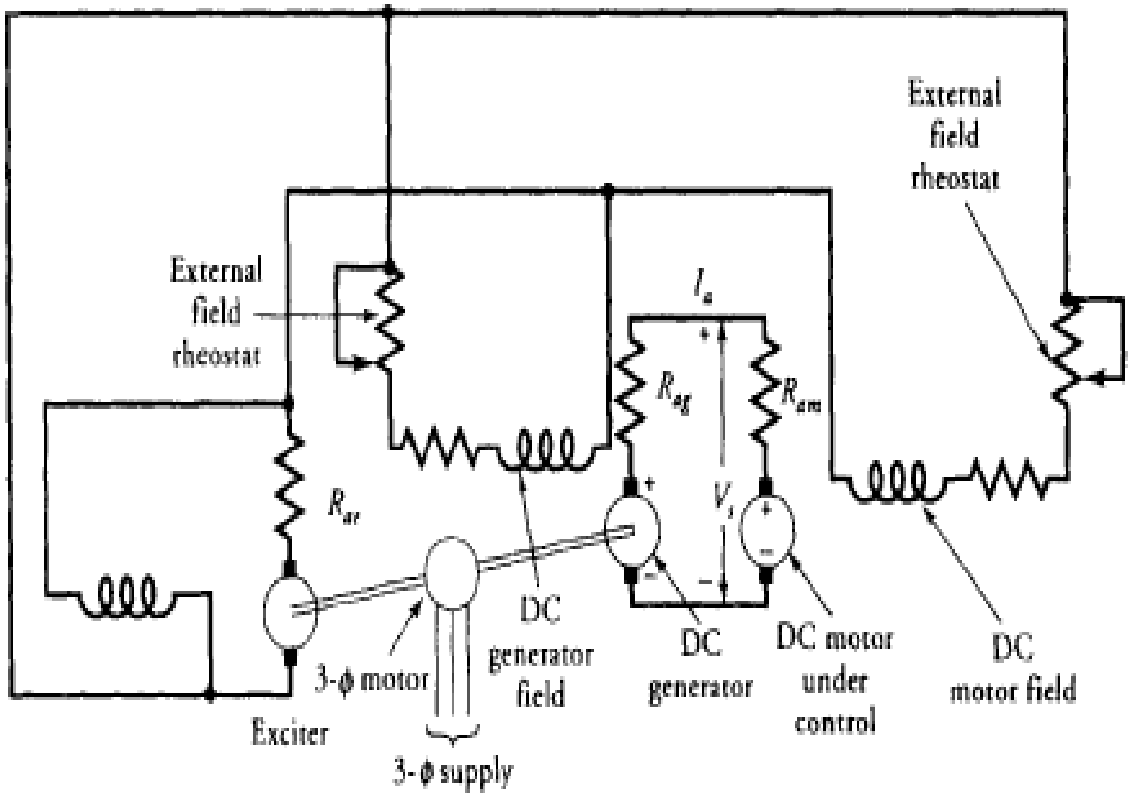
Electrical Machines I

Week 13: Ward Leonard Speed Control and DC Motor Braking

The Ward-Leonard speed controller

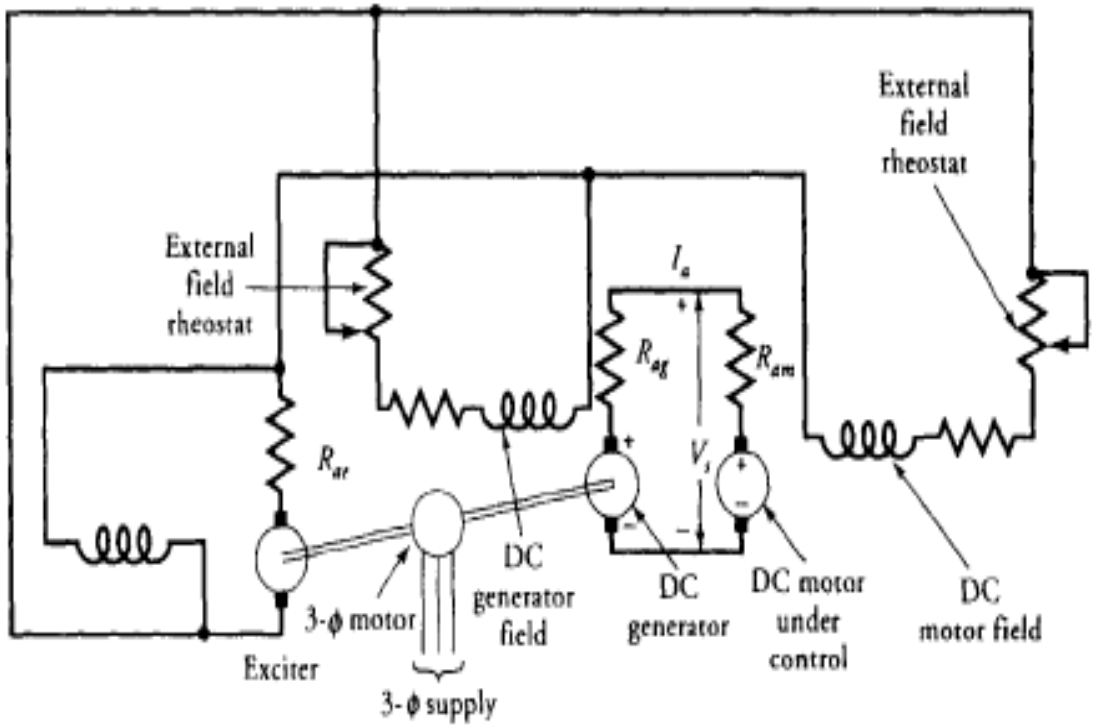
- The figure shows an ac motor serving as a prime mover for a dc generator, which in turn is used to supply a dc voltage to a dc motor by changing the field resistance.
- This system is called Ward-Leonard system.
- To control the speed of a dc motor, this system requires **two generators and an ac motor**.



- The three-phase ac motor acts as a prime mover that drives both generators. One generator, called the exciter, provides a constant voltage that is impressed upon the field windings of the other separately excited generator and the separately excited motor under control as shown.

The Ward-Leonard speed controller

