Lesson 18: Series Motor Torque-Speed Characteristics

ET 332a

Dc Motors, Generators and Energy Conversion Devices

Learning Objectives

- Use series dc motor model and equations to determine motor speed at different load levels
- Identify the torque-speed characteristic of a series dc motor
- Explain how a series dc motor can develop large starting torques

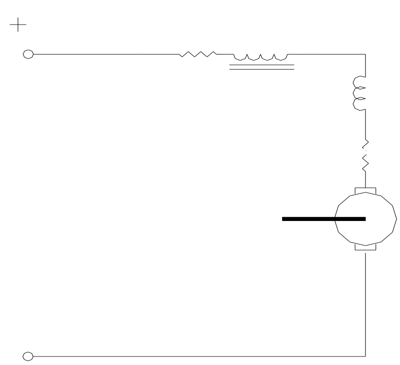
Series Dc Motor Example: Torque-Speed Characteristic

Example 18-1

A 550 V, 25 HP series connected 800 rpm dc motor draws 38 A at rated output. The total armature circuit resistance excluding the series field coil is 0.117 ohms. The series field resistance is 0.125 ohms.

a.) determine the developed torque supplied by the motor when it operates at rated output.
b.) determine the motor speed when the developed torque is reduced by 50% from rated
c.) repeat (b) with 75% reduction from rated
d.) plot the torque-speed curve for the motor. Can it be considered a constant speed machine?

Example 18-1 Solution (1)



$$T_d \omega = E_a I_a$$

$$\omega = 800\ \text{Rpm}\left[\frac{2\pi}{60}\right] = 83.78\ \text{rad/s}$$

$$E_a = V_T - I_a(R_s + R_a)$$

$$E_a = 550\text{V} - 38\text{A}(0.125\Omega + 0.117\Omega)$$

$$E_a = 540.8\text{V}$$

$E_a I_a = P_e = P_{em}$ electromechanical power developed in armature

Example 18-1 Solution (2)

$$E_a I_a = (540.8V)(38A) = 20{,}550W$$

$$T_D = \frac{E_a I_a}{\omega} = \frac{(540.8V)(38A)}{83.78 \text{ rad/s}} = \boxed{245.3 \text{ N-m}} \text{ ANS}$$

Part b.) 50% developed torque. Compute 50% torque speed value

$$T_{D50} = T_D - \left(\frac{50\%}{100}\right) T_D \qquad T_D = 245.3 \text{ N-m from above}$$

$$T_{D50} = 245.3 - 0.5(245.3)$$
$$T_{D50} = 122.65 \text{ N-m}$$

Example 18-1 Solution (3)

$$\text{Torque} \propto I_a^2$$

$$\frac{T_D}{T_{D50}} = \frac{K_T I_a^2}{K_T I_{a1}^2} \Rightarrow \frac{T_D}{T_{D50}} = \frac{I_a^2}{I_{a1}^2} \Rightarrow \sqrt{\frac{T_D}{T_{D50}}} = \frac{I_a}{I_{a50}}$$

I_{a50} = armature current at 50% rated torque

To find spee $\dfrac{n_1}{n_2} = \dfrac{\dfrac{E_{a1}}{\Phi_{p1} k_G}}{\dfrac{E_{a2}}{\Phi_{p2} k_G}}$ $\qquad \dfrac{n_1}{n_2} = \left[\dfrac{E_{a1}}{E_{a2}}\right]\left[\dfrac{\Phi_{p2}}{\Phi_{p1}}\right]$ $\qquad \Phi_{p2}$ reduced by reduction in I_a

n_1 = 800 RPM from problem statement

Example 18-1 Solution (4)

