Lesson 11: Separately Excited Motor Examples

ET 332a

Dc Motors, Generators and Energy Conversion Devices

Learning Objectives

After this presentation you will be able to:

- Write a power balance for a separately excited motor and compute its efficiency
- Explain how changing motor load affects efficiency
- Interpret motor nameplate data

Power Relationships for Dc Motors

The electromechanical power output from the armature is equal to the total electrical power input to the armature

KVL in armature circuit gives $$V_T = I_a \cdot R_{acir} + E_a$$

Multiply by I_a $$V_T \cdot I_a = I_a^2 \cdot R_{acir} + E_a I_a$$

From generator power balance $$P_{em} = E_a \cdot I_a$$
$$P_e = E_a \cdot I_a$$

Where: P_{em} = the mechanical power developed in the armature and P_e is the electrical power input to the motor

Combining above equations gives $$P_{em} = V_T \cdot I_a - I_a^2 \cdot R_{acir}$$

Where: $R_{acir} = R_a + R_{IP} + R_{CW}$

R_a = armature resistance R_{CW} = compensating winding resistance
R_{IP} = interpole resistance

Motor Nameplate Ratings

Motor nameplate data is given in horsepower (hp) and revolutions per minute (RPM).

All motor characteristics are standardized by National Electrical Manufacturers Association (NEMA)

Physical characteristics - size, dimensions shaft placement, etc.
Electrical characteristics - voltage rating torque/speed characteristics. HP ratings

Motor Nameplate Ratings

At rated voltage and current, motor delivers rated HP at rated speed.

Relationship between torque and mechanical power at shaft in terms of mechanical units.

$$P_{shaft} = \frac{T_{shaft} \cdot n}{5252} \text{ Hp}$$

Where: T_{shaft} = developed torque at motor shaft (lb-ft)
n = shaft speed (rpm)
P_{shaft} = shaft power output (hp)

Armature torque and power must be larger to overcome mechanical losses

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Example 11-1 Shaft Power Calculations

A 15 Hp separately excited motor is operating at its rated speed of 1200 rpm Determine the rated torque of the motor in ft-lbs.

Solution Rated mechanical power output $P_{shaft} = 15$ hp

$n = 1200$ Rpm Rated speed

$$P_{shaft} = \frac{T_{rated}\, n}{5252} \Rightarrow \frac{P_{shaft}\, 5252}{n} = T_{rated}$$

$$\frac{(15\text{ hp})(5252)}{1200\text{ RPM}} = T_{shaft}$$

$$65.65 \text{ lb-ft} = T_{shaft}$$

This is smaller than the actual torque developed at the armature

$$T\omega = E_a I_a$$

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Example 11-2 Torque Constant

A 25 Hp separately excited motor is operating at a speed of 250 rpm. It is supplied from a 120 V supply and draws 5.6 A. The total armature circuit resistance is .473 ohms. Find the torque constant for the machine

$$E_a = V_T - I_a R_{acir} \qquad E_a = 120V - (5.6A)(0.473\Omega) = 117.35V$$

$$P_e = E_a I_a = (117.35V)(5.6A) = 657.17W$$

$$P_{em} = P_e \qquad P_{em} = T\omega$$

Convert rpm to rad/sec $\omega = \frac{2\pi}{60}(250\ Rpm) = 26.167\ rad/s$

Find the torque $\frac{P_{em}}{\omega} = T \qquad \frac{657.17W}{26.167\ rad/sec} = \boxed{25.1\ N\text{-}m}$

Example 11-2 Torque Constant (2)

Remember

$$T = B_p I_a K_G \Rightarrow \frac{T}{I_a} = B_p K_G$$

B_p is constant for constant field current. So ……… $B_p K_G = K_T$ K_T is the motor torque constant

$$\frac{25.11\ N\text{-}m}{5.6A} = B_p K_G = 4.485\ \frac{N\text{-}m}{A}$$

Note: K_T is numerically equal to K_e when using SI units. In this case $K_e = 4.485$ V-sec/rad

General Speed Equations for Dc Motors

Remember $E_a = V_T - I_a \cdot R_{acir}$ $\quad n = \dfrac{E_a}{\Phi_p \cdot K_G}$

