Lesson 13 Shunt Connected Dc Motor Examples

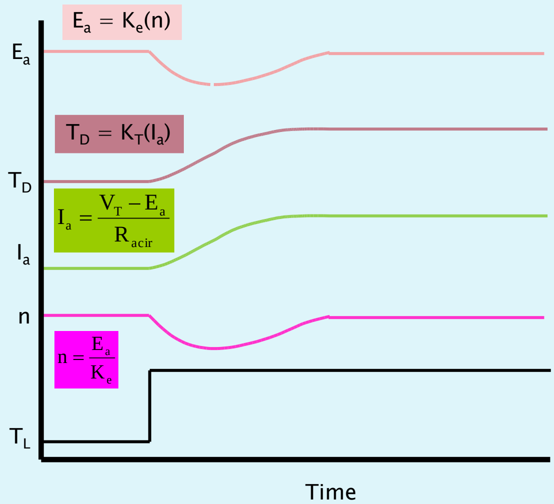
ET 332a

Dc Motors, Generators and Energy Conversion Devices

Learning Objectives

- Explain how changing field excitation of a shunt motor affects its performance
- Explain how the internal feedback inherent in the shunt motor maintains a nearly constant shaft speed.
- Use shunt motor equations and circuit model to compute motor operating conditions.

Dynamic Response of Shunt Motors



1.) Increasing T_L causes motor to slow.

2.) Reduced armature speed decreases E_a.

3.) More I_a flows in armature circuit. More I_a means more $T_{D.}$

4.) When T_D matches T_L system stabilizes at new operating point. I_a higher:

5.) E_a and n return to almost the same values

Dc Shunt Motor Solution Methods

Just as in other machines studied up to now, the motor speed, developed torque and generated emf are all proportional. If an operating point and a percent increase/decease is known, the new operating point can be found using proportions.

E_a is proportional to speed

$$\frac{E_{a1}}{E_{a2}} = \frac{n_1}{n_2}$$

T_D is proportional to armature Current

$$\frac{T_{D1}}{T_{D2}} = \frac{I_{a1}}{I_{a2}}$$

Speed is directly proportional to E_a and inversely proportional to field flux

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

Example 13-1:Shunt Motor Speed Control Using Field Weakening

A 10 HP 240 volt 1200 rpm motor is operating at rated conditions. Determine the percent change in shunt field flux required to lower the speed to 900 rpm. Assume that armature current remains the same.

Example 13-1 Solution (1)

Define speeds for two cases

$n_1 = 1200$ rpm $n_2 = 900$ rpm

Set up proportions

$$n_1 = \frac{V_T - I_{a1} \cdot R_{acir}}{\Phi_{p1} \cdot k_G} \qquad n_2 = \frac{V_T - I_{a2} \cdot R_{acir}}{\Phi_{p2} \cdot k_G}$$

$$\frac{n_1}{n_2} = \frac{\left[\dfrac{V_T - I_{a1} \cdot R_{acir}}{\Phi_{p1} \cdot k_G}\right]}{\left[\dfrac{V_T - I_{a2} \cdot R_{acir}}{\Phi_{p2} \cdot k_G}\right]} = \left[\frac{\cancel{V_T - I_{a1} \cdot R_{acir}}}{\Phi_{p1} \cdot \cancel{k_G}}\right] \cdot \left[\frac{\Phi_{p2} \cdot \cancel{k_G}}{\cancel{V_T - I_{a2} \cdot R_{acir}}}\right]$$

Since $I_{a1} = I_{a2}$ this simplifies

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

Find the value of Φ_{p2} assuming $\Phi_{p1} = 1$

$$\frac{1200\,\text{rpm}}{900\,\text{rpm}} = \left[\frac{\Phi_{p2}}{1}\right] = 1.33$$

$$\left[\frac{\Phi_{p2} - \Phi_{p1}}{\Phi_{p1}}\right] \cdot 100\% = \left[\frac{1.33 - 1}{1}\right] \cdot 100\% = 33\%$$

