

Part I: Principles of DC Drive Control

Learning Objectives:

- * to learn the basic characteristics of DC motors and their control parameters
- * to understand the various operating modes

DC motors and their representation:

The basic principle of a DC motor is the production of a torque as a result of the flux interaction between a “field” produced on the STATOR (either produced by a permanent magnet, or a field winding) and the current circulating in the “armature” windings on the ROTOR. In order to produce a torque of constant sign, the armature winding loops are connected to a set of “brushes” which commutate the current appropriately in each loop according to their geometric position. The commutator is a MECHANICAL RECTIFIER.

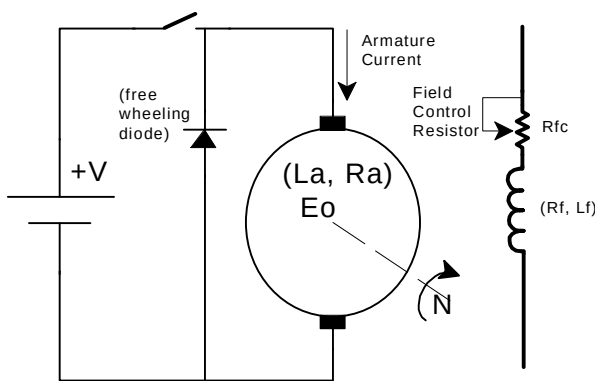


Fig 1: DC Motor

Note that reversal of either the field current or the armature current results in a torque in the opposite direction. However, reversal of both fields does not change the torque direction, hence it can be used as a “universal motor” with DC or AC feed if both windings are in series.

Basic Equations of a DC Machine:

Steady state conditions (assume all time varying quantities have a constant average value)

$$V_f = R_f I_f \quad (\text{field winding})$$

$$E = K_v \omega I_f \quad (\text{Counter emf or Back EMF})$$

$$V_a = R_a I_a + E = R_a I_a + K_v \omega I_f \quad (\text{armature voltage})$$

$$T_e = K_t I_f I_a = A + B\omega + T_{load} \quad (\text{electrical torque})$$

$$P_d = T_e \omega \quad (\text{developed power})$$

(The back emf assumes that the magnetizing characteristic, $E(I_f)$ is linear)

Speed control:

we can extract:
$$\omega = \frac{V_a - R_a I_a}{K_v I_f}$$
 and one can control the speed with

- 1) V_a “Voltage Control”
- 2) I_f “Field Control”
- 3) I_a (with I_f fixed) “Demand Torque”

In practice, for speeds less than the base speed (rated), the armature current and field currents are maintained at fixed values (hence **constant torque operation**), and the **armature voltage controls the speed**. For speeds higher than the base speed, the armature voltage is maintained at rated value, and the **field current is varied to control the speed** (note the hyperbolic characteristic). However,

this way the power developed P_d is maintained constant. This mode is referred to as “field weakening” operation.

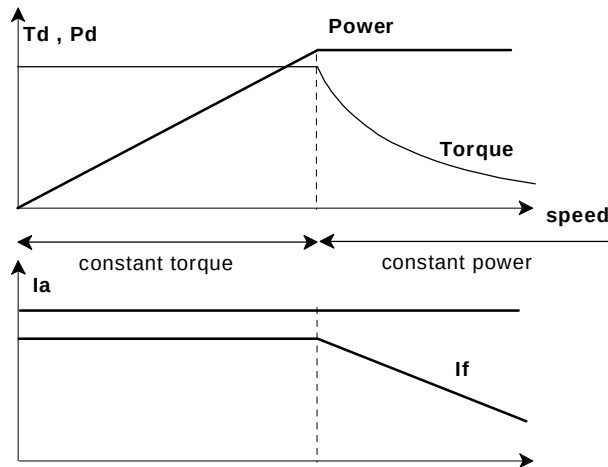


Fig 2: Control Modes

Case of Series Motor (or Universal Motor)

In this case the field winding is series with the armature winding, hence I_f and I_a are equal. This leads to:

$$\omega = \frac{V_a - (R_a + R_f)I_a}{K_v I_a}$$

One can either control the armature voltage (Voltage Control), or the armature current (Current Control) which is a measure of the torque control.

