ECE 320 / ECE 329   Recitation
Homework   Monday 26 March 2012
DC Machines

Do the following problems from the textbook:

1. <u>Questions</u> 8.2, 8.3, 8.4, 8.5, and 8.6 on page 552.

2. Problems 8.1, 8.2, and 8.3 on page 553.

3. Problems 8.4 and 8.6 on page 553.

4. Problem 8.7 on page 554. Using software may make this one quicker.

5. Problem 8.8 on page 554.

6. Problem 8.20 on page 559.

7. Problem 8.14a on page 556.

A series motor has the highest starting torque of any dc motor but tends to overspeed at no load. It is used for very high-torque applications where speed regulation is not important, such as a car starter.

A cumulatively compounded dc motor is a compromise between the series and the shunt motor, having some of the best characteristics of each. On the other hand, a differentially compounded dc motor is a complete disaster. It is unstable and tends to overspeed as load is added to it.

DC generators are dc machines used as generators. There are several different types of dc generators, differing in the manner in which their field fluxes are derived. These methods affect the output characteristics of the different types of generators. The common dc generator types are separately excited, shunt, series, cumulatively compounded, and differentially compounded.

The shunt and compounded dc generators depend on the nonlinearity of their magnetization curves for stable output voltages. If the magnetization curve of a dc machine were a straight line, then the magnetization curve and the terminal voltage line of the generator would never intersect. There would thus be no stable no-load voltage for the generator. Since nonlinear effects are at the heart of the generator's operation, the output voltages of dc generators can only be determined graphically or numerically by using a computer.

Today, dc generators have been replaced in many applications by ac power sources and solid-state electronic components. This is true even in the automobile, which is one of the most common users of dc power.

QUESTIONS

8–1. What is the speed regulation of a dc motor?

8–2. How can the speed of a shunt dc motor be controlled? Explain in detail.

8–3. What is the practical difference between a separately excited and a shunt dc motor?

8–4. What effect does armature reaction have on the torque–speed characteristic of a shunt dc motor? Can the effects of armature reaction be serious? What can be done to remedy this problem?

8–5. What are the desirable characteristics of the permanent magnets in PMDC machines?

8–6. What are the principal characteristics of a series dc motor? What are its uses?

8–7. What are the characteristics of a cumulatively compounded dc motor?

8–8. What are the problems associated with a differentially compounded dc motor?

8–9. What happens in a shunt dc motor if its field circuit opens while it is running?

8–10. Why is a starting resistor used in dc motor circuits?

8–11. How can a dc starting resistor be cut out of a motor's armature circuit at just the right time during starting?

8–12. What is the Ward-Leonard motor control system? What are its advantages and disadvantages?

8–13. What is regeneration?

8–14. What are the advantages and disadvantages of solid-state motor drives compared to the Ward-Leonard system?

8–15. What is the purpose of a field loss relay?

8–16. What types of protective features are included in typical solid-state dc motor drives? How do they work?

8–17. How can the direction of rotation of a separately excited dc motor be reversed?

8–18. How can the direction of rotation of a shunt dc motor be reversed?

8–19. How can the direction of rotation of a series dc motor be reversed?

8–20. Name and describe the features of the five types of generators covered in this chapter.

8–21. How does the voltage buildup occur in a shunt dc generator during starting?

8–22. What could cause voltage buildup on starting to fail to occur? How can this problem be remedied?

8–23. How does armature reaction affect the output voltage in a separately excited dc generator?

