ELEC 342: Electromechanical Energy Conversion and Transmission

Homework 4 (Chapter 4 from the Textbook)

- ✓ Examples (questions with full answers)
- ✓ **Assignments** (questions with no answers)

You need to submit on Canvas your answers (procedure + final answer) for "Assignments" only by 11:59 pm on the posted due date.

Summary:

- Follow through **Examples 4.6, 4.9, 4.13 (**adopted from the textbook).
- Solve Problems **P4.30**, **P4.31, P4.32, P4.38, P4.39**.

EXAMPLE 4.6

The dc machine (12 kW, 100 V, 1000 rpm) of Example 4.2 is connected to a 100 V dc supply and is operated as a dc shunt motor. At no-load condition, the motor runs at 1000 rpm, and the armature takes 6 amperes.

(a) Find the value of the resistance of the shunt field control rheostat (R_{fc}).

(b) Find the rotational losses at 1000 rpm.

(c) Find the speed, electromagnetic torque, and efficiency of the motor when rated current flows in the armature.

Solution

(a) No load, $I_a = 6$ A.

$$\begin{aligned} E_a &= V_t - I_a R_a \\ &= 100 - 6 \times 0.1 \\ &= 99.4 \text{ V} \end{aligned}$$

From the magnetization curve (Fig. 4.24), generating $E_a = 99.4$ V at 1000 rpm requires $I_f = 0.99$ A.

$$\begin{aligned} R_f = R_{fc} + R_{fw} &= \frac{V_t}{I_f} = \frac{100}{0.99} = 101\ \Omega \\ R_{fc} &= 101 - R_{fw} \\ &= 101 - 80 \\ &= 21\ \Omega \end{aligned}$$

(b) At no load, the electromagnetic power developed is lost as rotational power.

$$P_{\text{rotational}} = E_a I_a = 99.4 \times 6 = 596.4 \text{ W}$$

(c) The motor is loaded and $I_a = I_a|_{\text{rated}} = 120$ A (Example 4.2).

$$E_a|_{NL} = 99.4 \text{ V}$$

$$E_a|_{FL} = V_t - I_a R_a = 100 - 120 \times 0.1 = 88 \text{ V}$$

$$\frac{E_a|_{FL}}{E_a|_{NL}} = \frac{K_a \Phi_{FL} \omega_{FL}}{K_a \Phi_{NL} \omega_{NL}} = \frac{\omega_{FL}}{\omega_{NL}} \qquad \Phi_{NL} = \Phi_{FL}.$$

$$\omega_{FL} = \frac{E_a|_{FL}}{E_a|_{NL}} \omega_{NL} = \frac{88}{99.4} \times 1000 = 885.31 \text{ rpm}$$

$$\omega_m = \frac{885.31}{60} \times 2\pi = 92.71 \text{ rad/sec}$$

$$T = \frac{E_a I_a}{\omega_m} = \frac{88 \times 120}{92.71} = 113.9 \text{ N} \cdot \text{m}$$

$$
\begin{aligned}
P_{\text{out}} &= E_a I_a - P_{\text{rotational}} \\
&= 10{,}560 - 596.4 \\
&= 9963.6\ \text{W} \\
P_{\text{in}} &= V_t I_t = V_t(I_a + I_f) \\
&= 100(120 + 0.99) \\
&= 12{,}099\ \text{W}
\end{aligned}
$$

$$
\text{Eff} = \frac{P_{\text{out}}}{P_{\text{in}}} = \frac{9963.6}{12{,}099} \times 100\% = 82.35\%
$$

EXAMPLE 4.9

A 220 V, 7 hp series motor is mechanically coupled to a fan and draws 25 amps and runs at 300 rpm when connected to a 220 V supply with no external resistance connected to the armature circuit (i.e., $R_{ae} = 0$). The torque required by the fan is proportional to the square of the speed. $R_a = 0.6\ \Omega$ and $R_{sr} = 0.4\ \Omega$. Neglect rotational loss.

(a) Determine the power delivered to the fan and the torque developed by the machine.

(b) The speed is to be reduced to 200 rpm by inserting a resistance (R_{ae}) in the armature circuit. Determine the value of this resistance and the power delivered to the fan.

