5.4 REGENERATIVE BRAKING OF DC MOTOR

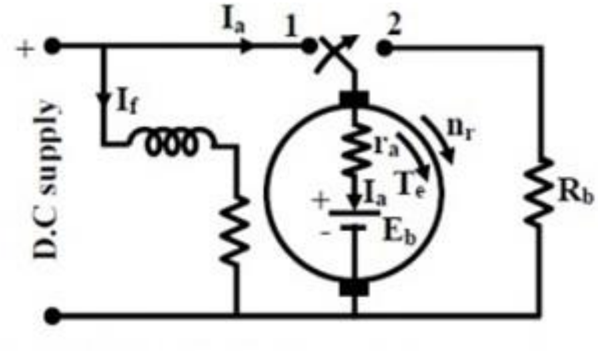

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Figure 5.4.1 Machine act as Motor

[Source: "'Electric Machinery Fundamentals" by Stephen J. Chapman, *Page: 389]*

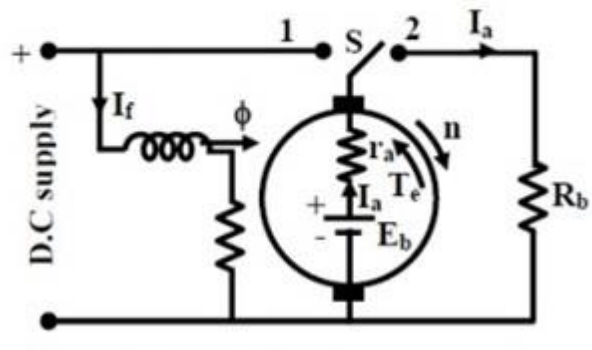


Figure 5.4.2 Machine act as Generator during Regenerative Braking

[Source: "'Electric Machinery Fundamentals" by Stephen J. Chapman, *Page: 389]*

Regenerative braking takes place whenever the speed of the motor exceeds the synchronous speed. This baking method is called regenerative baking because here the motor works as generator and supply itself is given power from the load, i.e. motors. The main criteria for regenerative braking is that the rotor has to rotate at a speed higher than synchronous speed, only then the motor will act as a generator and the direction of current flow through the circuit and direction of the torque reverses and braking takes place. The only disadvantage of this type of braking is that the motor has to run at super synchronous speed which may damage the motor mechanically and electrically, but regenerative braking can be done at sub synchronous speed if the variable frequency source is available.

Under this condition, the back emf E_b of the motor is greater than the supply voltage V, which reverses the direction of motor armature current. The machine now begins to operate as a generator and the energy generated is supplied to the source.

Regenerative braking can also be performed at very low speeds if the motor is connected as a separately excited generator. The excitation of the motor is increased as the speed is reduced so that the two equations shown below are satisfied.

$$E_b = \frac{nP\varphi Z}{A} \quad \text{and} \quad V = E_b - I_a R_a$$

The motor does not enter into saturation on increasing excitation.

Regenerative braking is possible with the shunt and separately excited motors. In compound motors, braking is possible only with weak series compounding.

Regenerative Braking in DC Shunt Motors

Under normal operating conditions the armature current is given by the equation shown below:

$$-I_a = \frac{V - E_b}{R_a}$$

When the load is lowered by a crane, hoist or lift causes the motor speed to be greater than the no-load speed, the back EMF becomes greater than the supply voltage. Consequently, armature current Ia becomes negative. The machines now begins to operate as a generator.

Regenerative Braking in DC Series Motors

In the case of DC Series Motor an increase in speed is followed by a decrease in the armature current and field flux. The back EMF Eb cannot be greater than the supply voltage. Regeneration is possible in DC Series Motor since the field current cannot be made greater than the armature current.

Regeneration is required where DC Series Motor is used extensively such as in traction, elevator hoists etc. For example – In an electro-locomotive moving down the gradient, a constant speed may be necessary. In hoist drives, the speed is to be limited whenever it becomes dangerously high.One commonly used method of regenerative braking of DC Series Motor is to connect it as a shunt motor. Since the resistance of the field winding is low, a series resistance is connected in the field circuit to limit the current within the safe value.

