DC Motors Suggested Problems

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Problems 8-1 to 8-12 refer to the following dc motor:

$P_{rated} = 30$ hp	$I_{L,rated} = 110$ A
$V_T = 240$ V	$N_F = 2700$ turns per pole
$n_{rated} = 1800$ r/min	$N_{SE} = 14$ turns per pole
$R_A = 0.19\ \Omega$	$R_F = 75\ \Omega$
$R_S = 0.02\ \Omega$	$R_{adj} = 100$ to $400\ \Omega$

Rotational losses = 3550 W at full load

Magnetization curve as shown in Figure P8-1

In Problems 8-1 through 8-7, assume that the motor described above can be connected in shunt. The equivalent circuit of the shunt motor is shown in Figure P8-2.

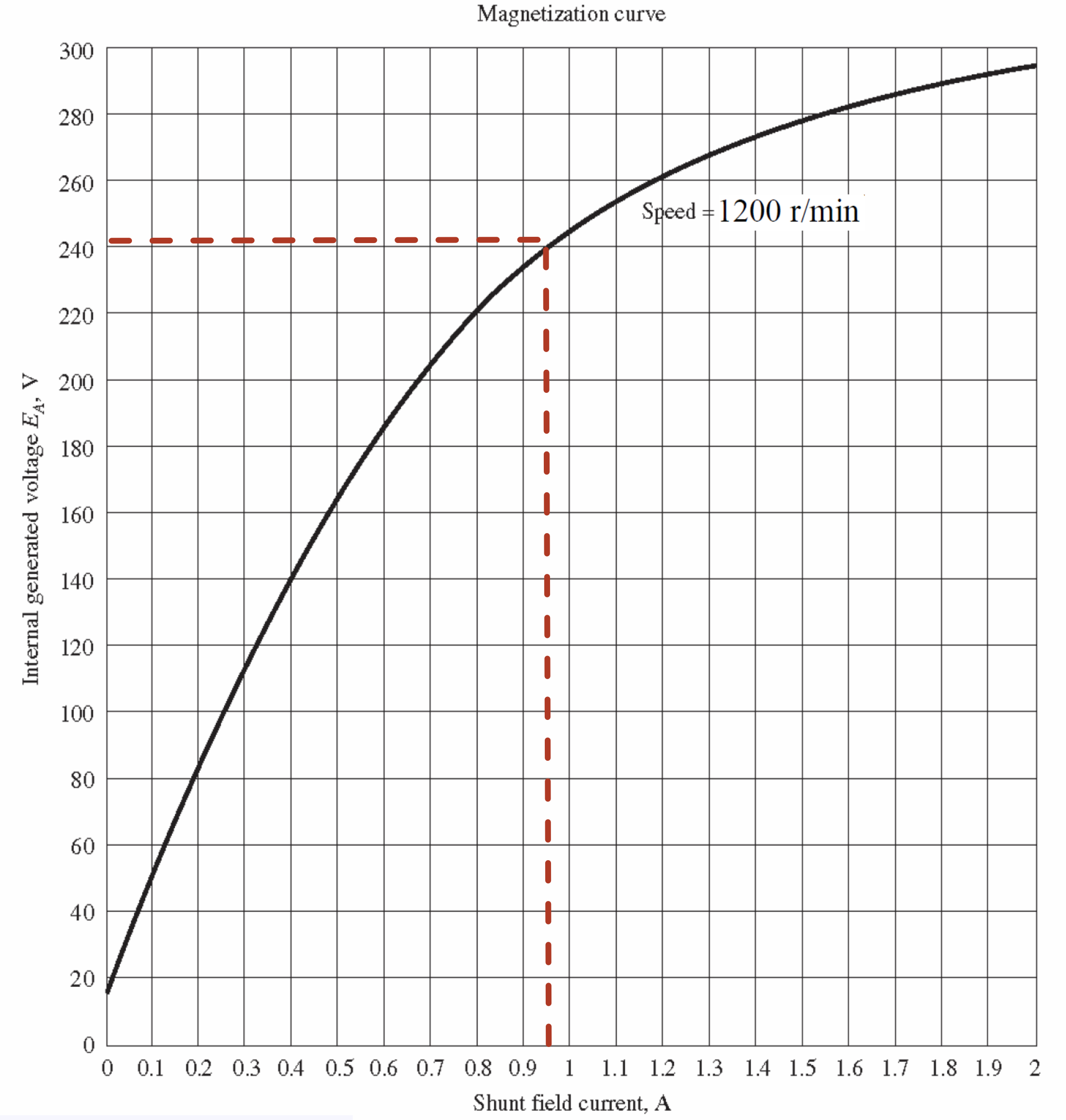


FIGURE P8–1

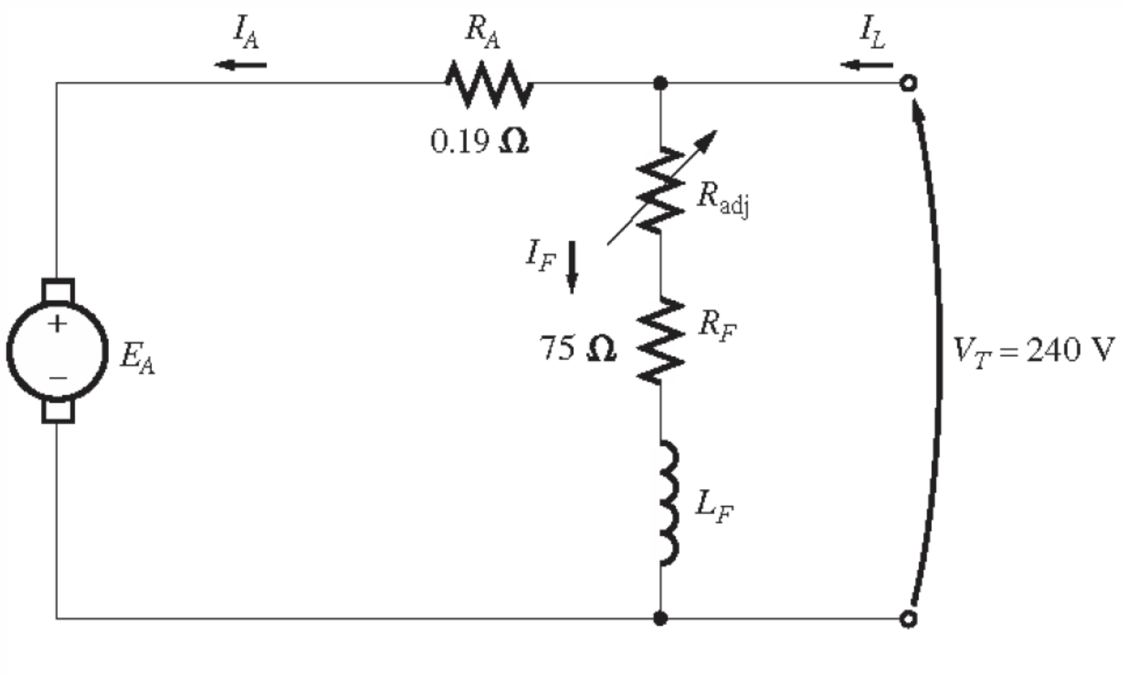


FIGURE P8–2
The equivalent circuit of the shunt motor in Problems 8–1 to 8–7.

8-1. If the resistor R_{adj} is adjusted to 175 Ω what is the rotational speed of the motor at no-load conditions?

SOLUTION At no-load conditions, $E_A = V_T = 240\text{ V}$. The field current is given by

$$I_F = \frac{V_T}{R_{\text{adj}} + R_F} = \frac{240\text{ V}}{175\ \Omega + 75\ \Omega} = \frac{240\text{ V}}{250\ \Omega} = 0.960\text{ A}$$

From Figure P9-1, this field current would produce an internal generated voltage E_{Ao} of 241 V at a speed n_o of 1200 r/min. Therefore, the speed n with a voltage E_A of 240 V would be

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

$$n = \left(\frac{E_A}{E_{Ao}}\right) n_o = \left(\frac{240\text{ V}}{241\text{ V}}\right)(1200\text{ r/min}) = 1195\text{ r/min}$$

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

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

8-6. What is the starting current of this machine if it is started by connecting it directly to the power supply V_T? How does this starting current compare to the full-load current of the motor?