8–24. What causes the extraordinarily fast voltage drop with increasing load in a differentially compounded dc generator?
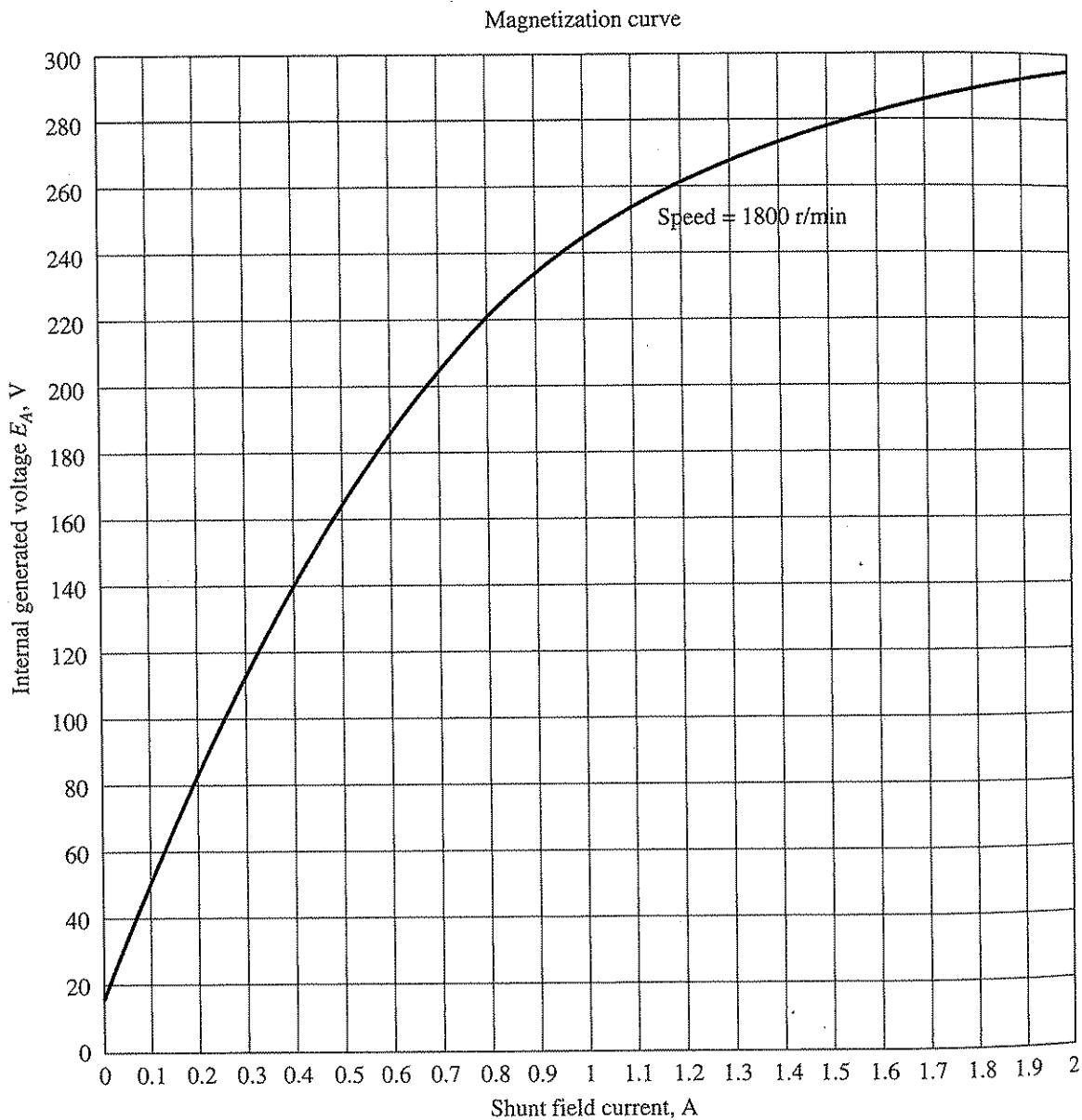
PROBLEMS

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

$$P_{rated} = 30 \text{ hp} \qquad\qquad I_{L,rated} = 110 \text{ A}$$

$$V_T = 240 \text{ V} \qquad\qquad N_F = 2700 \text{ turns per pole}$$

$$n_{rated} = 1800 \text{ r/min} \qquad N_{SE} = 14 \text{ turns per pole}$$

$$R_A = 0.19 \ \Omega \qquad\qquad R_F = 75 \ \Omega$$

$$R_S = 0.02 \ \Omega \qquad\qquad R_{adj} = 100 \text{ to } 400 \ \Omega$$

Rotational losses = 3550 W at full load.