Find I_{a50}

$$I_{a50} = \frac{1}{\sqrt{\frac{T_D}{T_{D50}}}}$$

$$(38A)\left[\frac{1}{\sqrt{\frac{245.3\ N\text{-}m}{122.65\ N\text{-}m}}}\right] = I_{a50}$$

$$I_{a50} = 26.87A$$

In linear region of magnetization curve
Φ_p is proportional to I_a
$I_f = I_a$ in series connection so…

$$\frac{\Phi_{p1}}{\Phi_{p2}} = \frac{I_{a1}}{I_{a2}}$$

Example 18-1 Solution (5)

$$E_{a2} = V_T - I_{a50}(R_{acie} + R_s)$$

$$E_{a2} = 550V - 26.87A(0.117 + 0.125\Omega)$$

$$E_{a2} = 543.5V$$

$$E_{a1} = 540.8 \text{ from Part a}$$

$$n_2 = \left[\frac{\Phi_{p1}}{\Phi_{p2}}\right]\left[\frac{E_{a2}}{E_{a1}}\right] n_1$$

$$\frac{\Phi_{p1}}{\Phi_{p2}} = \frac{38\ A}{26.87A} = 1.414$$

$$n_2 = 1.414\left[\frac{543.5V}{540.8V}\right](800Rpm)$$

$$n_2 = 1137\ Rpm$$

Answer

Example 18-1 Solution (6)

Part c.) 75% developed torque. Compute 75% torque speed value

From previous equations

$$\sqrt{\frac{T_D}{T_{D75}}} = \frac{I_a}{I_{a75}} \Rightarrow I_{a75} = I_a \left[\frac{1}{\sqrt{\frac{T_D}{T_{D75}}}}\right]$$

$$T_{D75} = 0.75\left[T_D\right]$$

$$I_{a75} = (38\,A)\left[\frac{1}{\sqrt{\frac{245.3\,N\text{-}m}{61.325\,N\text{-}m}}}\right] \qquad I_{a75} = 19\,A$$

$$T_{D75} = 0.75(245.3\ N\text{-}m)$$

$$T_{D75} = 61.325\ N\text{-}m$$

Example 18-1 Solution (7)

Determine new value of E_a and flux ratio

$$\frac{\Phi_{p1}}{\Phi_{p2}} = \frac{I_{a1}}{I_{a2}} = \frac{38A}{19A} = 2.0$$

$$E_{a2} = V_T - I_{a75}(R_s + R_{acie})$$

$$E_{a2} = 550\,V - 19\,A(0.117 + 0.125\,\Omega)$$

$$E_{a2} = 545.4\,V$$

$$E_{a1} = 540.8\,V \quad \text{part(a)}$$

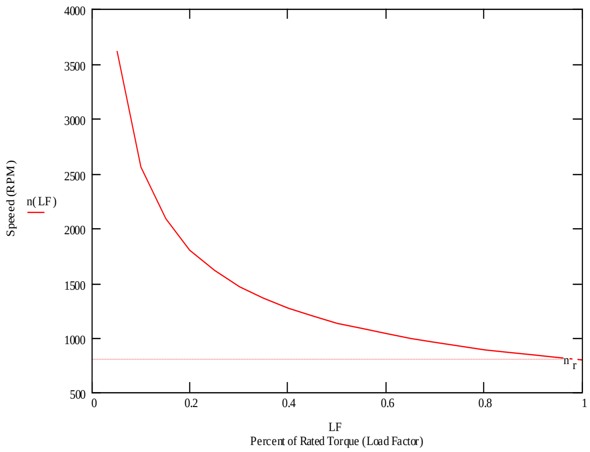
Speed at 75% load

$$n_2 = \left[\frac{\Phi_{p1}}{\Phi_{p2}}\right]\left[\frac{E_{a2}}{E_{a1}}\right] n_1 \qquad n_2 = 2.0\left[\frac{545.4\,V}{540.8\,V}\right](800\ Rpm)$$

$$\boxed{n_2 = 1614\ Rpm}$$

Answer

Series Motor Torque-Speed Characteristic



Rated speed is 800 rpm. At no load, the speed will increase exponentially and destroy the machine. (Last point plotted was at 5% rated load)

MathCAD equations

$$I_L(LF) := I_a \cdot \frac{1}{\sqrt{\frac{1}{LF}}}$$

$$n(LF) := \frac{I_a}{I_L(LF)} \cdot \frac{V_T - I_L(LF) \cdot (R_s + R_a)}{V_T - I_a \cdot (R_s + R_a)} \cdot n_r$$

