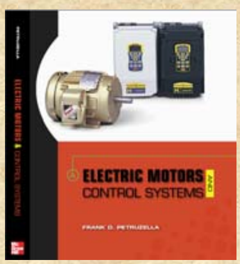


Chapter 5

Electric Motors

PART 2 Direct Current Motors

Direct current motors are not used as much as alternating current types because all electric utility systems deliver alternating current.

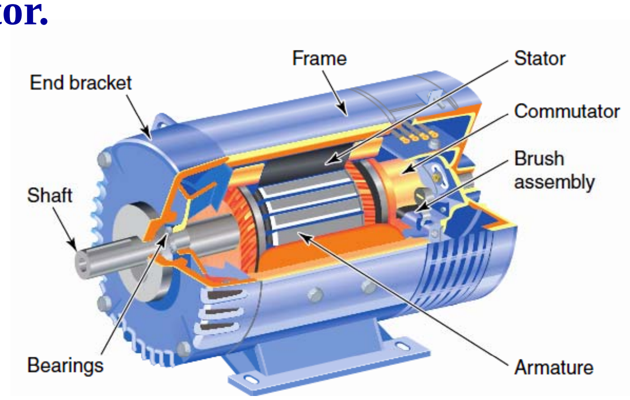

Mining And Drilling


Elevators


Cranes

For special applications it is advantageous to transform the alternating current into direct current in order to use DC motors.

The construction of a DC motor is considerably more complicated and expensive than that of an AC motor.

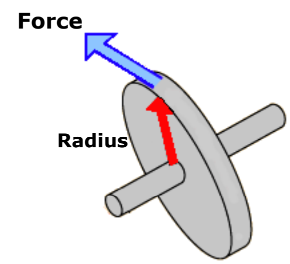


Maintenance of the brush/commutator assembly found on DC motors is significant compared to that of AC motor designs.

Motor *speed, torque* and *horsepower (HP),* are important parameters used to predict DC motor performance.

Motor *speed* refers to the rotational speed of the motor's shaft and is measured in revolutions per minute (rpm).

Motor *torque* refers to the turning force supplied by the motor's shaft. Torque consists of *force* acting on a *radius.*



=

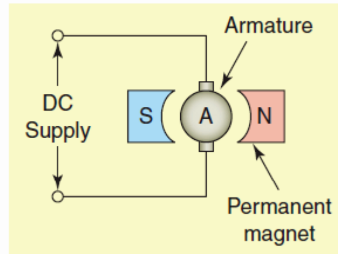
1 HP

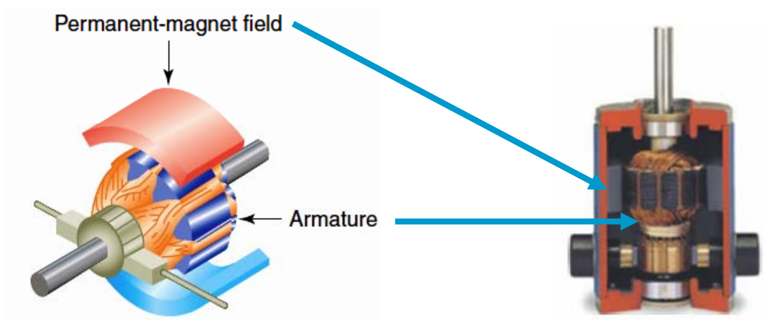
746 Watts

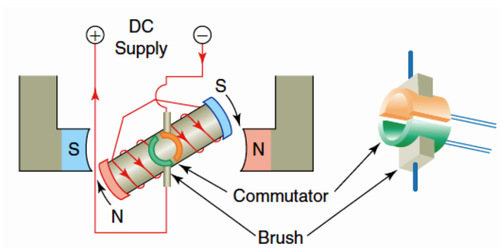
Motor *horsepower* refers to the *rate* at which work is done.

PERMANENT-MAGNET DC MOTOR

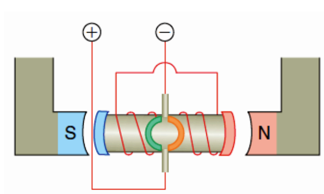
Permanent-magnet DC motors use permanent magnets to supply the main field flux and electromagnets to provide the armature flux.