Magnetization curve is as shown in Figure P8–1.

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

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

8–2. Assuming no armature reaction, what is the speed of the motor at full load? What is the speed regulation of the motor?

8–3. If the motor is operating at full load and if its variable resistance R_{adj} is increased to 250 Ω, what is the new speed of the motor? Compare the full-load speed of the motor with $R_{adj} = 175 \ \Omega$ to the full-load speed with $R_{adj} = 250 \ \Omega$. (Assume no armature reaction, as in the previous problem.)

8–4. Assume that the motor is operating at full load and that the variable resistor R_{adj} is again 175 Ω. If the armature reaction is 2000 A • turns at full load, what is the speed of the motor? How does it compare to the result for Problem 8–2?

8–5. If R_{adj} can be adjusted from 100 to 400 Ω, what are the maximum and minimum no-load speeds possible with this motor?

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?

Magnetization curve

FIGURE P8–1
The magnetization curve for the dc motor in Problems 8–1 to 8–12. This curve was made at a constant speed of 1800 r/min.

**8–7.** Plot the torque–speed characteristic of this motor assuming no armature reaction, and again assuming a full-load armature reaction of 1200 A • turns. (Assume that the armature reaction increases linearly with increases in armature current.)

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.

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

8–9. For the separately excited motor of Problem 8–8:
   (a) What is the maximum no-load speed attainable by varying both V_A and R_{adj}?
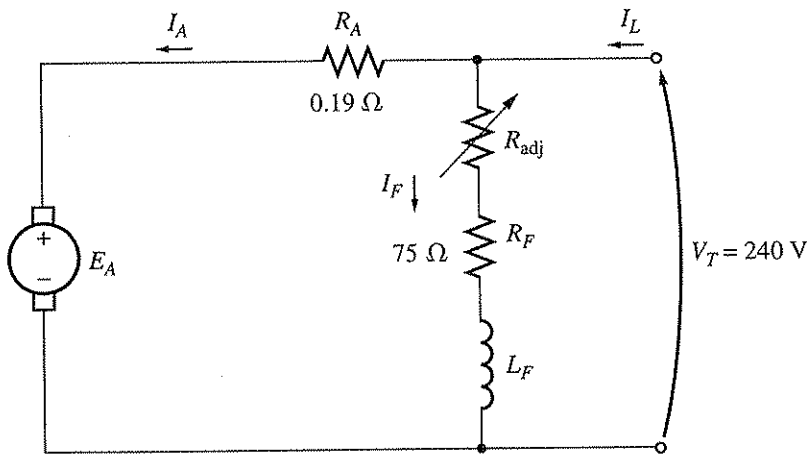
FIGURE P8–2
The equivalent circuit of the shunt motor in Problems 8–1 to 8–7.
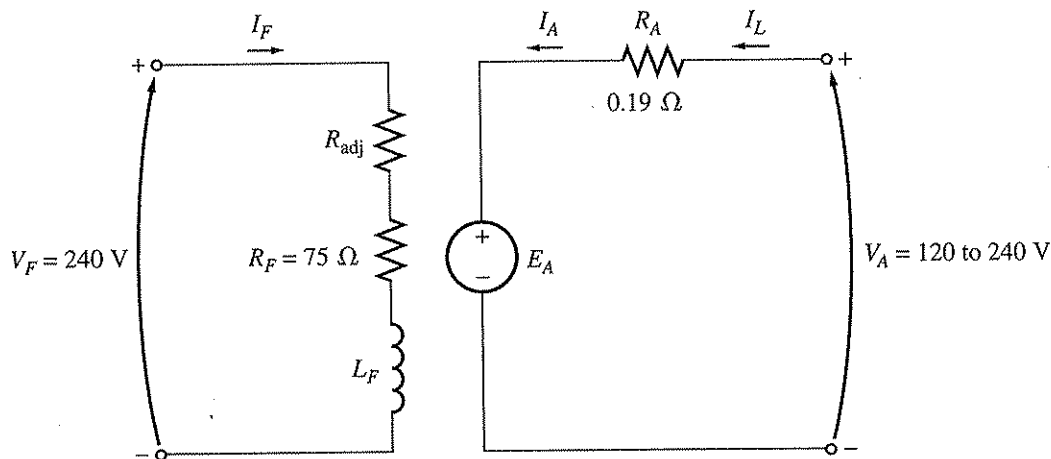
FIGURE P8–3
The equivalent circuit of the separately excited motor in Problems 8–8 and 8–9.