Vary value of LF to generate curve

Starting Series Connected Dc Motors

Series motors develop extremely high starting torques

Under locked rotor conditions $E_a = 0$ so...

$$I_{as} = \frac{V_T}{R_{acir} + R_s} \qquad T_D = k_T \cdot I_a^{\ 2}$$

Where I_{as} = starting armature current
R_s = series field resistance
R_{acir} = total armature resistance
T_D = developed torque
k_T = motor torque constant
V_T = terminal voltage

Since $R_{acir} + R_s << 1$ then $I_{as} >> I_a$ when operating at rated speed

Series Motor Starting Example

<u>Example 18-2</u>: Using the values from the previous example, find the series motor starting currents and starting torque of the machine from that example. Assume linear magnetization curves

$V_T = 550\text{V}$ $\quad R_{acir} + R_s = 0.117\,\Omega + 0.125\,\Omega$

$R_{acir} + R_s = 0.242\,\Omega$

$$I_{as} = \frac{550\text{V}}{0.242\,\Omega} = 2273\text{ A} \quad \text{Wow!}$$

Find the developed starting torque. Find k_T from rated conditions.

In previous example
$T_D = 245.3$ N-m
$I_a = 38$ A

$$T_D = k_T I_a^2$$

$$\frac{T_D}{I_a^2} = k_T$$

$$\frac{245.3\text{ N-m}}{(38\text{ A})^2} = k_T$$

$$0.1698\text{ N-m}/\text{A}^2$$

Example 18-2 Solution (2)

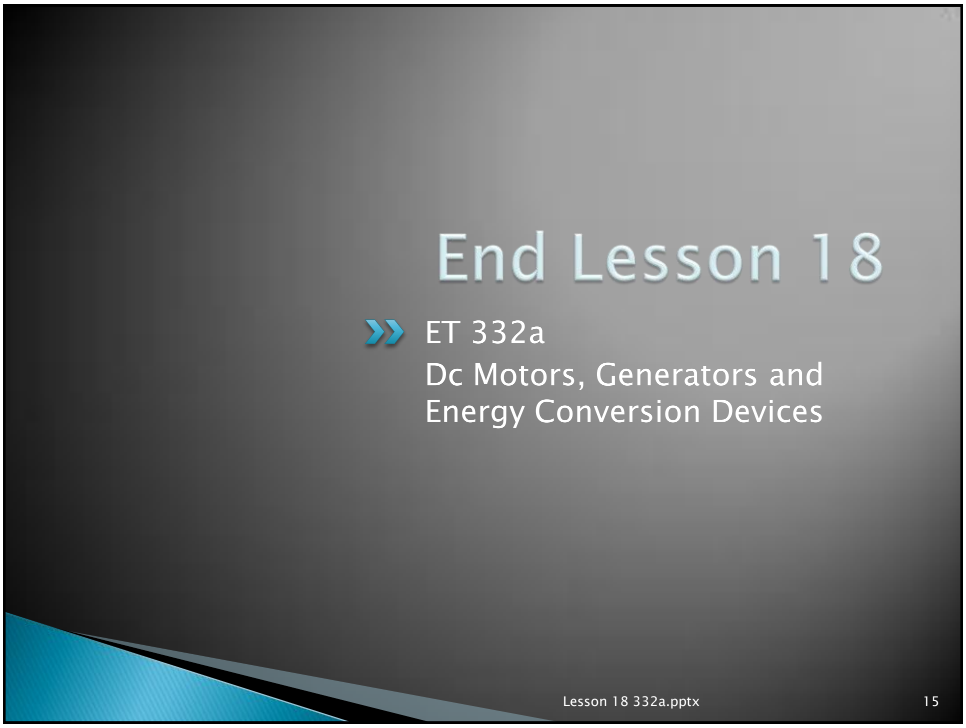
T_{DS} = starting developed torque

$$T_{DS} = k_T I_{as}^2$$

$$T_{DS} = (0.1698\text{ N-m}/\text{A}^2)(2273\text{ A})^2$$

$$T_{DS} = 877{,}066\text{ N-m} \quad \text{Wow!}$$

Saturation limits torque to lower value since flux is not proportional to armature current for large values of current.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