SOLUTION The starting current of this machine (ignoring the small field current) is

$$I_{L,\text{start}} = \frac{V_T}{R_A} = \frac{240\text{ V}}{0.19\ \Omega} = 1260\text{ A}$$

The rated current is 110 A, so the starting current is 11.5 times greater than the full-load current. This much current is extremely likely to damage the motor.

For Problems 8-8 and 8-9, the shunt dc motor is reconnected separately excited, as shown in Figure P8-3. It has a fixed field voltage V_F of 240 V and an armature voltage V_A that can be varied from 120 to 240 V.

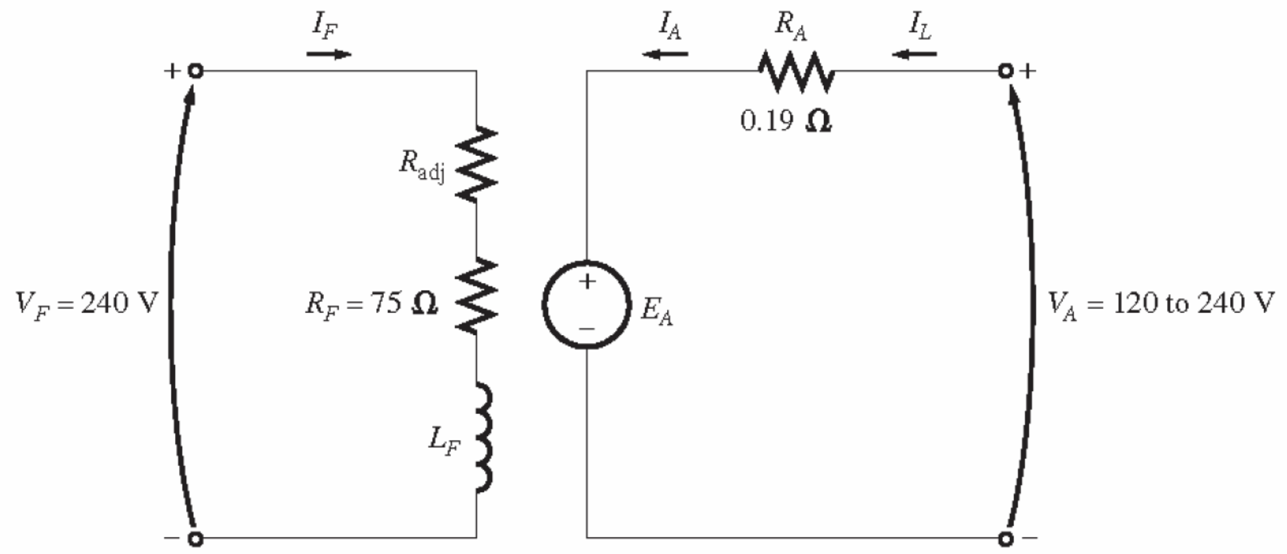


FIGURE P8–3
The equivalent circuit of the separately excited motor in Problems 8–8 and 8–9.

8-8. What is the no-load speed of this separately excited motor when R_{adj} = 175 Ω and *(a)* V_A = 120 V, *(b)* V_A = 180 V, *(c)* V_A = 240 V?

SOLUTION At no-load conditions, $E_A = V_A$. The field current is given by

$$I_F = \frac{V_F}{R_{adj} + R_F} = \frac{240\text{ V}}{175\ \Omega + 76\ \Omega} = \frac{240\text{ V}}{250\ \Omega} = 0.96\text{ A}$$

From Figure P8-1, this field current would produce an internal generated voltage E_{Ao} of 241 V at a speed n_o of 1200 r/min. Therefore, the speed n with a voltage of 240 V would be

From Figure P8-1, this field current would produce an internal generated voltage E_{Ao} of 241 V at a speed n_o of 1200 r/min. Therefore, the speed n with a voltage of V_A would be

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

$$n = \left(\frac{E_A}{E_{Ao}}\right) n_o$$

(a) If $V_A = 120$ V, then $E_A = 120$ V, and

$$n = \left(\frac{120 \text{ V}}{241 \text{ V}}\right)(1200 \text{ r/min}) = 598 \text{ r/min}$$