- The armature winding of the motor is permanently connected to the armature terminals of the other generator, whose voltage can be varied by varying its field current. The variable armature voltage provides the means by which the motor speed can be controlled.
- It must be obvious that we need a set of **three** machines to control the speed of a dc motor. The system is expensive but is used where an unusually wide and very sensitive speed control is desired.



DC Motor Braking:

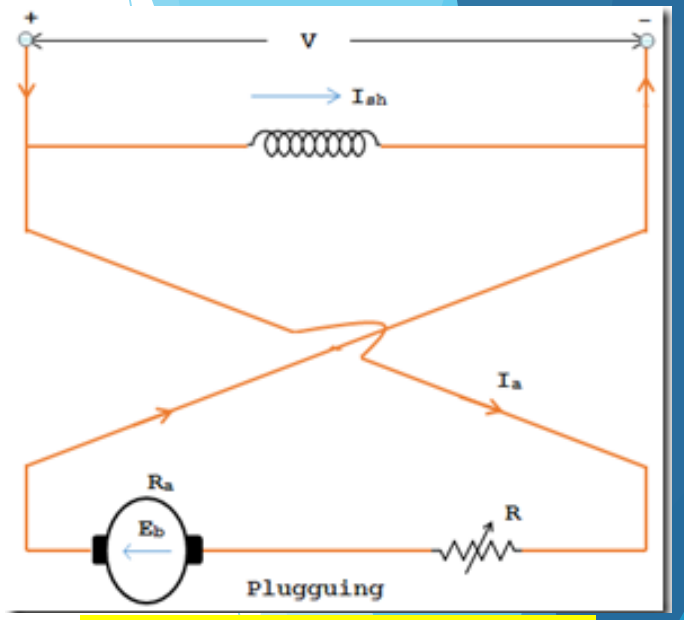
- In certain applications, it may be necessary to **either stop the motor quickly or reverse its direction of rotation**.
- The motor may be stopped by using **frictional braking**. The drawbacks of frictional braking are that the operation is:
  - difficult to control,
  - dependent upon the braking surface, and
  - far from being smooth.
- The three commonly employed methods are
  1) **Plugging,**
  2) **Rheostatic or dynamic braking, and**
  3) **Regenerative braking.**