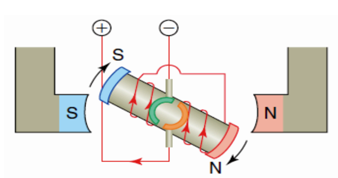




- **The armature poles are attracted to field poles of opposite polarity causing the armature to rotate in a clockwise direction**

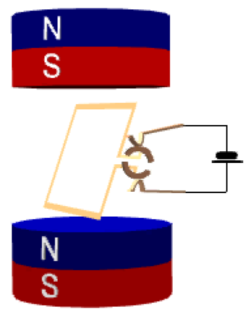


- **When the armature poles are in line with the field poles, the brushes are at the gap in the commutator and no current flows in the armature.**

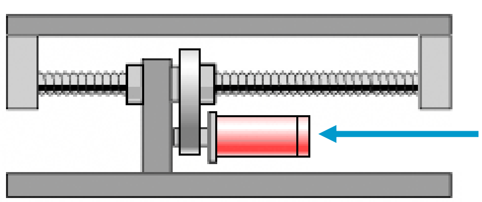


- **Once passed the neutral point current and polarity of the armature reverses direction due to the commutator's reversing action.**

Permanent-Magnet DC Motor Simulation

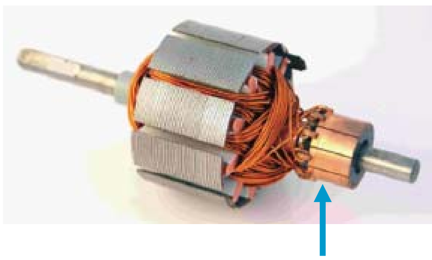


Permanent magnet motors produce high *torque* as compared to wound field motors. They are ideal for servo motor applications due to their linear speed/torque characteristics.

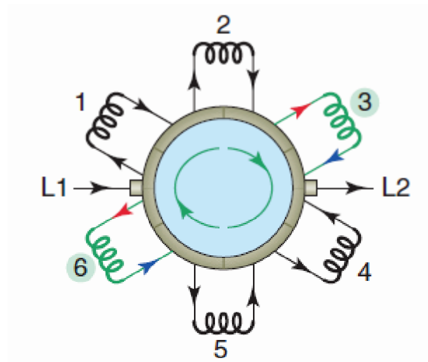


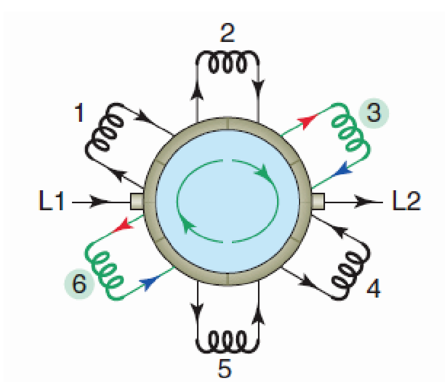
Permanent magnet motors are limited in load-handling ability and are therefore used only for low horsepower load duty.

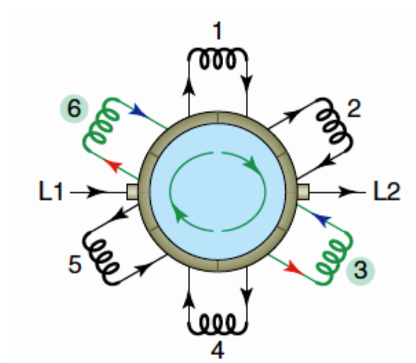
A constant torque is achieved by constructing the armature as a series of small sections connected to the *segments of a commutator*.