Combine the two above to get speed equation

$$n = \frac{V_T - I_a \cdot R_{acir}}{\Phi_p \cdot K_G}$$

Where: R_{acir} = armature circuit resistance

I_a armature current

K_G = machine constant

n = speed (rpm)

Φ_p = field flux

General Speed Equations for Dc Motors

Speed inversely proportional to the field flux. Decreasing the field flux increases speed **providing sufficient torque is developed to produce necessary acceleration.**

Remember $T_D = k_T \cdot I_f \cdot I_a$

$$n = \frac{V_T - I_a \cdot R_{acir}}{\Phi_p \cdot K_G}$$

Decreasing I_f reduces field flux but also reduces developed torque

Controlled by I_f

Motor Speed and Terminal Voltage

Motor speed is directly proportional to the terminal voltage. Increasing V_T increases n, Decreasing V_T decreases n

Example 11-3: A 50 HP, 240 Vdc separately excited motor is operating at 1000 rpm. The motor draws 7800 watts from dc supply. The total armature resistance is 0.221 Ω. Find:

a.) The emf constant, K_e of the motor
b.) The motor speed if the terminal voltage is reduced by 20% and the power drawn remains the same.

Example 11-3 Solution (1)

Part a.)

$$n = \frac{V_T - I_a R_{acir}}{\Phi_p K_G}$$

Remember $\Phi_p K_G = K_e$

K_e = emf constant

$n = 1000$ Rpm $V_T = 240V$ $R_{acir} = 0.221\ \Omega$

Find I_a $P_e = V_T I_a$ electric input power

$$\frac{P_e}{V_T} = I_a \Rightarrow \frac{7800W}{240V} = I_a$$

$32.5A = I_a$

$$n = \frac{V_T - I_a R_{acir}}{K_e} \quad K_e = \frac{V_T - I_a R_{acir}}{n}$$

$$K_e = \frac{240V - (32.5A)(0.221\ \Omega)}{1000\ Rpm}$$

$$\boxed{K_e = 0.2328\ V/Rpm}$$

Example 11-3 Solution (2)

Part b. K_e remains the same, no change in the field current

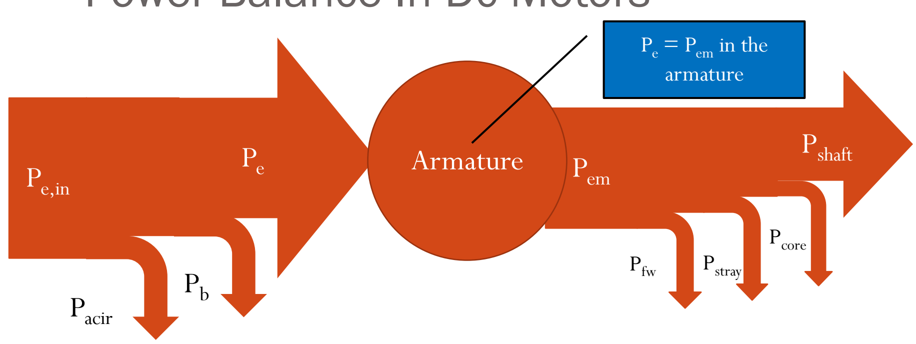
$$V_{T2} = V_T - V_T\left(\frac{20\%}{100\%}\right) \qquad V_{T2} = 240 - 240(0.20) = 192\text{V}$$

P_e Remains constant $\qquad \frac{P_{in}}{V_{T2}} = I_{a2} \qquad \frac{7800\text{W}}{192\text{V}} = 40.625\text{A}$

$$n_2 = \frac{V_{T2} - I_{a2}R_{acir}}{K_e} = \frac{192\text{V} - (40.625\text{A})(0.221\text{ A})}{0.2328\text{ V/Rpm}}$$

$n_2 = 786.2$ Rpm $\qquad$ Calculate % speed change $\qquad \frac{1000 - 786.2}{1000} \times 100\% = \boxed{21.3\%}$