Prony brake system

DC Motor Braking: Plugging or Counter Current Braking

Stopping and/or reversing the direction of a dc motor by reversing the supply connections to the armature terminals is known as plugging.

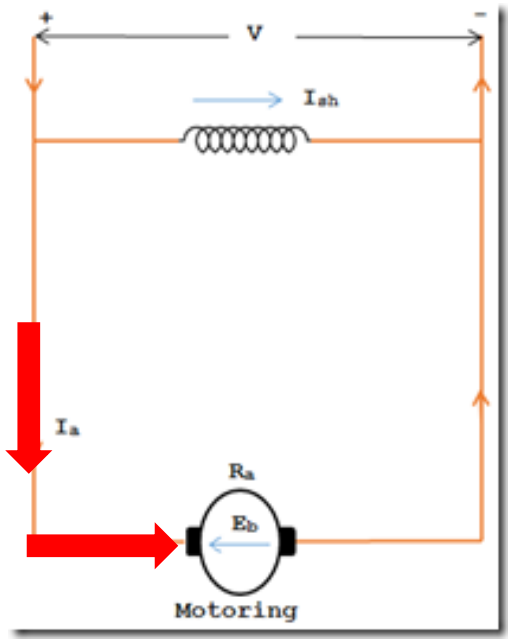
- **The field-winding connections for shunt motors are left undisturbed.**
- This method is employed to control the dc motors used in **elevators, rolling mills, printing presses, and machine tools.**
- Just prior to plugging, the back emf in the motor is opposing the applied source voltage. Because the armature resistance is usually very small, the back emf is almost equal and opposite to the applied voltage.
- At plugging, **the back emf and the applied voltage are in the same direction**. Thus, the total voltage in the armature circuit is almost twice as much as the applied voltage. To protect the motor from a sudden increase in the armature current, an external resistance must be added in series with the armature circuit. The circuit connections, in their simplest forms, for shunt and series motors are given later.



Plugging action:

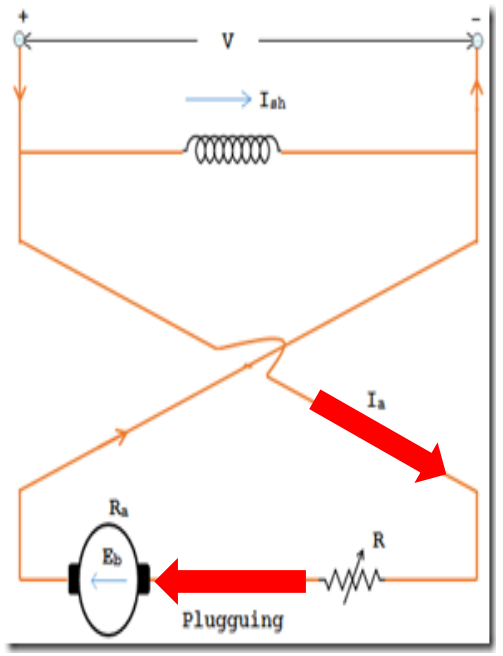
$$V_t = -E_a + I_a R_a$$

DC Motor Braking: Plugging or Counter Current Braking



Motor action:

$$V_t = E_a + I_a R_a$$



Plugging action:

