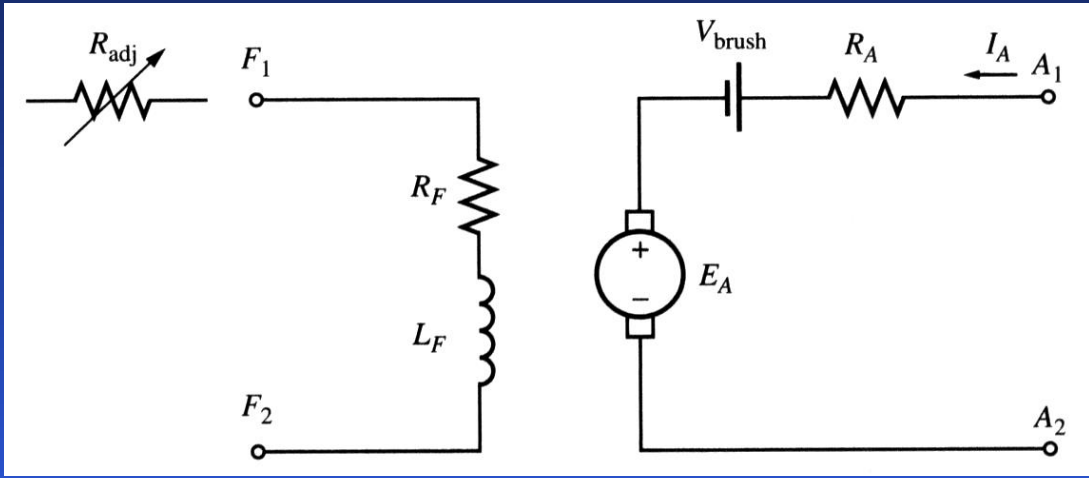
# Chapter 9

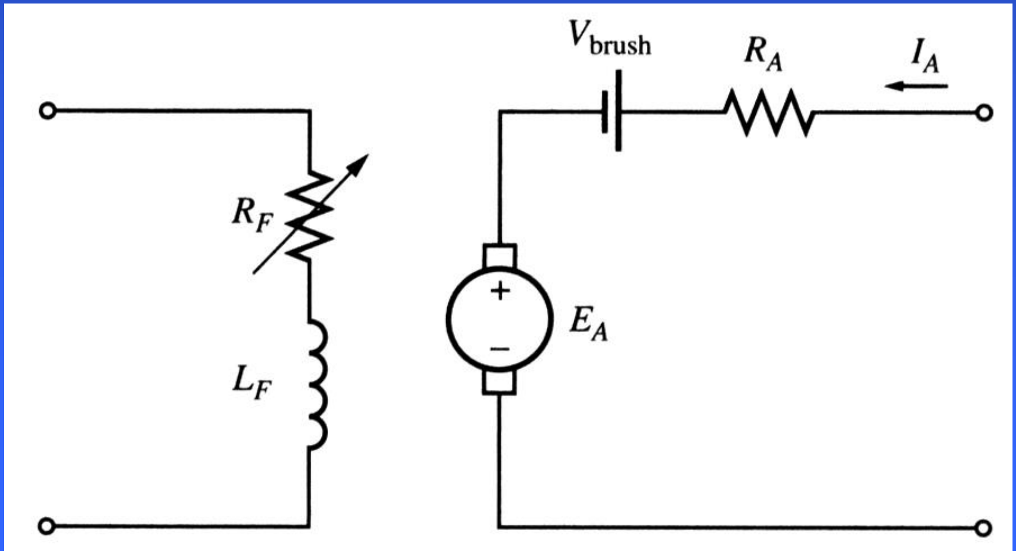
# Motors and Generators

# Equivalent circuit of a DC motor

The armature circuit (the entire rotor structure) is represented by an ideal voltage source $E_A$ and a resistor $R_A$. A battery $V_{brush}$ in the opposite to a current flow in the machine direction indicates brush voltage drop.

The field coils producing the magnetic flux are represented by inductor $L_F$ and resistor $R_F$. The resistor $R_{adj}$ represents an external variable resistor (sometimes lumped together with the field coil resistance) used to control the amount of current in the field circuit.



# Equivalent circuit of a DC motor

Sometimes, when the brush drop voltage is small, it may be left out. Also, some DC motors have more than one field coil…

The internal generated voltage in the machine is

$$E_A = K\phi\omega \qquad (5.43.1)$$

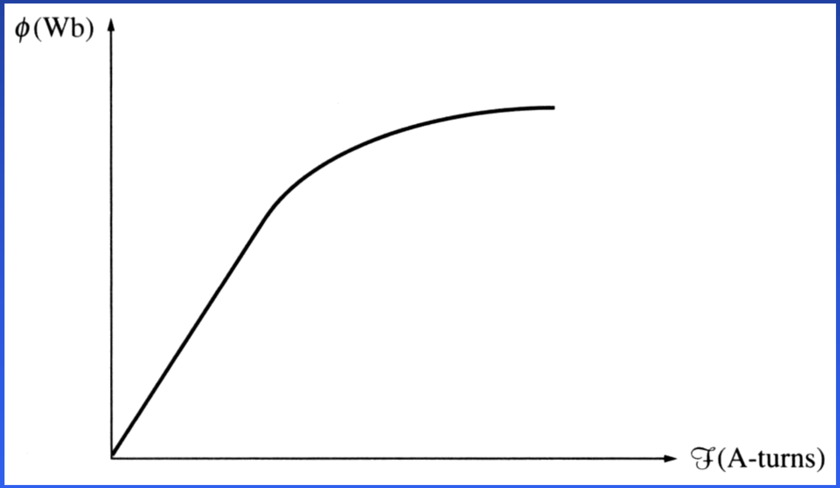
The induced torque developed by the machine is