(b) If $V_A = 180$ V, then $E_A = 180$ V, and

$$n = \left(\frac{180 \text{ V}}{241 \text{ V}}\right)(1200 \text{ r/min}) = 986 \text{ r/min}$$

(c) If $V_A = 240$ V, then $E_A = 240$ V, and

$$n = \left(\frac{240 \text{ V}}{241 \text{ V}}\right)(1200 \text{ r/min}) = 1195 \text{ r/min}$$

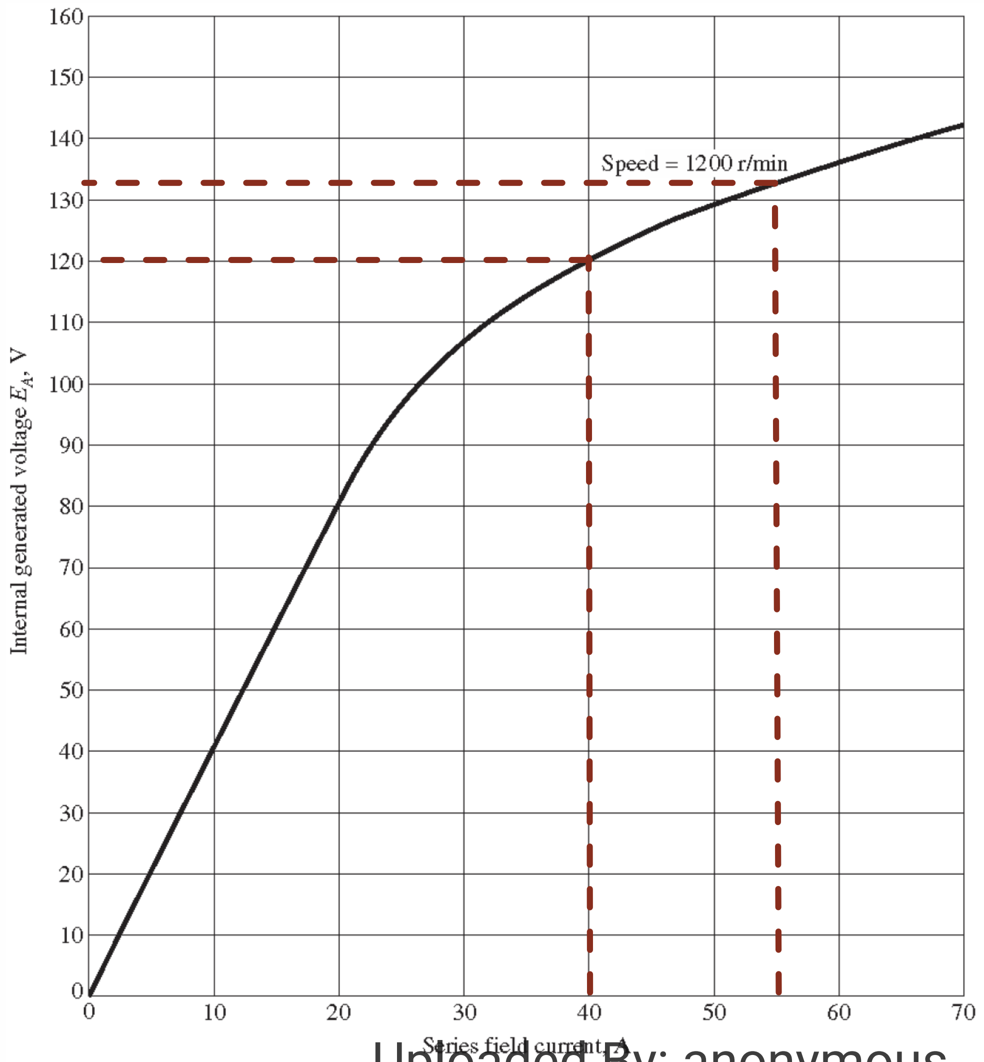
8-13. A 7.5-hp 120-V series dc motor has an armature resistance of 0.1 Ω and a series field resistance of 0.08 Ω. At full load, the current input is 56 A, and the rated speed is 1050 r/min. Its magnetization curve is shown in Figure P8-5. The core losses are 220 W, and the mechanical losses are 230 W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

(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

(c) Plot the torque-speed characteristic for this motor.