$$V_t = -E_a + I_a R_a$$

This means that the armature current will reverse its direction

DC Motor Braking: Plugging

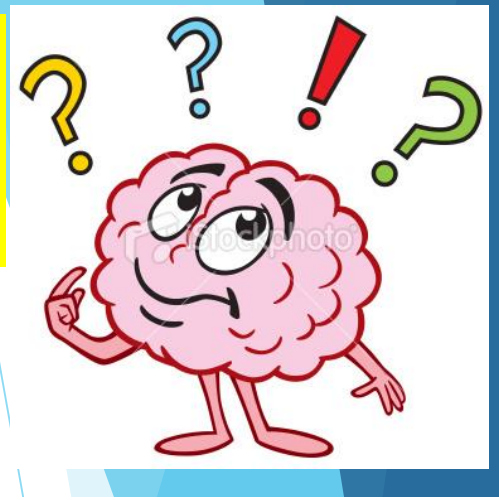
- This means that the armature current will reverse its direction
- As the current in the armature winding reverses direction, it produces a force that tends to rotate the armature in a direction opposite to its initial rotation. This causes the motor to slow down, stop, and then pick up speed in the opposite direction.
- Plugging, allows us to **reverse the direction of rotation of a motor**. This technique can also be **used to brake the motor by simply disconnecting the power from the motor when it comes to rest**. **As** a further safeguard, mechanical brakes can also be applied when the motor is coming to rest.

DC Motor Braking: Plugging

$$I_a = \frac{V_s + E_a}{R + (R_a + R_f)} = \frac{V_s}{R + (R_a + R_f)} + \frac{E_a}{R + (R_a + R_f)}$$

$$= \frac{V_s}{R+(R_a+R_f)} + \frac{K_a \varphi \omega}{R+(R_a+R_f)}$$

R is the extra added resistance

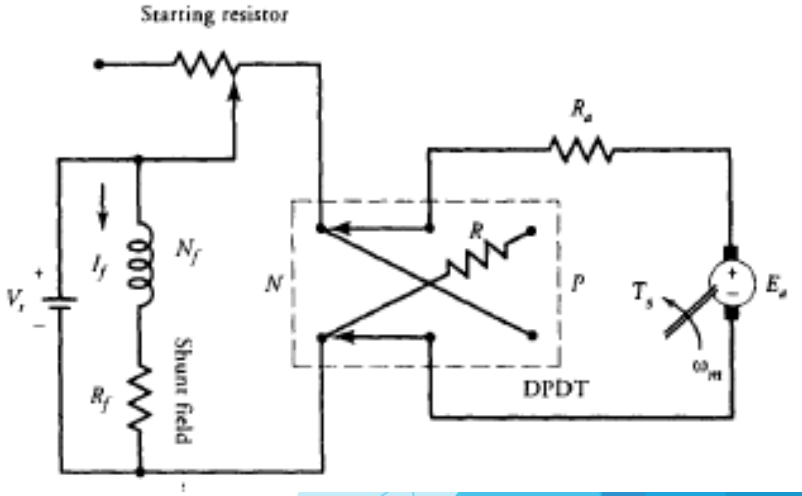


Thus, the braking torque is

$$T_b = K_a I_a \varphi = K_a \varphi \frac{V_s}{R + (R_a+R_f)} + K_a \varphi \frac{K_a \varphi \omega}{R + (R_a+R_f)}$$

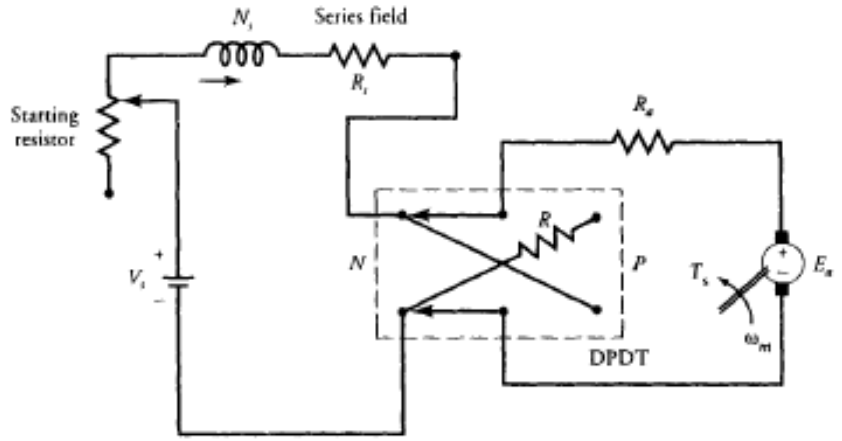
$$= K_1 \varphi + K_2 \varphi^2 \omega$$