(b) What is the minimum no-load speed attainable by varying both V_A and R_{adj}?

(c) What is the motor's efficiency at rated conditions? [*Note:* Assume that (1) the brush voltage drop is 2 V; (2) the core loss is to be determined at an armature voltage equal to the armature voltage under full load; and (3) stray load losses are 1 percent of full load.]

For Problems 8–10 to 8–11, the motor is connected cumulatively compounded as shown in Figure P8–4

8–10. If the motor is connected cumulatively compounded with $R_{adj} = 175 \ \Omega$:

(a) What is its no-load speed of the motor?

(b) What is its full-load speed of the motor?

(c) What is its speed regulation?

(d) Calculate and plot the torque–speed characteristic for this motor. (Neglect armature effects in this problem.)

This motor has compensating windings and interpoles. The magnetization curve for this motor at 3000 r/min is shown in Figure P8–6.

8–16. The motor described above is connected in *shunt.*
   (a) What is the no-load speed of this motor when $R_{adj} = 120\ \Omega$?
   (b) What is its full-load speed?
   (c) What is its speed regulation?
   (d) Plot the torque–speed characteristic for this motor.
   (e) Under no-load conditions, what range of possible speeds can be achieved by adjusting R_{adj}?

8–17. This machine is now connected as a cumulatively compounded dc motor with $R_{adj} = 120\ \Omega$.
   (a) What is the no-load speed of this motor?
   (b) What is its full-load speed?
   (c) What is its speed regulation?
   (d) Plot the torque–speed characteristic for this motor.

8–18. The motor is reconnected differentially compounded with $R_{adj} = 120\ \Omega$. Derive the shape of its torque–speed characteristic.

8–19. A series motor is now constructed from this machine by leaving the shunt field out entirely. Derive the torque–speed characteristic of the resulting motor.

8–20. An automatic starter circuit is to be designed for a shunt motor rated at 20 hp, 240 V, and 75 A. The armature resistance of the motor is 0.12 Ω, and the shunt field resistance is 40 Ω. The motor is to start with no more than 250 percent of its rated armature current, and as soon as the current falls to rated value, a starting resistor stage is to be cut out. How many stages of starting resistance are needed, and how big should each one be?

8–21. A 10-hp, 120-V, 1000 r/min shunt dc motor has a full-load armature current of 70 A when operating at rated conditions. The armature resistance of the motor is $R_A = 0.12\ \Omega$, and the field resistance R_F is 40 Ω. The adjustable resistance in the field circuit R_{adj} may be varied over the range from 0 to 200 Ω and is currently set to 100 Ω. Armature reaction may be ignored in this machine. The magnetization curve for this motor, taken at a speed of 1000 r/min, is given in the following table:

