its full-load speed?

(c) What is its speed regulation?

(a) If R_{adj} = 120 Ω, the total field resistance is 320 Ω, and the resulting field current is

$$I_F = \frac{V_T}{R_F + R_{adj}} = \frac{240 \text{ V}}{200\ \Omega + 120\ \Omega} = 0.75 \text{ A}$$

This field current would produce a voltage E_{Ao} of 245 V at a speed of n_o = 3000 r/min. The actual E_A is 240 V, so the actual speed will be

$$n = \frac{E_A}{E_{Ao}} n_o = \frac{240 \text{ V}}{245 \text{ V}} (3000 \text{ r/min}) = 2939 \text{ r/min}$$

(b) At full load, $I_A = I_L - I_F = 100 \text{ A} - 0.75 \text{ A} = 99.25 \text{ A}$, and

$$E_A = V_T - I_A R_A = 240 \text{ V} - (99.25 \text{ A})(0.14\ \Omega) = 226.1 \text{ V}$$

Therefore, the speed at full load will be

$$n = \frac{E_A}{E_{Ao}} n_o = \frac{226.1 \text{ V}}{245 \text{ V}} (3000 \text{ r/min}) = 2769 \text{ r/min}$$

(c) The speed regulation of this motor is

$$\text{SR} = \frac{n_{nl} - n_{fl}}{n_{fl}} \times 100\% = \frac{2939 \text{ r/min} - 2769 \text{ r/min}}{2769 \text{ r/min}} \times 100\% = 6.16\%$$

8-17. This machine is now connected as a cumulatively compounded dc motor with R_{adj} = 120 Ω.

(a) What is the no-load speed of this motor?

(b) What is its full-load speed?

(c) What is its speed regulation?

SOLUTION

(a) The field current will be

$$I_F = \frac{V_T}{R_F + R_{adj}} = \frac{240 \text{ V}}{200\ \Omega + 120\ \Omega} = 0.75 \text{ A}$$

At no load, $I_A = 0 \text{ A}$, and

$$E_A = V_T - I_A (R_A + R_S) = 240 \text{ V}$$

and the effective field current will be

$$I_F^* = I_F + \frac{N_{SE}}{N_F} I_A = 0.75 \text{ A} + \frac{15 \text{ turns}}{1500 \text{ turns}} (0 \text{ A}) = 0.75 \text{ A}$$

This field current would produce a voltage E_{Ao} of 245 V at a speed of n_o = 3000 r/min. The actual E_A is 240 V, so the actual speed at full load will be

$$n = \frac{E_A}{E_{Ao}} n_o = \frac{240 \text{ V}}{245 \text{ V}} (3000 \text{ r/min}) = 2939 \text{ r/min}$$

(b) The field current will be

$$I_F = \frac{V_T}{R_F + R_{\text{adj}}} = \frac{240 \text{ V}}{200 \ \Omega \ + \ 120 \ \Omega} = 0.75 \text{ A}$$

At full load, $I_A = I_L - I_F = 100 \text{ A} \ - \ 0.75 \text{ A} \ = \ 99.25 \text{ A}$, and

$$E_A = V_T - I_A\left(R_A + R_S\right) = 240 \text{ V} \ - \ \left(99.25 \text{ A}\right)\left(0.14 \ \Omega + 0.05 \ \Omega\right) = 221.1 \text{ V}$$

and the effective field current will be

$$I_F^* = I_F + \frac{N_{\text{SE}}}{N_F} I_A = 0.75 \text{ A} + \frac{15 \text{ turns}}{1500 \text{ turns}}\left(99.25 \text{ A}\right) = 1.74 \text{ A}$$

This field current would produce a voltage E_{Ao} of 292 V at a speed of n_o = 3000 r/min. The actual E_A is 240 V, so the actual speed at full load will be

$$n = \frac{E_A}{E_{Ao}} n_o = \frac{221.1 \text{ V}}{292 \text{ V}} \left(3000 \text{ r/min}\right) = 2272 \text{ r/min}$$

(c) The speed regulation of this motor is

$$\text{SR} = \frac{n_{\text{nl}} - n_{\text{fl}}}{n_{\text{fl}}} \times 100\% = \frac{2939 \text{ r/min} \ - \ 2272 \text{ r/min}}{2272 \text{ r/min}} \times 100\% = 29.4\%$$

8-22. The magnetization curve for a separately excited dc generator is shown in Figure P8-7. The generator is rated at 6 kW, 120 V, 50 A, and 1800 r/min and is shown in Figure P8-8. Its field circuit is rated at 5A. The following data are known about the machine:

$R_A = 0.18 \ \Omega$ $\qquad V_F = 120 \text{ V}$

$R_{\text{adj}} = 0 \text{ to } 40 \ \Omega$ $\qquad R_F = 20 \ \Omega$

$N_F = 1000$ turns per pole

Answer the following questions about this generator, assuming no armature reaction.

(a) If this generator is operating at no load, what is the range of voltage adjustments that can be achieved by changing R_{adj}?

(b) If the field rheostat is allowed to vary from 0 to 30 Ω and the generator's speed is allowed to vary from 1500 to 2000 r/min, what are the maximum and minimum no-load voltages in the generator?