Where : $K_1 = \frac{K_a V_s}{R+(R_a+R_f)}, K_2 = \frac{K_a^2}{R+(R_a+R_f)}$



Shunt motor

DC Motor Braking: Plugging



Series motor

- For the series motor, the flux also depends upon the armature current, which in turn depends upon the motor speed. Since the flux in a shunt motor is constant, the above equation, for a shunt motor, becomes

$$T_b = K_a I_a \varphi = K_a \varphi \frac{V_s}{R + (R_a + R_f)} + K_a \varphi \frac{K_a \varphi \omega}{R + (R_a + R_f)}$$

$$= \boxed{K_1 \varphi} + \boxed{K_2 \varphi^2} \omega$$

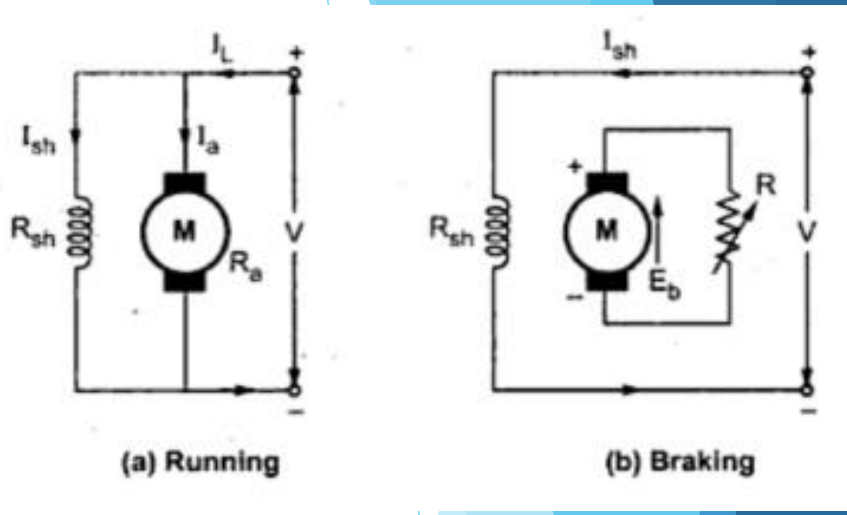
constants

$$T_b = K_3 + K_4 \omega \qquad K_3 = K_1 \varphi \; and \; K_4 = K_2 \varphi^2$$

- From the above equation, it is obvious that even when a shunt motor is reaching zero speed, there is some braking torque, $T_b = K_3$. If the supply voltage is not disconnected at the instant the motor reaches zero speed, it will accelerate in the reverse direction.

DC Motor Braking: Rheostat or Dynamic Braking

- If the armature winding of a dc motor is suddenly disconnected from the source, the motor will coast to a stop. The time taken by the motor to come to rest depends upon the kinetic energy stored in the rotating system.
- If the armature winding, after being disconnected from the source, is connected across a variable resistance *R*, the back emf will produce a current in the reverse direction. This current will result in a torque that opposes the rotation and forces the motor to come to a halt.
- The dynamic braking effect is controlled by varying *R*.
- At the time of dynamic braking, *R* is selected to limit the inrush of armature current to about 150% of its rated value. As the motor speed falls, so does the induced emf and the current through R. Thus, the dynamic braking action is maximum at first and diminishes to zero as the motor comes to a stop.