$$\tau_{ind} = K\phi I_A \qquad (5.43.2)$$

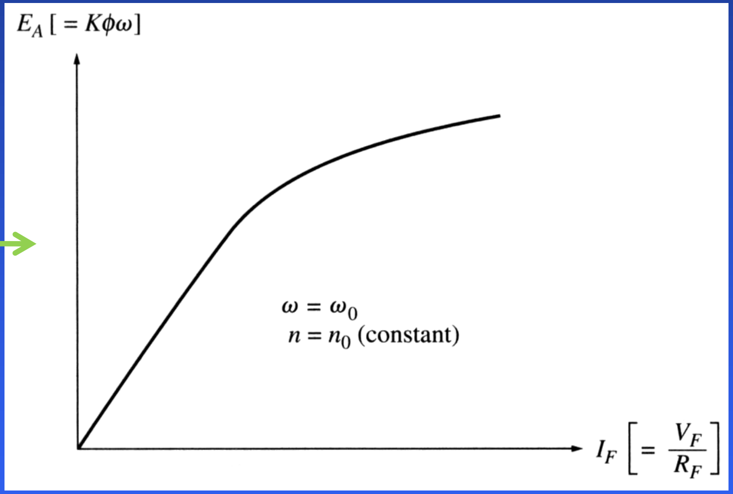
Here $K$ is the constant depending on the design of a particular DC machine (number and commutation of rotor coils, etc.) and $\phi$ is the total flux inside the machine.

# Magnetization curve of a DC machine

The internal generated voltage $E_A$ is directly proportional to the flux in the machine and the speed of its rotation.
The field current in a DC machine produces a field mmf ☞ $= N_F I_F$, which produces a flux in the machine according to the magnetization curve.

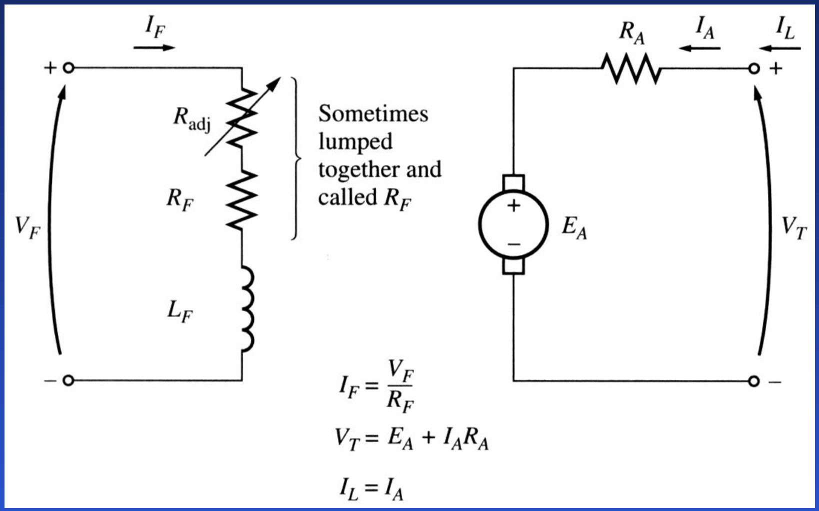



or in terms of internal voltage vs. field current for a given speed.

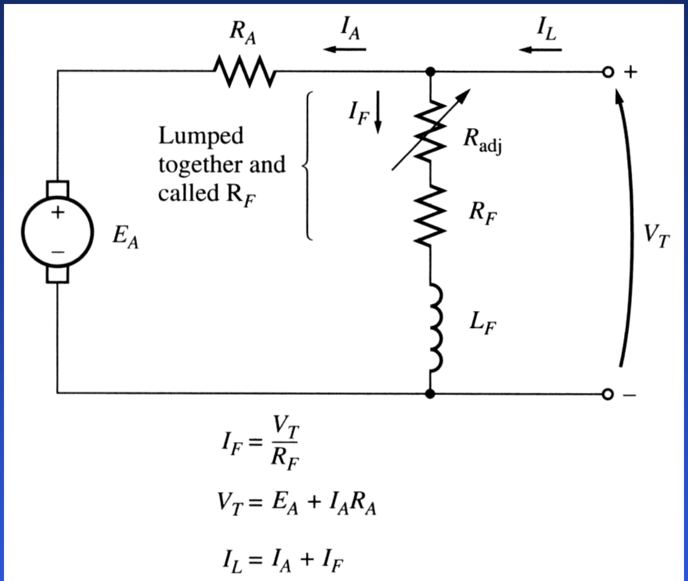



To get the maximum possible power per weight out of the machine, most motors and generators are operating near the saturation point on the magnetization curve. Therefore, when operating at full load, often a large increase in current $I_F$ may be needed for small increases in the generated voltage $E_A$.