Applications of Regenerative Braking

- Regenerative braking is used especially where frequent braking and slowing of drives is required.
- It is most useful in holding a descending load of high potential energy at a constant speed.
- Regenerative braking is used to control the speed of motors driving loads such as in electric locomotives, elevators, cranes and hoists.
- Regenerative braking cannot be used for stopping the motor. It is used for controlling the speed above the no-load speed of the motor driving.

Plugging Type Braking or Counter Current Braking

In a dc motor a reversed torque is obtained by reversing the current either in the armature or in the field (not both), Polarity reversal of field winding is rarely used because it results in longer braking time due to relatively large inductance of the field winding in comparison to that can be obtained by polarity reversal of armature winding.

The connections for dc series and shunt motors during normal running and braking conditions are shown in Figs. In case of a dc series motor it should be ensured that the direction of flow of current in the field winding remains unchanged when the current flow in the armature winding is reversed.

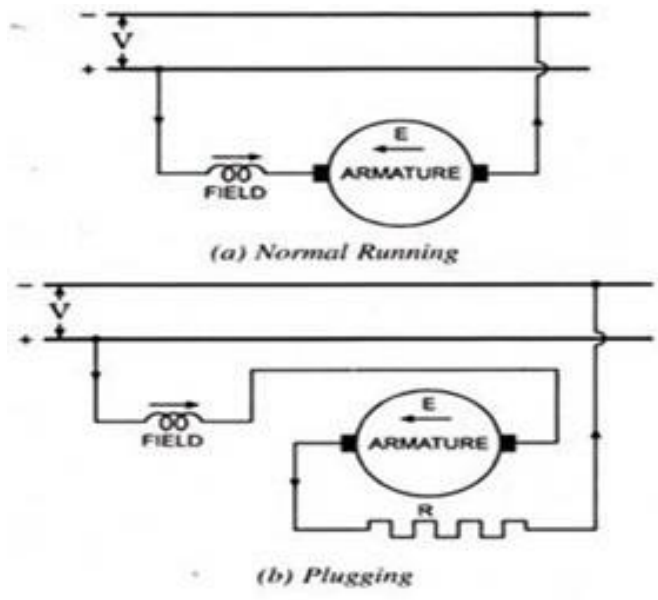


Figure 5.4.3 Normal Running and Plugging of DC Series Motor

[Source: "'Electric Machinery Fundamentals" by Stephen J. Chapman*, Page: 393]*

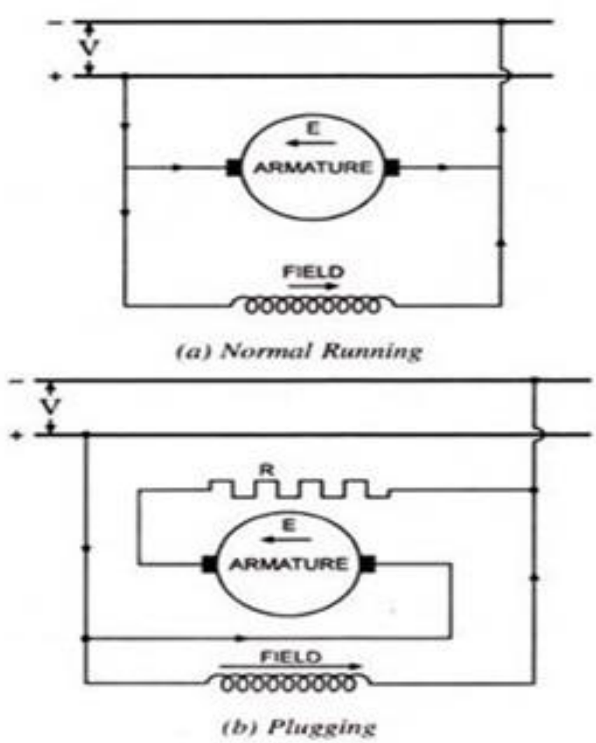


Figure 5.4.3 Normal Running and Plugging of DC Shunt Motor

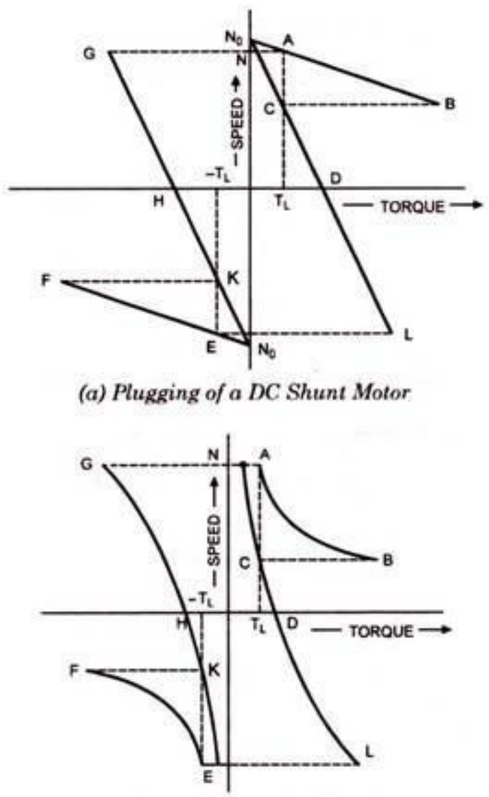
[Source: "'Electric Machinery Fundamentals" by Stephen J. Chapman*, Page: 393]*

In the normal running position the back emf is nearly equal to applied voltage and opposite in direction, so that a small voltage acts across the armature circuit to drive the normal current through a small resistance of the motor. In the plugging position, the induced emf acts in the direction of applied voltage, therefore, at the instant of switching the motor to the plugging position, twice of supply voltage acts across the machine circuit and heavy current would flow (about twice the current drawn by the stationary motor on normal rated voltage). Hence to avoid flow of heavy current and limit it to the safer value, it is necessary that switching performing the plugging operation may also re-insert starting resistance and some additional resistance in series with the armature circuit of the motor.

Figures explain the plugging operation of the dc shunt and series motors respectively on a quadrant diagram.

AB and EF represent the speed-torque characteristics of the motor in normal and reverse direction of rotation without any external resistance, while CL and KG represent the same with external resistances respectively. A is the initial operating point with load, speed N and load torque T_L and the external resistance zero.