Power Balance In Dc Motors



$P_{e,in}$ = electric power in at terminals (W)
P_{acir} = armature circuit losses $I_a^2(R_{acir})$ (W)
P_b = losses due to brush drop $V_b(I_a)$ (W)
P_e = electric power delivered to armature $(E_a)\cdot I_a$ circuit (W)
P_{em} = Electromechanical power developed in armature $(T_d)\cdot\omega$ (W)

P_{fw} = friction and windage losses (W) (from test)
P_{stray} = stray load losses (W) (from test)
P_{core} = core losses (W) (from test)
P_{shaft} = total mechanical power develop at the shaft (Rated hp)

$P_{fw} + P_{stray} + P_{core}$ are called rotational losses

Motor Efficiency

Remember from generators

$$\eta = \left[\frac{P_{out}}{P_{in}}\right] \cdot 100\%$$

Just like generators, efficiency varies with motor P_{shaft}. Nameplate efficiency occurs at rated output.

For motors: $P_{out} = P_{shaft}$ mechanical power developed at the shaft
$P_{in} = P_{e,in}$ the electrical power supplied to the terminals
η = percent efficiency

In terms of losses $P_{losses} = P_{acir} + P_b + P_{fw} + P_{core} + P_{stray}$

Where P_{acir} = armature circuit losses
P_b = brush losses
P_{fw} = friction and windage losses
P_{core} = core losses
P_{stray} = stray losses

$$\eta = \left[\frac{P_{out}}{P_{out} + P_{losses}}\right] \cdot 100\%$$

Example 11-4 Motor Solutions Using Efficiency

A separately excited dc motor is rated at 100 HP, 600 V at 1200 rpm. The total armature resistance is 0.24 ohms. When the motor is delivering 75 HP at 1200 rpm its efficiency is 88%. At the 75 HP output find:

a.) the motor armature current
b.) counter emf (Ea)
c.) torque at the shaft
d.) an estimate of the mechanical losses

Example 11-4 Solution (1)

a.) Find the armature current. Use efficiency to relate P_{shaft} to $P_{e,in}$

$$P_{out} = 75\,hp\left[\frac{746\,W}{1\,hp}\right] = 55{,}950\,W$$

$$\eta = \left[\frac{P_{out}}{P_{in}}\right]100\% \qquad \eta = 88\%$$

$$P_{e,in} = \frac{P_{out}}{\eta/100} = \frac{55{,}950\,W}{88/100}$$

$$P_{e,in} = 63{,}580\,W$$

$$V_T = 600\,V$$

$$I_a = \frac{P_{e,in}}{V_T} = \frac{63{,}580\,W}{600\,V}$$

$$\boxed{I_a = 106\,A}$$

Example 11-4 Solution (2)

b.) Find E_a. Use the current from part a to find the emf

$$V_T = E_a + I_a R_{acir} \Rightarrow V_T - I_a R_{acir} = E_a$$

$$E_a = 600\,V - (0.24\,\Omega)(106\,A) = \boxed{574.6\,V}$$

c.) Find shaft torque (N-m). Use rated Hp and speed

$$P_{out} = P_{shaft} = 55{,}950\,W \quad \text{Part a}$$

convert speed to rad/sec

$$1200\,Rpm\left[\frac{2\pi}{60}\right] = 125.7\,rad/s$$

$$T_{shaft} = \frac{P_{shaft}}{\omega} = \frac{55{,}950\,W}{125.7\,rad/s} = \boxed{445.2\,N\text{-}m}$$

Example 11-4 Solution (3)

d.) Estimate the rotational losses (mechanical losses)

MECHANICAL LOSSES

$P_{fw} + P_{core} + P_{stray}$

$P_{fw} + P_{core} + P_{stray} = P_{em} - P_{shaft}$

$P_{em} = P_e = E_a I_a \qquad E_a = 574.6\text{V}$

$I_a = 106\text{ A}$

$P_{em} = (574.6\text{V})(106\text{A}) = 60{,}907.6\text{ W}$

$60{,}907.6\text{ W} - 55{,}950\text{W} = \boxed{4957.6\text{W}}$

About 6.6 hp

End Lesson 11

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