Answer

Example 13-2

A 200 volt shunt motor is rated a 5 HP and 1000 rpm. At rated output it draws 25 A of line current. The total armature circuit resistance is 0.5 ohms. The field resistance is 100 ohms

a.) find the total rotational losses of the motor at rated conditions

b.) Find the no load speed of the motor at 200 volts

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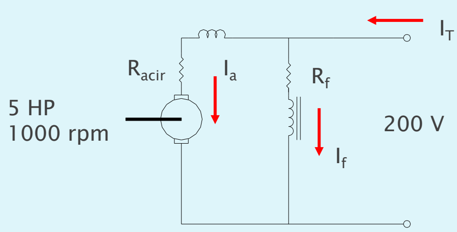
Example 13-2 Solution (1)



$I_T = 25$ A Find I_a

$I_T = 25\,A$

$I_T = I_a + I_f$

$I_a = I_T - I_f$

$I_f = \frac{V_T}{R_f} = \frac{200V}{100\Omega} = 2A$

$I_a = 25A - 2A = 23A$

Rotational losses are the difference between P_{em} and P_{shaft}

$P_{shaft} = 5hp\left[\frac{746W}{1hp}\right] = 3730W$

$P_{em} = P_e$ power developed in armature

$P_e = E_a I_a$

Find E_a

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Example 13-2 Solution (2)

$R_{acir} = 0.5\,\Omega \quad V_T = 200\,V$

$E_{a1} = V_T - I_{a1} R_{acir}$

$E_{a1} = 200\,V - (23\,A)(0.5\,\Omega)$

$E_{a1} = 188.5\,V$

$P_e = E_a I_a = (188.5\,V)(23\,A)$

$P_e = 4335.5\,W$

$P_{rot} = P_e - P_{shaft}$

$P_{rot} = 4335.5\,W - 3730\,W$

$\boxed{P_{rot} = 605.5\,W}$ ← Answer

Example 13-2 Solution (3)

b.) At no-load the only power absorbed is what is required to supply P_{rot}.

$E_a I_a = P_{em} = P_e = 605.5\,W$

Power balance on electric side of motor. Neglecting brushes

$E_a I_a = V_T I_{a2} - I_{a2}^2 R_{acir}$

$605.5 = 200\, I_{a2} - 0.5\, I_{a2}^2$

$V_T = 200\,V$

$R_{acir} = 0.5\,\Omega$

Put into standard form $-0.5 I_{a2}^2 + 200\, I_{a2} - 605.5 = 0$

Solve quadratic for I_a $\quad I_{a21} = 396.95\,A \qquad I_{a22} = 3.051\,A$

Example 13-2 Solution (4)

Torques is proportional to armature current I_a. Lower power requires lower torque and armature current

$T \propto I_a$

use $I_{a22} = 3.051\,A$

Find E_{a2} using $I_{a22} = 3.051\,A$

$$E_{a2} = V_T - I_{a22} R_{acir}$$

$$E_{a2} = 200V - (3.051A)(0.55\Omega)$$

$$E_{a2} = 198.5\,V$$

Speed is proportional to E_a

$$\frac{E_{a1}}{E_{a2}} = \frac{n_1}{n_2} \Rightarrow \frac{n_2}{n_1} = \frac{E_{a2}}{E_{a1}}$$

Example 13-2 Solution (5)

Solve the previous equation for n_2

$$\left[\frac{E_{a2}}{E_{a1}}\right] n_1 = n_2 \qquad n_1 = 1000\,Rpm$$

$$\left[\frac{198.5V}{188.5V}\right](1000\,Rpm) = n_2$$

$$\boxed{1053\,Rpm = n_2}$$

Answer

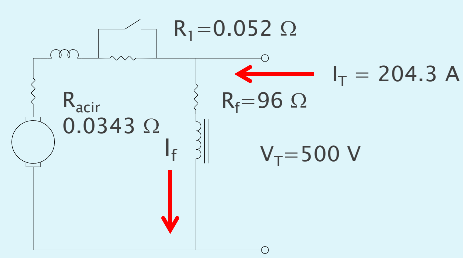
Example 13-3: Effects of Changing Field Excitation