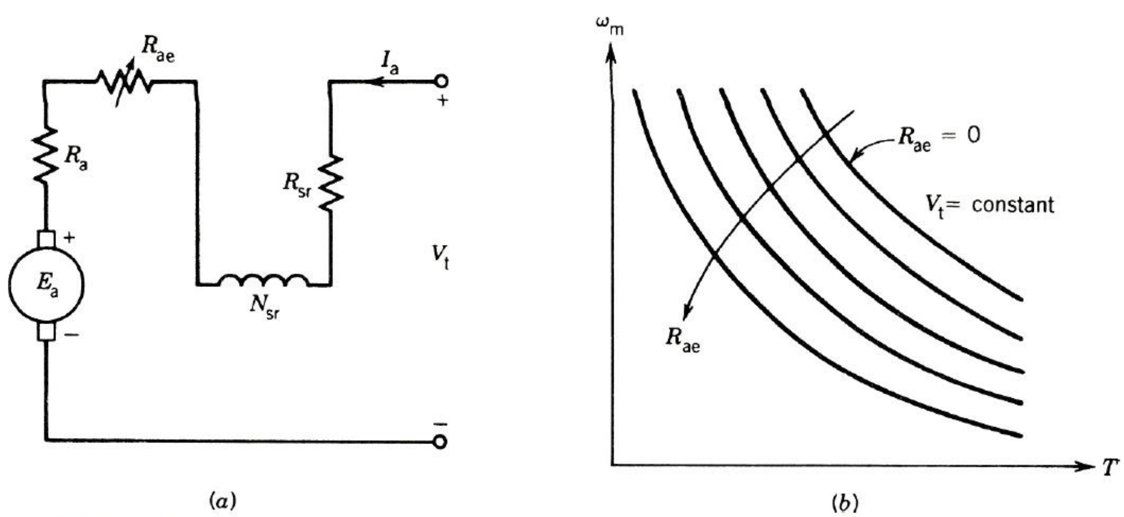

FIGURE 4.55 Series motor.

Solution

(a) From Fig. 4.55*a*

$$
\begin{aligned}
\mathrm{E_a} &= V_\mathrm{t} - I_\mathrm{a}(R_\mathrm{a} + R_\mathrm{sr} + R_\mathrm{ae}) \\
&= 220 - 25(0.6 + 0.4 + 0) \\
&= 195\ \mathrm{V} \\
P &= E_\mathrm{a} I_\mathrm{a} \\
&= 195 \times 25 \\
&= 4880\ \mathrm{W} \\
&= \frac{4880}{746}\ \mathrm{hp} = 6.54\ \mathrm{hp} \\
T &= \frac{E_\mathrm{a} I_\mathrm{a}}{\omega_\mathrm{m}} \\
&= \frac{4880}{300 \times 2\pi/60} \\
&= 155.2\ \mathrm{N \cdot m}
\end{aligned}
$$

(b)

$$
\begin{aligned}
T &= K_\mathrm{sr} I_\mathrm{a}^2 \\
155.2 &= K_\mathrm{sr} 25^2 \\
K_\mathrm{sr} &= 0.248 \\
T|_{200\ \mathrm{rpm}} &= \left(\frac{200}{300}\right)^2 \times 155.2 \\
&= 68.98\ \mathrm{N \cdot m}
\end{aligned}
$$

From Eq. 4.54

$$\frac{200}{60} \times 2\pi = \frac{200}{\sqrt{0.248}\sqrt{68.98}} - \frac{0.6 + 0.4 + R_{ae}}{0.248}$$

$$R_{ae} = 7\ \Omega$$

$$P = T\omega_m = 68.98 \times \frac{200}{60} \times 2\pi = 1444\text{W} \rightarrow 1.94\text{ hp}$$

or

$$68.98 = 0.248 I_a^2$$

$$I_a = 16.68\text{ amps}$$

$$E_a = K_{sr} I_a \omega_m$$

$$= 0.248 \times 16.68 \times \frac{200}{60} \times 2\pi$$

$$= 86.57\text{ V}$$

$$E_a = V_t - I_a(R_a + R_{sr} + R_{ae})$$

$$86.57 = 220 - 16.68(0.6 + 0.4 + R_{ae})$$

$$R_{ae} = 7\ \Omega$$

$$P = E_a I_a = 86.57 \times 16.68$$

$$E_a = K_{sr} I_a \omega_m \quad (4.50)$$

$$T = K_{sr} I_a^2 \quad (4.51)$$

$$E_a = V_t - I_a(R_a + R_{ae} + R_{sr}) \quad (4.52)$$

$$\omega_m = \frac{V_t}{K_{sr} I_a} - \frac{R_a + R_{sr} + R_{ae}}{K_{sr}} \quad (4.53)$$

$$\omega_m = \frac{V_t}{\sqrt{K_{sr}}\sqrt{T}} - \frac{R_a + R_{sr} + R_{ae}}{K_{sr}} \quad (4.54)$$

EXAMPLE 4.13

The speed of a separately excited dc motor is controlled by a chopper as shown in Fig. 4.62*a*. The dc supply voltage is 120 V, the armature circuit resistance $R_a = 0.5\ \Omega$, the armature circuit inductance $L_a = 20$ mH, and the motor constant is $K_a\Phi = 0.05$ V/rpm. The motor drives a constant-torque load requiring an average armature current of 20 A. Assume that motor current is continuous.