When plugging is resorted, the motor continues to run in the normal direction but develops torque in reverse direction and point G is the operating point (on characteristic KHG, as resistance is inserted here). The speed falls till it reaches point H (zero) and at this stage supply should be switched off, failing which the motor attains speed in reverse direction under motoring action and operates at point E on switching out external resistance.



(a) Plugging of a DC Shunt Motor

(b) Plugging of a DC Series Motor

Figure 5.4.4 Quadrant Diagram

[Source: "'Electric Machinery Fundamentals" by Stephen J. Chapman, *Page: 396]*

Dynamic Braking of DC Motor

If an electric motor is simply detached from the power supply, then it will stop but for large motors, it will take a longer time due to high rotating inertia because the energy which is stored has to dissolve throughout bearing & wind friction. The condition can be enhanced by pushing the motor to function as a generator through braking; a torque opposite to the path of rotation will be forced on the shaft, thus helping the device to come to discontinue rapidly. Throughout the braking action, the early KE which is stored within the rotor is either dissolute in an exterior resistance otherwise fed back to the power supply.

In this kind of braking, the dc shunt motor is detached from the power supply & a braking resistor (Rb) is connected across the armature. So this motor will function as a generator to generate the braking torque.

Throughout this braking, once this motor functions as a generator, then K.E (kinetic energy) will store within the rotary parts of the DC motor. The load which is connected can be changed into electrical energy. This energy will dissipate like a heat within the braking resistance (Rb) & the resistance of the armature circuit (Ra). This kind of Braking is an ineffective method of braking because the energy which is generated will dissipate like heat within the resistances.

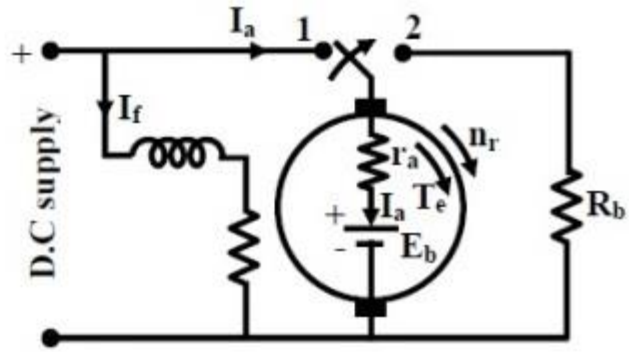


Figure 5.4.5(a) Dynamic Braking of DC motor

[Source: "'Electric Machinery Fundamentals" by Stephen J. Chapman*, Page: 397]*

In a common motoring method, switch 'S' is connected to two positions like 1& 1′. The supply voltage including polarity and external resistance (Rb) is connected across 2 & 2′ terminals. But, in motor mode, this circuit part remains stationary. To start braking, the switch is thrown in the direction of positions 2 & 2′ at t = 0, thus detaching the armature as of the supply of left hand. The armature current at t = 0+ will be Ia = (Eb + V)/(ra + Rb) because 'Eb' & the voltage supply from the right hand have preservative polarities through the good features of the connection.