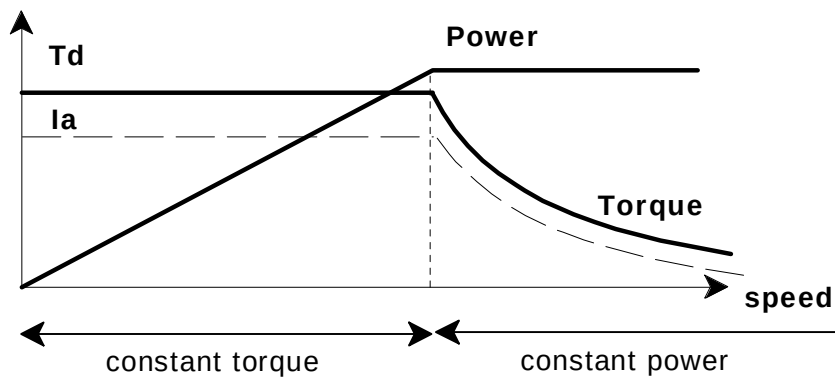


Fig 3: DC Series Motor Control

Operating Modes of DC Motors:

Motoring:

The back emf $E < V_a$
both I_a and I_f are positive. The motor develops a torque to meet the load torque.

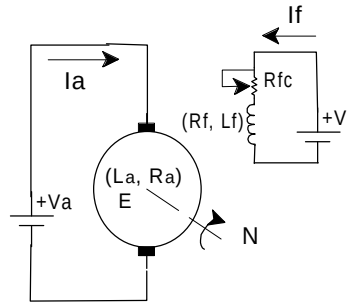


Fig 4: Motoring Forward

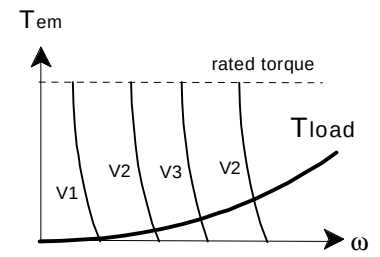


FIG 5 torque speed

Dynamic Breaking:

The voltage source is removed, and the armature is shorted. The kinetic energy stored in the rotor of the motor is dissipated in the armature resistance since the machine now works as a generator. Note here that theoretically, since the armature voltage is proportional to the speed, the motor would never stop... but in fact because there is also friction and viscous friction (windage), the motor will stop as soon as the speed is at a certain low value.

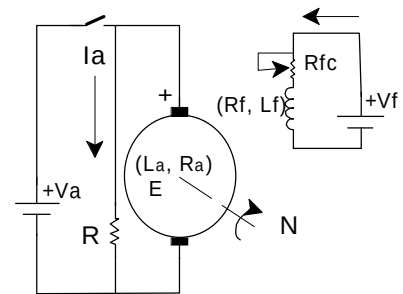


Fig 6: Dynamic Breaking

Regenerative Breaking:

The back emf $E > V_a$, the machine acts as a generator, and the armature current flows towards the source, hence energy stored in the machine rotor is fed back to the source. Note however that this will cause the machine to slow down usually until $E=V_a$ and then revert to mode 1.

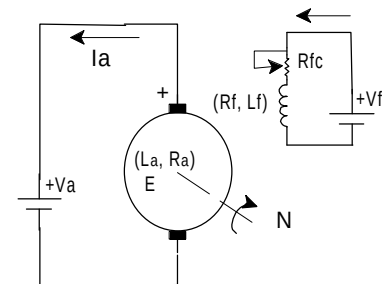


Fig 7: Regenerative Breaking

Plugging:

Plugging is when the field current is reversed, hence the back emf changes sign, and the equation of the machine becomes:

$$V_a = -E - R_a I_a \quad \text{hence} \quad I_a = \frac{V_a + E}{R_a}$$

which means a very high torque generated in

the opposite direction of rotation. A very powerful braking takes place. However it must be noted that the armature has to be opened as soon as the motor reaches zero speed, otherwise it will start rotating in the opposite direction.