Commutator Segments



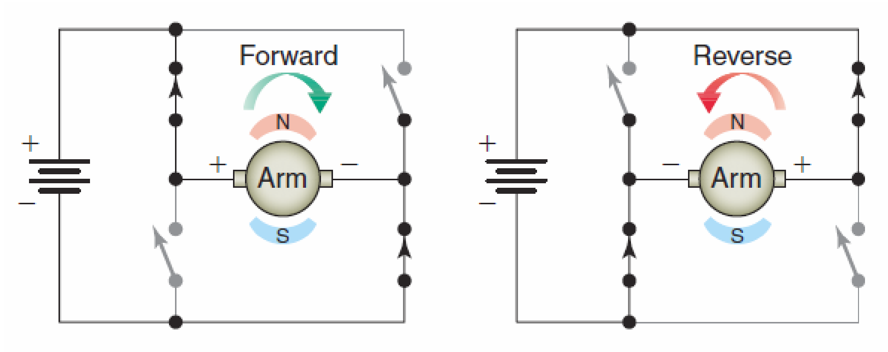




Currents in coils 3 and 6 have changed direction

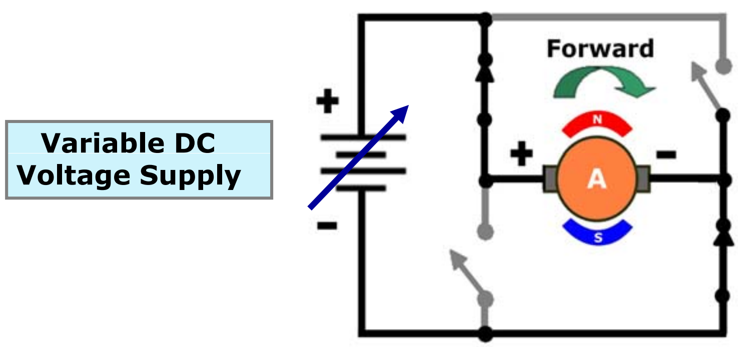
- **The commutator can be regarded as a switch that maintains the proper direction of current in the armature coils to produce constant unidirectional torque.**
- **If the armature rotates through 1/6 of a revolution clockwise, the current in coils 3 and 6 will have changed direction.**

The *direction of rotation* of a permanent magnet DC motor is determined by the direction of the current flow through the armature.



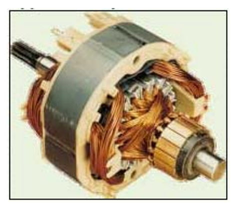
Reversing the *polarity* of the voltage applied to the armature will reverse the direction of rotation.

Variable speed control of a PM motor is obtained by varying the value of the voltage applied to the armature. The speed of the motor varies directly with the amount of armature voltage applied. The *higher the value of the armature voltage the faster* the motor will run.

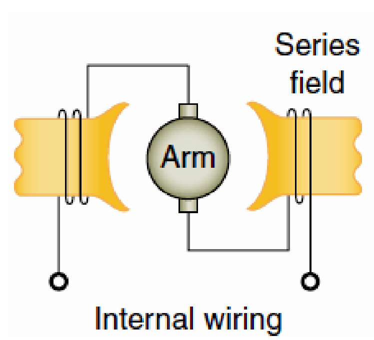


SERIES DC MOTOR

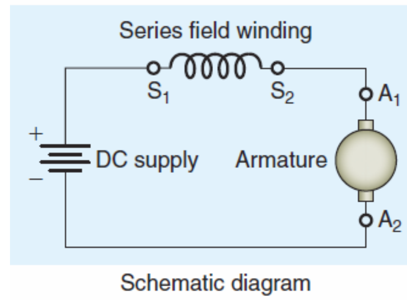
Wound-field **DC motors are usually classified as series-wound, shunt-wound, or compound-wound.**

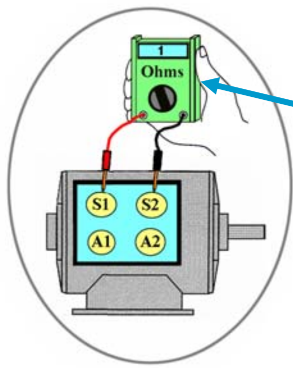


A *series-wound* DC motor consists of a series field winding connected in series with the armature.



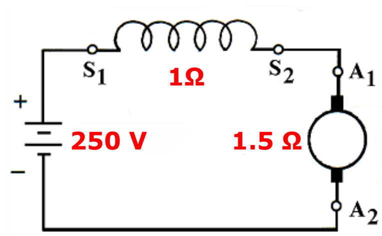
Since the series field winding will carry the same amount of current as the armature it is wound with heavy-gauge wire that is large enough to carry the full motor load current.



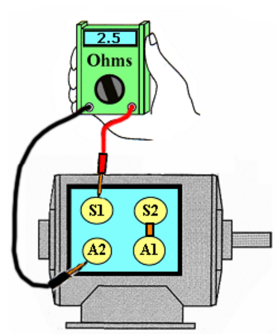


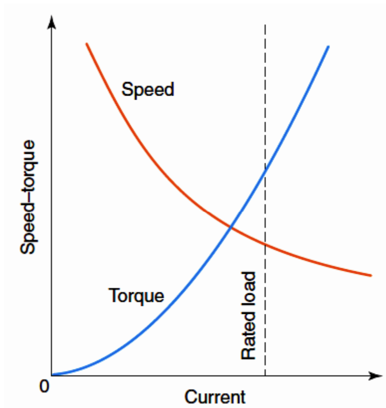
Due to the large diameter of the series winding, the winding will have fewer turns of wire and a *very low resistance* value.