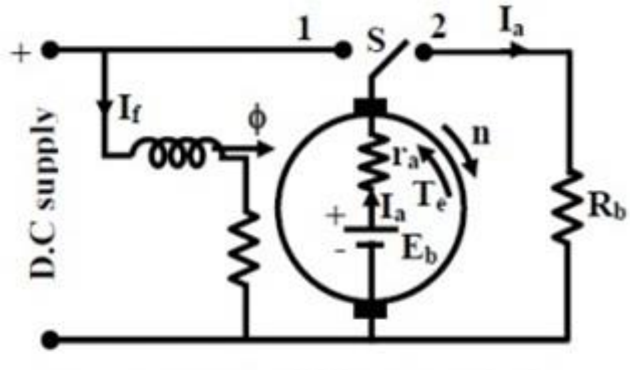


Figure 5.4.5(b) Dynamic Braking of DC motor

[Source: "'Electric Machinery Fundamentals" by Stephen J. Chapman, *Page: 397]*

In a common motoring method, switch 'S' is connected to two positions like 1& 1′. The supply voltage including polarity and external resistance (Rb) is connected across 2 & 2′ terminals. But, in motor mode, this circuit part remains stationary. To start braking, the switch is thrown in the direction of positions 2 & 2′ at t = 0, thus detaching the armature as of the supply of left hand. The armature current at t = 0+ will be Ia = (Eb + V)/(ra + Rb) because 'Eb' & the voltage supply from the right hand have preservative polarities through the good features of the connection.

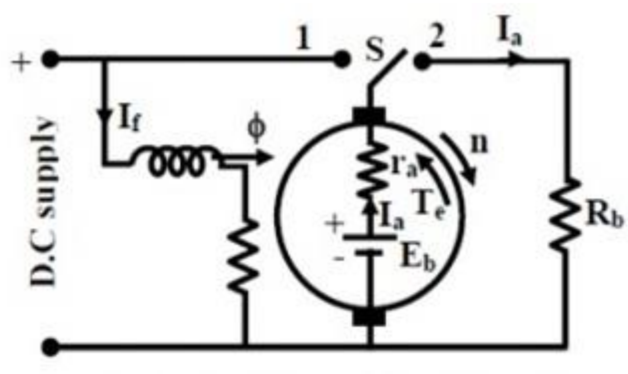


Figure 5.4.5(c) Dynamic Braking of DC motor

[Source: "'Electric Machinery Fundamentals" by Stephen J. Chapman, *Page: 397]*

Here the direction of 'Ia' can be reversed by generating 'Te' within reverse direction toward 'n'. Once the 'Eb' decreases, 'Ia' decreases with time while speeding decreases. But, 'Ia' cannot turn into zero at any time because of the occurrence of the voltage supply. So dissimilar to rheostatic, an extensive magnitude of braking torque will exist. Therefore, stopping the motor is probably faster compare with rheostatic braking. However, if the switch 'S' constant within the positions of 1′ & 2′ & even after zero speed so the machine will begin picking up speed within the opposite direction to work as a motor. So maintenance must be taken for detaching the supply at the right hand, and then the armature speed moment will become zero.

Advantages & Disadvantages

The advantages and disadvantages are

- This is a much-used method where en electric motor is worked as a generator once it is detached from the power source
- In this braking, the energy which is stored will dissipate through the resistance of braking & other components used in the circuit.
- This will reduce braking components based on wear on friction & regeneration reduces the usage of net energy.

Applications of Dynamic Braking

- The dynamic braking technique is used to stop a DC motor & widely used in industrial applications.
- These systems are utilized in the applications of fans, centrifuges, pumps, rapid or continuous braking, and certain conveyor belts.
- These are used where rapid slow down & reversing are required.
- These are used on railcars through several units, trolleybuses, electric trams, light rail vehicles, hybrid electric & electric automobiles.