Notice the armature current direction in motor and brake action

DC Motor Braking: Rheostat or Dynamic Braking

At any time during the dynamic braking process, the armature current is:

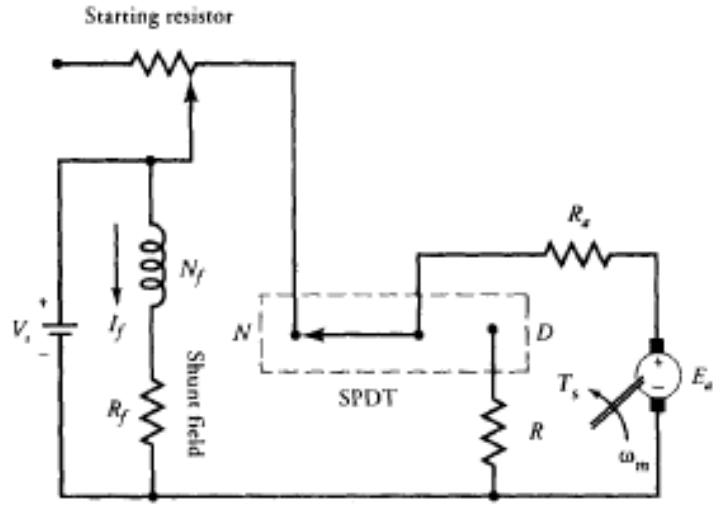
$$I_a = \frac{E_a}{R + (R_a + R_f)} = \frac{K_a \varphi \omega}{R + (R_a + R_f)}$$

and the braking torque is: (notice that supply voltage at braking is zero here)

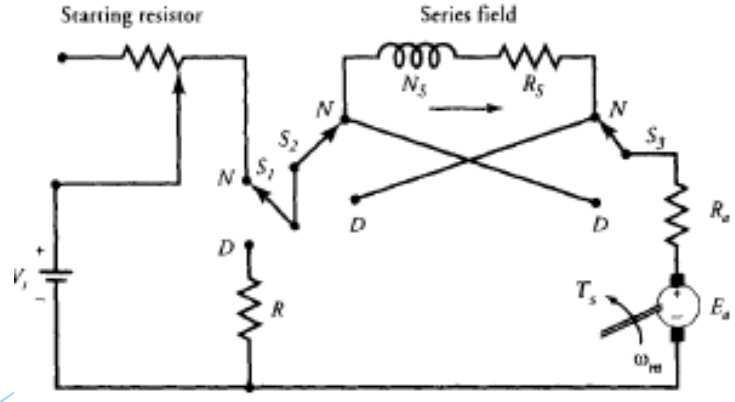
$$T_b = K_a I_a \varphi = \frac{K_a^2 \varphi^2 \omega}{R + (R_a + R_f)} = K_2 \, \varphi^2 \omega$$

Since the flux in a series motor is proportional to the armature current, $\varphi = k_f I_a$, the braking torque for a series motor becomes

$$T_{sb} = K_2 \, k_f^2 I_a^2 \omega$$



Shunt motor



Series motor

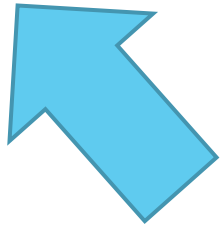
DC Motor Braking: Rheostat or Dynamic Braking

On the other hand, the braking torque for a shunt motor is:

$$T_b = K_4\omega$$

and the it is evident that the braking torque vanishes as the motor speed approaches zero

The electrical energy produced by the motors is dissipated as heat. Large cooling fans are necessary to protect the resistors from damage. Modern systems have thermal monitoring and when the temperature of the bank becomes excessive