E_A, V	5	78	95	112	118	126
I_F, A	0.00	0.80	1.00	1.28	1.44	2.88

   (a) What is the speed of this motor when it is running at the rated conditions specified above?
   (b) The output power from the motor is 10 hp at rated conditions. What is the output torque of the motor?
   (c) What are the copper losses and rotational losses in the motor at full load (ignore stray losses)?
   (d) What is the efficiency of the motor at full load?
   (e) If the motor is now unloaded with no changes in terminal voltage or R_{adj}, what is the no-load speed of the motor?
   (f) Suppose that the motor is running at the no-load conditions described in part (e). What would happen to the motor if its field circuit were to open? Ignoring armature reaction, what would the final steady-state speed of the motor be under those conditions?
   (g) What range of no-load speeds is possible in this motor, given the range of field resistance adjustments available with R_{adj}?
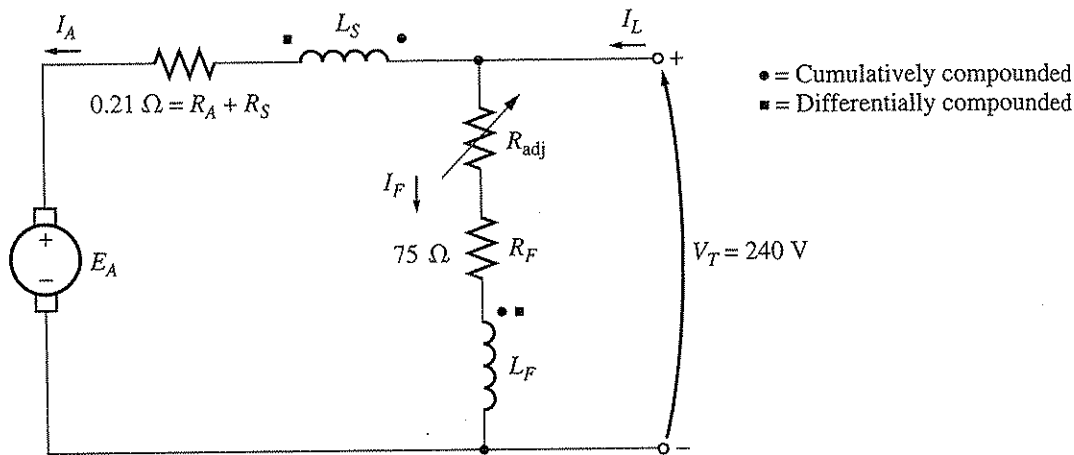
FIGURE P8-4
The equivalent circuit of the compounded motor in Problems 8-10 to 8-12.

8-11. The motor is connected cumulatively compounded and is operating at full load. What will the new speed of the motor be if R_{adj} is increased to 250 Ω? How does the new speed compare to the full-load speed calculated in Problem 8-10?

For Problem 8-12, the motor is now connected differentially compounded as shown in Figure P8-4.

8-12. The motor is now connected differentially compounded.
   (a) If $R_{adj} = 175 \ \Omega$, what is the no-load speed of the motor?
   (b) What is the motor's speed when the armature current reaches 20 A? 40 A? 60 A?
   (c) Calculate and plot the torque-speed characteristic curve of this motor.

8-13. A 15-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 115 A, and the rated speed is 1050 r/min. Its magnetization curve is shown in Figure P8-5. The core losses are 420 W, and the mechanical losses are 460 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 70 A?
   (c) Plot the torque-speed characteristic for this motor.

8-14. A 20-hp, 240-V, 76-A, 900 r/min series motor has a field winding of 33 turns per pole. Its armature resistance is 0.09 Ω, and its field resistance is 0.06 Ω. The magnetization curve expressed in terms of magnetomotive force versus E_A at 900 r/min is given by the following table:

E_A, V	95	150	188	212	229	243
$\mathscr{F}$, A • turns	500	1000	1500	2000	2500	3000

Armature reaction is negligible in this machine.
   (a) Compute the motor's torque, speed, and output power at 33, 67, 100, and 133 percent of full-load armature current. (Neglect rotational losses.)
   (b) Plot the terminal characteristic of this machine.