Determine the

(a) Range of speed control.

(b) Range of the duty cycle α.

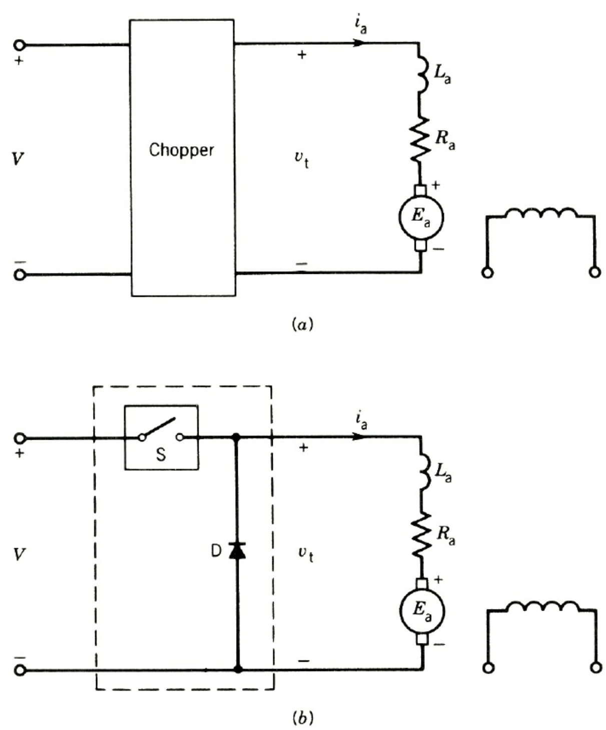

FIGURE 4.62 Chopper circuit and its operation.

$$V_t = E_a + I_a R_a \tag{4.61a}$$

$$E_a = K_a \Phi \omega_m \tag{4.61b}$$

$$T = K_a \Phi I_a \tag{4.61c}$$

$$V_t = \frac{t_{on}}{T} V \tag{4.62}$$

$$= \alpha V \tag{4.63}$$

Solution

Minimum speed is zero, at which $E_a = 0$. Therefore, from Eq. 4.61a,

$$V_t = I_a R_a = 20 \times 0.5 = 10 \text{ V}$$

From Eq. 4.63,

$$10 = 120\alpha$$

$$\alpha = \frac{1}{12}$$

Maximum speed corresponds to $\alpha = 1$, at which $V_t = V = 120$ V. Therefore,

$$\begin{aligned} E_a &= V_t - I_a R_a \\ &= 120 - (20 \times 0.5) \\ &= 110 \text{ V} \end{aligned}$$

From Eq. 4.61b,

$$N = \frac{E_a}{K_a \Phi} = \frac{110}{0.05} = 2200 \text{ rpm}$$

(a) The range of speed is $0 < N < 2200$ rpm.

(b) The range of the duty cycle is $\frac{1}{12} < \alpha < 1$. ■

Problems from Textbook

P 4.30):

A permanent magnet dc motor drives a mechanical load requiring a constant torque of 25 N · m. The motor produces 10 N · m with an armature current of 10 A. The resistance of the armature circuit is 0.2 Ω. A 200 V dc supply is applied to the armature terminals. Determine the speed of the motor.

P 4.31):

A dc shunt motor drives an elevator load which requires a constant torque of 300 N · m. The motor is connected to a 600 V dc supply and the motor rotates at 1500 rpm. The armature resistance is 0.5 Ω.

(a) Determine the armature current.

(b) If the shunt field flux is reduced by 10%, determine the armature current and the speed of the motor.

P 4.32):

A dc shunt motor is connected to a 230 V supply and delivers power to a load drawing an armature current of 200 amperes and running at a speed of 1200 rpm. $R_a = 0.2\ \Omega$.

(a) Determine the value of the generated voltage at this load condition.

(b) Determine the value of the load torque. The rotational losses are 500 watts.

(c) Determine the efficiency of the motor if the field circuit resistance is 115 Ω.

P 4.38):

A dc motor is mechanically connected to a constant-torque load. When the armature is connected to a 120 V dc supply, it draws an armature current of value 8 A and runs at 1800 rpm. The armature resistance is $R_a = 0.08\ \Omega$. Accidentally, the field circuit breaks and the flux drops to the residual flux, which is only 5% of the original flux.

(a) Determine the value of the armature current immediately after the field circuit breaks (i.e., before the speed has had time to change from 1800 rpm).

(b) Determine the theoretical final speed of the motor after the field circuit breaks.

P 4.39):

A 600 V dc series motor has armature and field winding resistance of 0.5 Ω. When connected to a 600 V supply, it operates at 500 rpm and takes 75 A. If the load torque is reduced to half, determine

(a) The armature current.

(b) The speed at which it will operate.

Assume that the flux is proportional to current and neglect armature reaction.