# Motor types: Separately excited and Shunt DC motors




Note: when the voltage to the field circuit is assumed constant, there is no difference between them…




**Separately excited DC motor**: a field circuit is supplied from a separate constant voltage power source.

**Shunt DC motor**: a field circuit gets its power from the armature terminals of the motor.

For the armature circuit of these motors:

$$V_T = E_A + I_A R_A \quad (5.45.1)$$

# Shunt motor: terminal characteristic

A terminal characteristic of a machine is a plot of the machine's output quantities vs. each other.

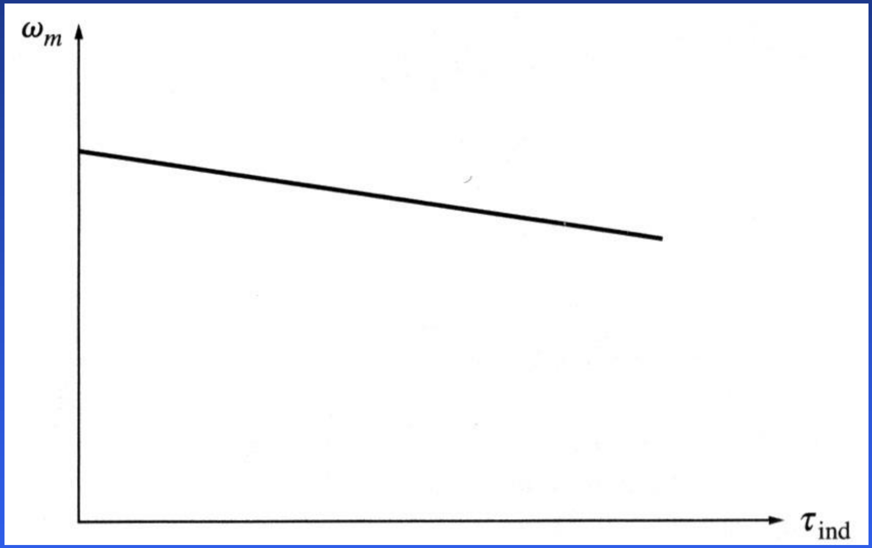
For a motor, the output quantities are shaft torque and speed. Therefore, the terminal characteristic of a motor is its output torque vs. speed.

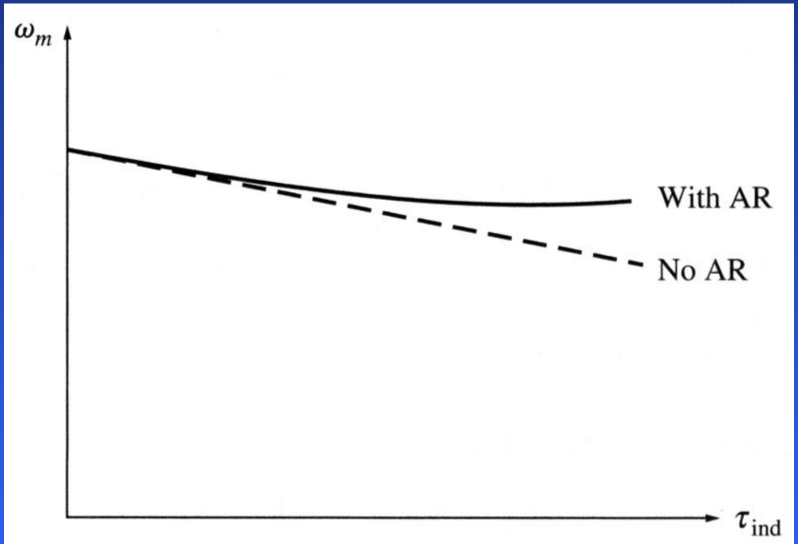
If the load on the shaft increases, the load torque $\tau_{load}$ will exceed the induced torque $\tau_{ind}$, and the motor will slow down. Slowing down the motor will decrease its internal generated voltage (since $E_A = K\phi\omega$), so the armature current increases ($I_A = (V_T - E_A)/R_A$). As the armature current increases, the induced torque in the motor increases (since $\tau_{ind} = K\phi I_A$), and the induced torque will equal the load torque at a lower speed $\omega$.

$$\omega = \frac{V_T}{K\phi} - \frac{R_A}{\left(K\phi\right)^2}\tau_{ind} \qquad (5.46.1)$$

# Shunt motor: terminal characteristic

Assuming that the terminal voltage and other terms are constant, the motor's speed vary linearly with torque.




However, if a motor has an armature reaction, flux-weakening reduces the flux when torque increases. Therefore, the motor's speed will increase. If a shunt (or separately excited) motor has compensating windings, and the motor's speed and armature current are known for any value of load, it's possible to calculate the speed for any other value of load.