Weakening the field increases speed but reduces torque

Example 13-3: A 500 volt 125 HP 1150 rpm shunt motor operates at rated conditions, driving a constant-torque load. The line current at rated conditions is 204.3 amps. The total armature resistance is 0.0343 ohms the field resistance is 96 ohms.

a) Determine the steady-state armature current if a 0.052 ohm resistor is connected in series with the armature and the field is weakened by 10% from its rated value.
b) b.) Determine the steady-state speed for conditions in part a.

Example 13-3: Solution (1)



$I_a = I_T - I_f$

$I_f = \frac{V_T}{R_f} = \frac{500\,V}{96\,\Omega} = 5.21\,A$

$I_a = 204.3\,A - 5.21\,A$

$I_a = 199.1\,A$

Find E_a at rated conditions

$R_{acir} = 0.0343\,\Omega$

$V_T = 500\,V$

$E_a = V_T - I_a R_{acir}$

$E_a = 500\,V - (199.1\,A)(0.0343\,\Omega)$

$E_a = 493.2\,V$

Find Power Developed in the armature

$P_e = P_{em} = E_a I_a$

Example 13-3: Solution (2)

$$P_{em} = (493.2\,V)(199.1\,A) = 93{,}196.1\,W$$

$$T_D = \frac{P_{em}}{\omega} \qquad n_1 = 1150\ Rpm$$

$$\omega = \left[\frac{2\pi}{60}\right](1150\ Rpm) = 120.43\ rad/s$$

Developed torque

$$T_D = \frac{93{,}196.1\,W}{120.43\ rad/s} = 815.4\ N\text{-}m$$

Switch in additional resistance, R_1, and weaken field

$T_{D1} = T_{D2}$ Constant torque load

Example 13-3: Solution (3)

Field weakened by 10% reduces the value of K_T by 10% assuming no magnetic saturation

Initial K_T

$$T_{D1} = K_T I_{a1} \qquad \frac{T_{D1}}{I_{a1}} = K_T$$

$$K_T = \frac{815.9\ N\text{-}m}{199.1\,A}$$

$$K_T = 4.1\ N\text{-}m/A$$

$K_{T2} = K_T$ under field weakening

$$K_{T2} = K_T - 0.1K_T$$

$$K_{T2} = 4.1 - 0.1(4.1)\ N\text{-}m/A$$

$$K_{T2} = 3.69\ N\text{-}m/A$$

Find I_{a2} using torque constant

Example 13-3: Solution (4)

$T_{D2} = T_{D1} = 815.4\ N\text{-}m$

$\frac{T_{D2}}{K_{T2}} = I_{a2}$

$\frac{815.4\ N\text{-}m}{3.69\ N\text{-}m/A} = \boxed{220.97A}$

Answer Part a

b.) Find speed under the above conditions

$\frac{n_1}{n_2} = \frac{\frac{E_{a1}}{\Phi_{p1} K_G}}{\frac{E_{a2}}{\Phi_{p2} K_G}}$

$\Phi_{p2} = 0.9\Phi_{p1}$

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Example 13-3: Solution (5)

$E_{a2} = V_T - I_{a2}(R_{arm} + R_1)$

$E_{a2} = 500V - (220.97A)(0.0343\Omega + 0.052\Omega)$

$E_{a2} = 480.93$

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

$n_2 = 1150\ Rpm\left[\frac{480.93V}{493.2V}\right]\left[\frac{\Phi_{p1}}{0.9\Phi_{p1}}\right]$

$\boxed{n_2 = 1246\ Rpm}$

Answer Part b

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End Lesson 13

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