FIGURE P8–5



SOLUTION

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

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

The input power is

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

Therefore the efficiency is

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

; The actual output power since the input current and all power losses are given (Pstray neglected):

$$P_{out} = P_{in} - P_{cu} - P_{core} - P_{mech}$$
$$P_{out} = P_{in} - I_A^2(R_A + R_s) - P_{core} - P_{mech}$$
$$P_{out} = 6720 - 56^2(0.1 + 0.08) - 220 - 230$$
$$P_{out} = 6720 - 564.5 - 220 - 230$$
$$P_{out} = 6720 - 564.5 - 220 - 230$$
$$P_{out} = 5705.5W$$
$$\eta = \frac{P_{out}}{P_{in}} 100\% = \frac{5705.5}{6720} 100\% = 84.9\%$$

(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

$$E_{A1} = V_T - I_A(R_A + R_S) = 120 \text{ V} - (56 \text{ A})(0.10\ \Omega + 0.08\ \Omega) = 109.9 \text{ V}$$

The final speed is given by the equation

$$\frac{E_{A2}}{E_{A1}} = \frac{K\ \phi_2\ \omega_2}{K\ \phi_1\ \omega_1} = \frac{E_{Ao,2}\ n_2}{E_{Ao,1}\ n_1}$$

$E_{Ao,1}$, and $E_{Ao,2}$ *are the internally generated voltages at the two currents* (56A and 40A, respectively), *but at the same* 1200*rpm speed* obtained from the magnetization curve!

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

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

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

$$P_{\text{conv}} = E_{A2}I_{A2} = (112.8\text{ V})(40\text{ A}) = 4512\text{ W}$$