A series wound DC motor has both a low resistance series field and armature circuit. Because of this, when voltage is *first* applied to it, the current is high *(I = E/R).* This high current results in strong magnetic fields inside the motor that produce a *high torque* ideal for starting very heavy mechanical loads.



$$I = E / R = 250\ V / 2.5\ \Omega = 100\ A$$





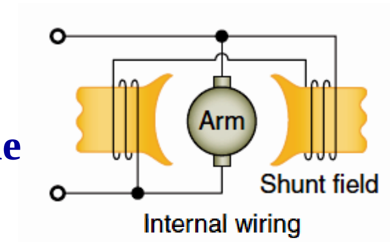
- **The speed of a series motor varies widely between no load and rated load.**
  - **The motor runs fast with a light load (low current) and runs substantially slower as the motor load increases.**
  - **Due to its ability to start very heavy loads series motors are often used in cranes, hoists, and elevators.**

The no-load speed of a series motor can increase to the point of damaging the motor. For this reason, it should never be operated without a load of some type coupled to it.

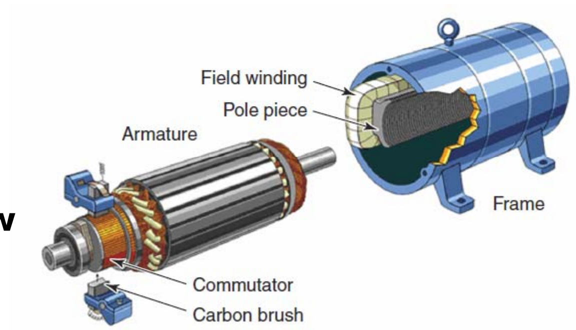
Series DC Crane Hoist Motor

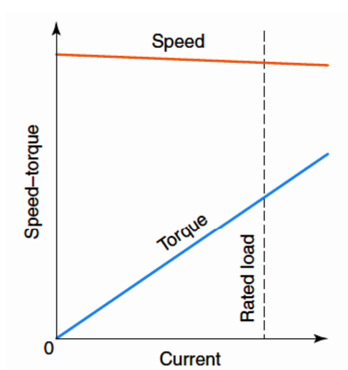
SHUNT DC MOTOR

A *shunt-wound* DC motor consists of a shunt field connected in parallel with the armature.

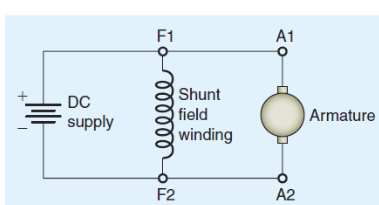


The shunt field winding is made up of many turns of small-gauge wire and has a *much higher resistance* and lower current flow when compared to that of a series field winding.





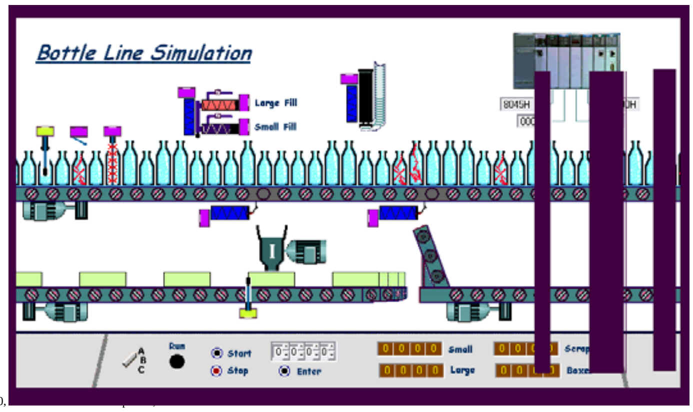
- **The field winding is connected directly across the power supply so the field current does not vary with motor speed, as in the series motor.**
- **Therefore, the torque of the shunt motor will vary only with the current through the armature.**
  - **When the motor is starting and speed is very low, the motor has very little torque.**
  - **After the motor reaches full rpm, its torque is at its fullest potential.**
  - **The runs almost as fast fully loaded as it does with no load.**



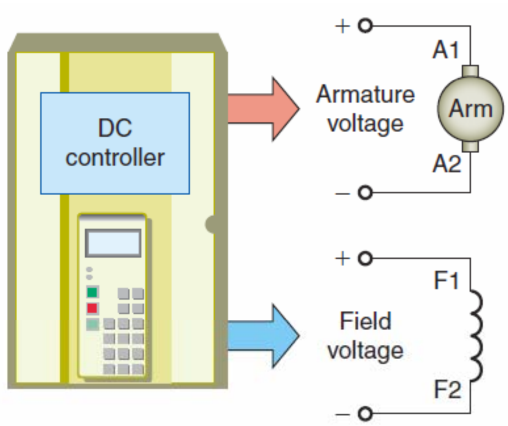
Schematic diagram

Shunt motors are particularly suitable for applications such as conveyors where *constant speed* is desired and when high starting torque is not needed.