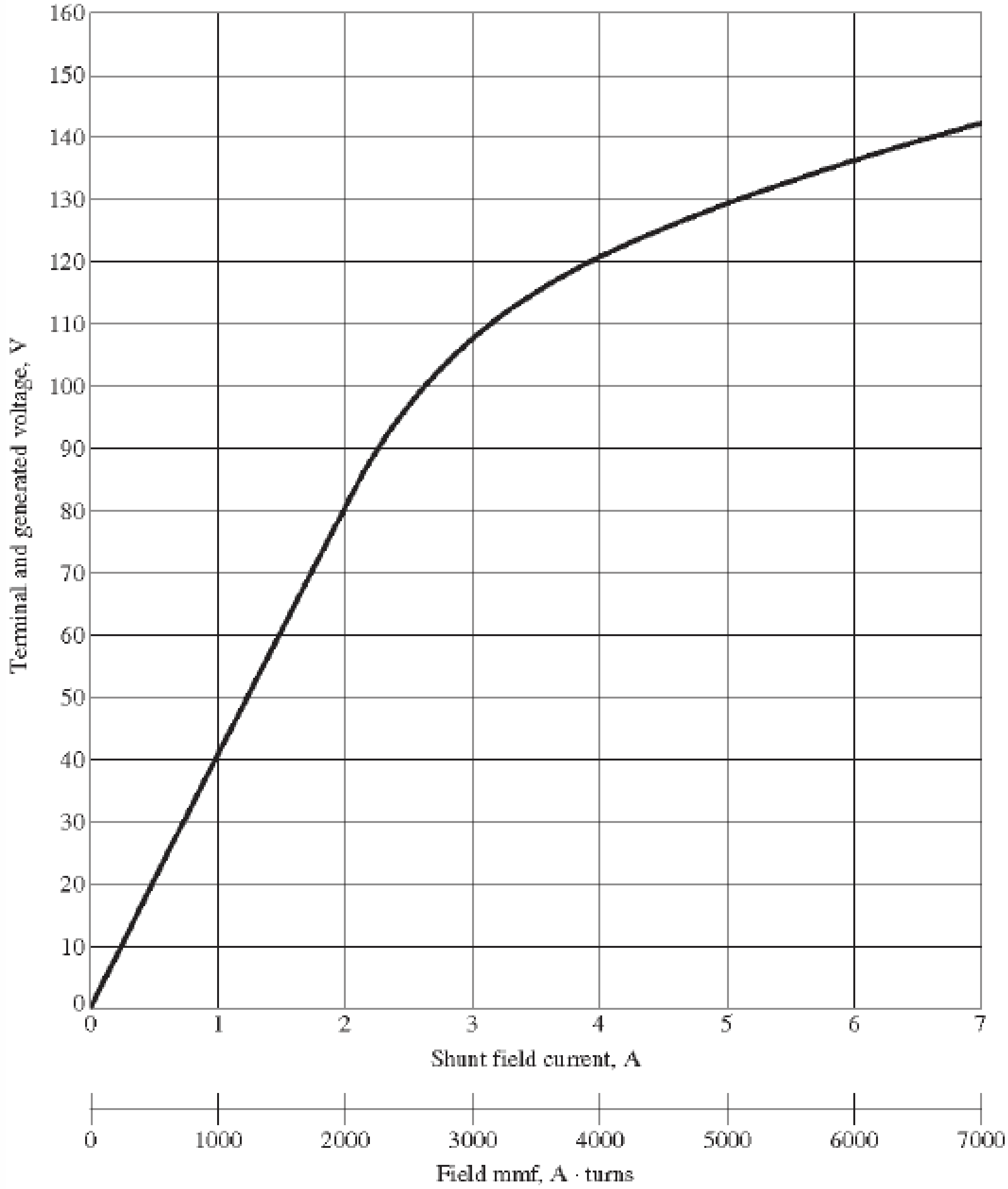

FIGURE P8–7
The magnetization curve for Problems 8–22 to 8–28. This curve was taken at a speed of 1800 r/min.

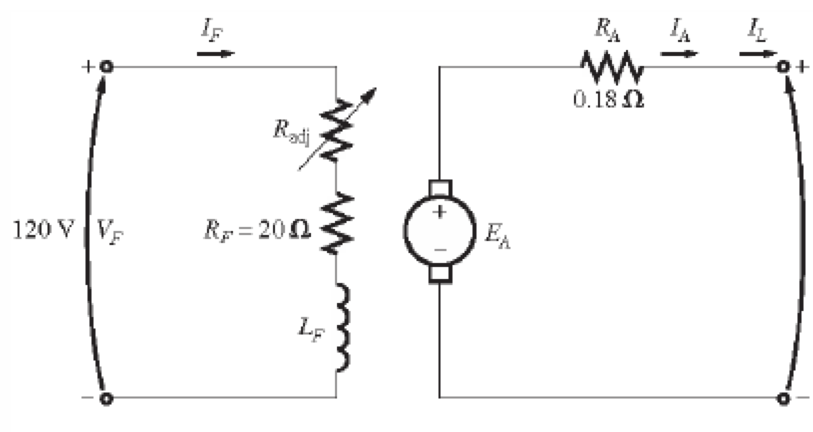

FIGURE P8–8
The separately excited dc generator in Problems 8–22 to 8–24.

SOLUTION

(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 $R_{adj} = 0\ \Omega$. 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 $R_{adj} = 40\ \Omega$. 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 $R_{adj} = 0\ \Omega$. 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 $R_{adj} = 30\ \Omega$. The current is

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

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

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

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