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 1195 r/min are

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

Therefore, the output power is

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

and the efficiency is

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

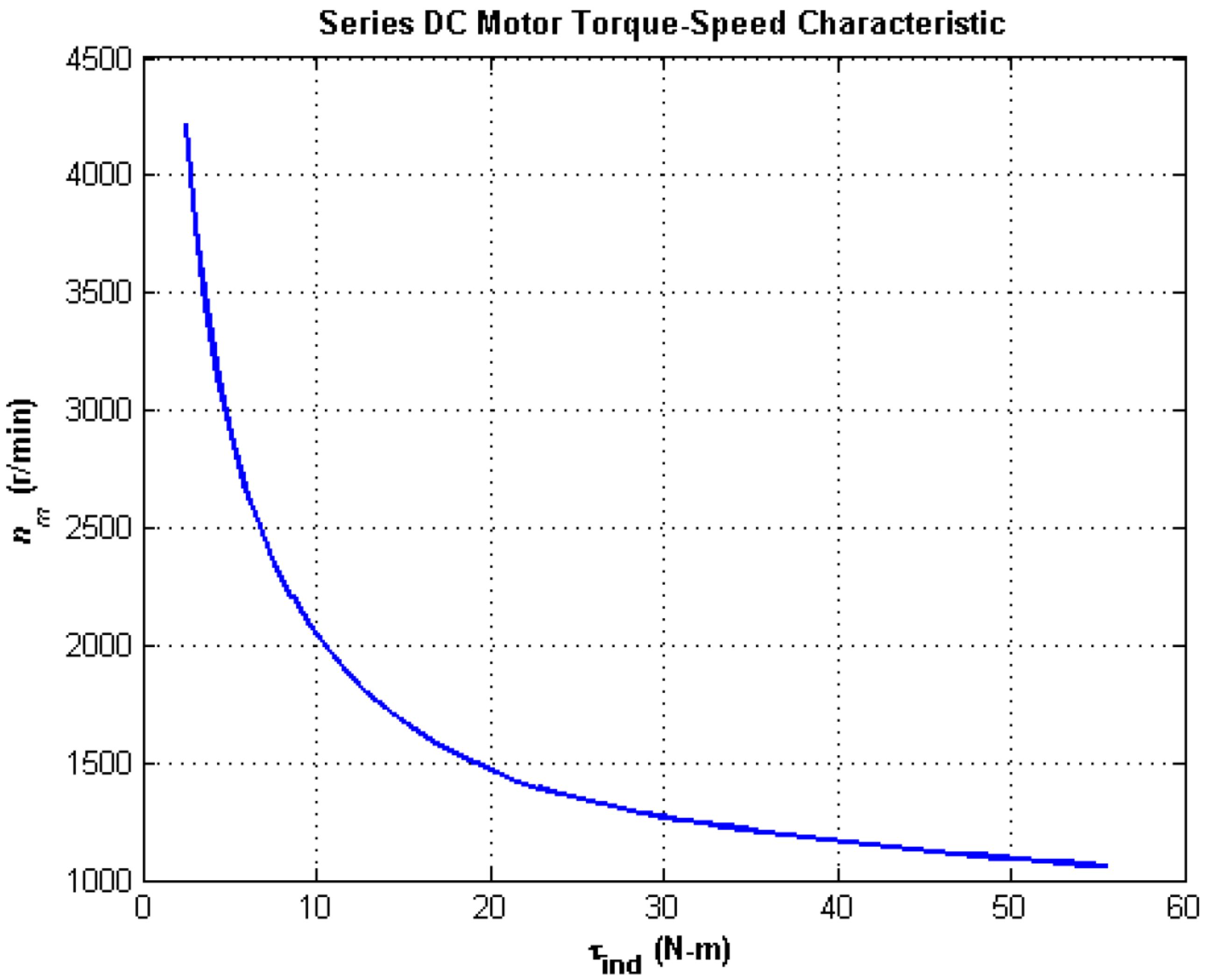
(c) A MATLAB program to plot the torque-speed characteristic of this motor is shown below:

```
% M-file: prob9_13.m
% M-file to create a plot of the torque-speed curve of the
%   the series dc motor in Problem 9-13.
% Get the magnetization curve.  Note that this curve is
% defined for a speed of 1200 r/min.
load p85_mag.dat
if_values = p85_mag(:,1);
ea_values = p85_mag(:,2);
n_0 = 1200;

% First, initialize the values needed in this program.
v_t = 120;                % Terminal voltage (V)
r_a = 0.36;               % Armature + field resistance (ohms)
i_a = 9:1:58;             % Armature (line) currents (A)

% Calculate the internal generate voltage e_a.
e_a = v_t - i_a * r_a;

% Calculate the resulting internal generated voltage at
% 1200 r/min by interpolating the motor's magnetization
% curve.  Note that the field current is the same as the
% armature current for this motor.
e_a0 = interp1(if_values,ea_values,i_a,'spline');

% Calculate the motor's speed, using the known fact that
% the motor runs at 1050 r/min at a current of 58 A.  We
% know that
%
%   Ea2      K' phi2 n2       Eao2  n2
%  ----- = ------------- =  ----------
%   Ea1      K' phi1 n1       Eao1  n1
%
```

```
%                  Ea2    Eao1
%     ==> n2 = ----- ------ n1
%                  Ea1    Eao2
%
% where Ea0 is the internal generated voltage at 1200 r/min
% for a given field current.
%
% Speed will be calculated by reference to full load speed
% and current.
n1 = 1050;           % 1050 r/min at full load
Eao1 = interp1(if_values,ea_values,58,'spline');
Ea1  = v_t - 58 * r_a;

% Get speed
Eao2 = interp1(if_values,ea_values,i_a,'spline');
n = (e_a./Ea1) .* (Eao1 ./ Eao2) * n1;

% Calculate the induced torque corresponding to each
% speed from Equations (8-55) and (8-56).
t_ind = e_a .* i_a ./ (n * 2 * pi / 60);

% Plot the torque-speed curve
figure(1);
plot(t_ind,n,'b-','LineWidth',2.0);
hold on;
xlabel('\bf\tau_{ind} (N-m)');
```

```
ylabel('\bf\itn_{m} \rm\bf(r/min)');
title ('\bfSeries DC Motor Torque-Speed Characteristic');
grid on;
hold off;
```

The resulting torque-speed characteristic is shown below:



Many Thanks

for

Your Attention!

Reference

- Instructor's Solutions Manual to accompany Electric Machinery Fundamentals by Stephen Chapman, 5th Ed., McGraw-Hill, Inc., 2012.