Typical shunt-wound DC conveyor motor



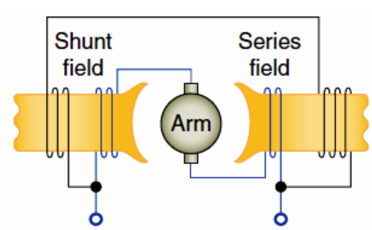
The field winding of a shunt motor can be *separately excited* or connected to the same voltage source as the armature.



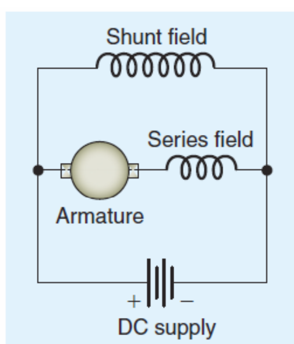
An advantage to separately exciting the shunt field is that a variable speed drive can be used to provide independent control of the field and armature.

COMPOUND DC MOTOR

A *compound-wound* DC motor is a combination of the shunt-wound and series-wound types.



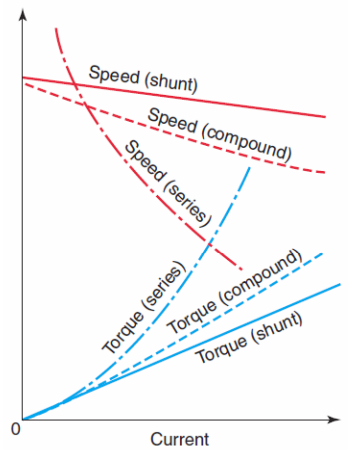
Internal wiring

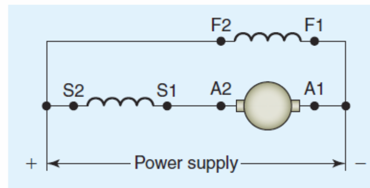


Schematic diagram

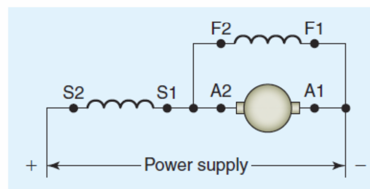
- **The shunt field gives this type of motor the constant speed advantage of a regular shunt motor.**
- **The series field gives it the advantage of being able to develop a large torque when the motor is started under a heavy load.**

This motor is normally connected *cumulative-compound* so that under load the series field flux and shunt field act in the same direction to strengthen the total field flux.





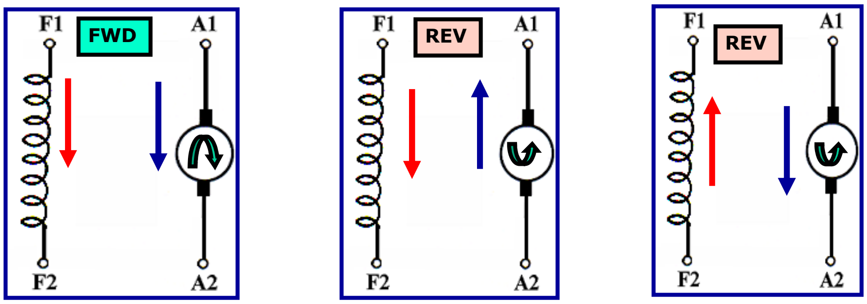
Long-shunt cumulative connection



Short-shunt cumulative connection

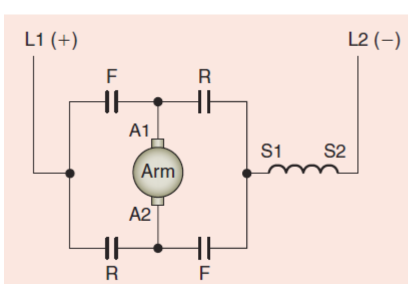
DIRECTION OF ROTATION

The *direction of rotation* of a DC motor depends on the direction of the field and the direction of the current flow through the armature.