Two Transistor control of regenerative operation

When the main switch opens, the armature current $I(a1)$ has to be dissipated through the freewheeling diode.

Then if one closes switch T1, the machine behaves as a generator with the energy stored in its inertia. Therefore the armature current $I(a2)$ will start flowing and follows $I(1)$. After a certain time one opens the switch T1, and the current $I(a2)$ has to be redirected via diode D2 back to the source with $I(2)$. This is because of the inductance of the machine acts as an emf restoring the flux stored in the magnetic field.

Then one closes T1 again and so on.

The chopping rate of switch T1 can be set in order to control the average current (I_{a2}), usually 1.5 times rated value. This is possible only if the speed is fast enough to provide terminal voltage. When the emf E reaches $E = R_a I(\text{rated})$, the switch T1 remains closed for maximum breaking possible with the given emf.

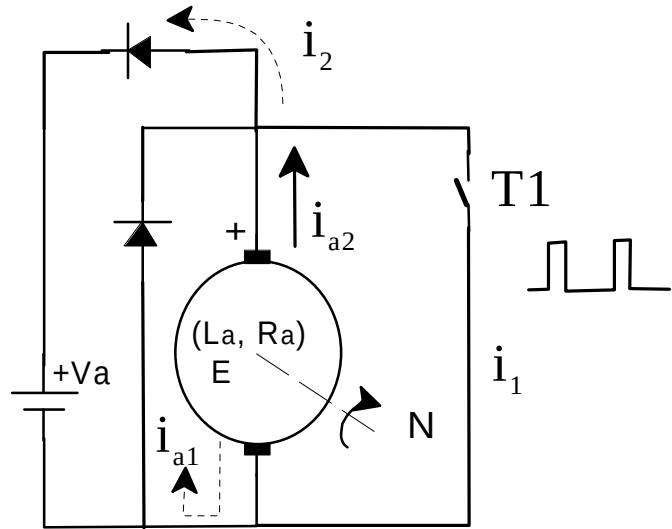
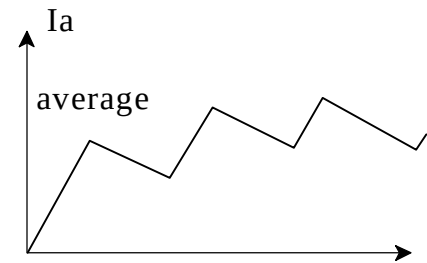


Fig 7: Regenerative Control



Four Quadrant Operation:

Figure 8 summarizes the modes of operation in a four quadrant representation.

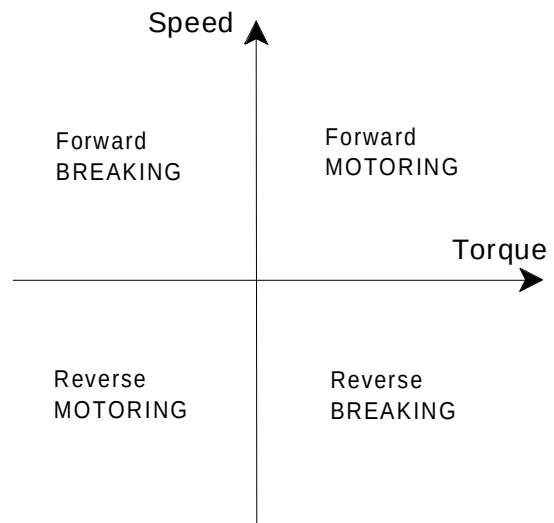


Fig 8: 4 quadrant operation