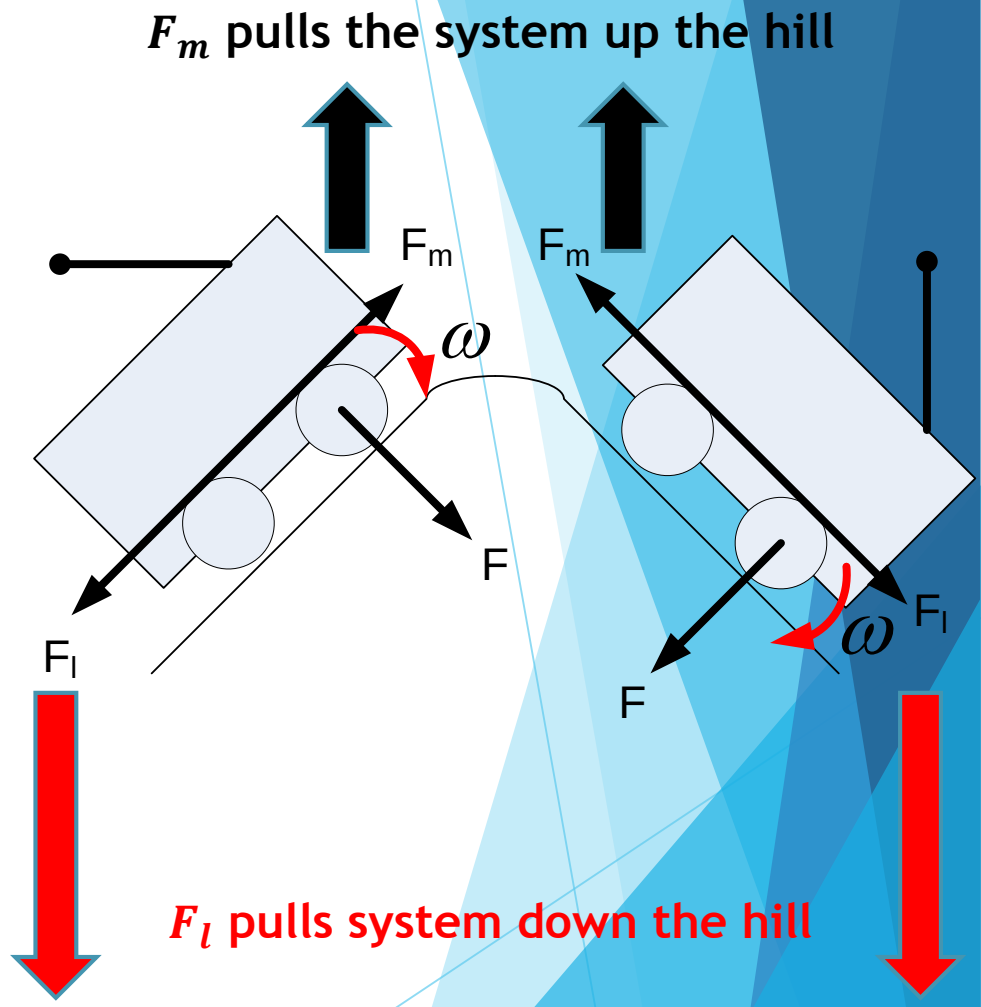


Unlike when we used the plugging technique

DC Motor Braking: Regenerative Braking

- Regenerative braking is used in applications in which the motor speed is likely to increase from its rated value.
- Such applications include electric trains, elevators, cranes, and hoists. Under normal operation of a dc motor, say a permanent-magnet (PM) motor in an electric train, the back emf is slightly less than the applied voltage.

Motor speed is unidirectional but in this example the system torques are bidirectional



F_m pulls the system up the hill
F_l pulls system down the hill
F producing a friction force

DC Motor Braking: Regenerative Braking

here the motor works as generator and the supply itself is given power from the load

- When the train is going downhill, as the motor speed increases, so does the back emf in the motor.
- If the back emf becomes higher than the applied voltage, the current in the armature winding reverses its direction and the motor becomes a generator. It sends power back to the source and/or other devices operating from the same source.
- The reversal of armature current produces a torque in a direction opposite to the motor speed. Consequently, the motor speed falls until the back emf in the motor is less than the applied voltage. The regenerative action not only controls the speed of the motor but also develops power that may be used elsewhere.
- Regeneration is used in applications such as battery charging and electric cars and trains

Questions:

- What is meant by Ward Leonard method of speed control.
- State the types of braking techniques in DC motors. State the main differences of each technique
- What is meant by regeneration action? State applications that uses regeneration action