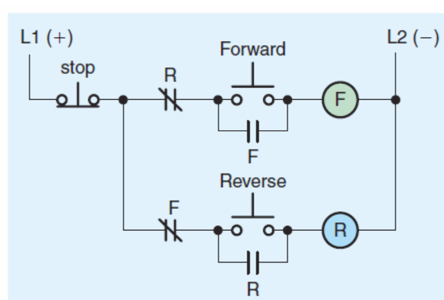


If either the direction of the field current or the direction of the current flow through the armature is reversed, the rotation of the motor will reverse.

DC Series Motor Reversing Motor Starter

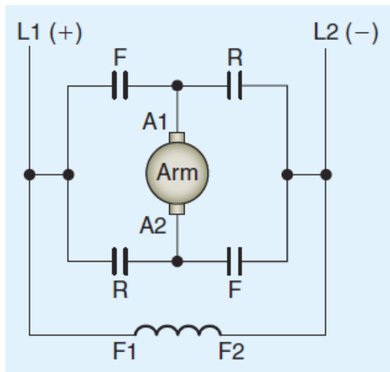


Power circuit

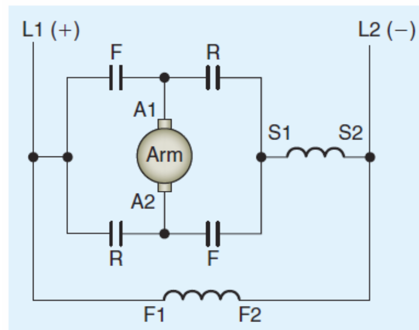


Control circuit

DC Shunt And Compound Motor Reversing

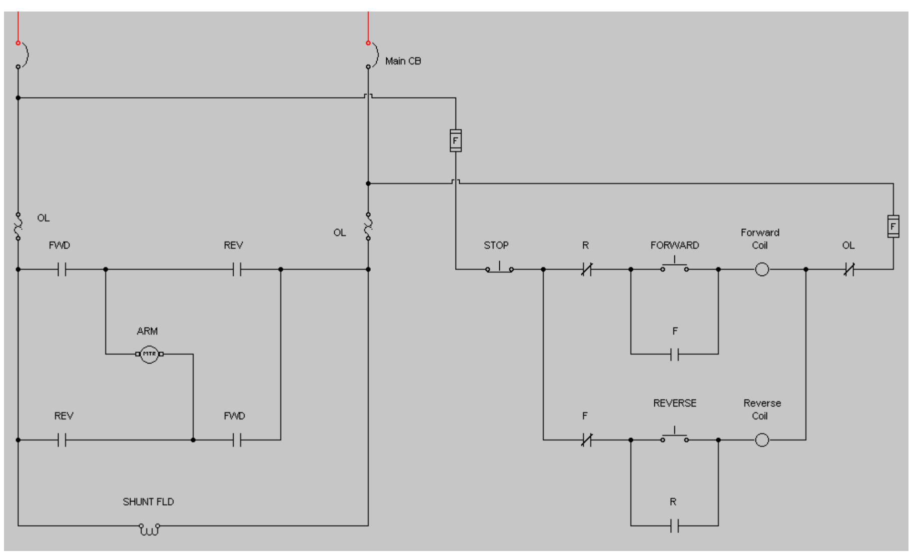


Shunt motor



Compound motor

Simulated DC Shunt Motor Reversing

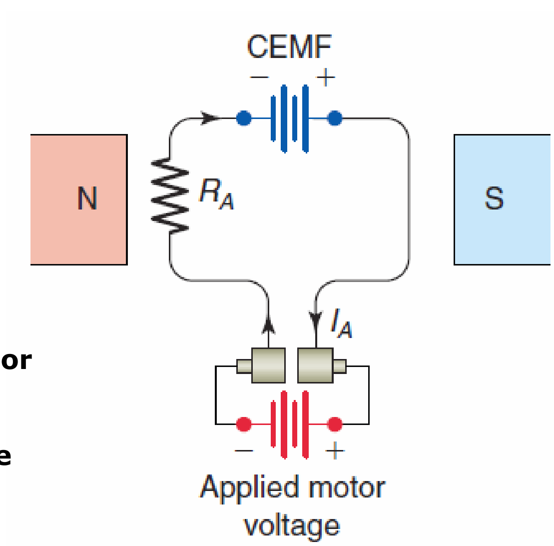


MOTOR COUNTER ELECTROMOTIVE FORCE (CEMF)

Counter EMF **is a form of resistance that opposes and limits the flow of motor armature current.**

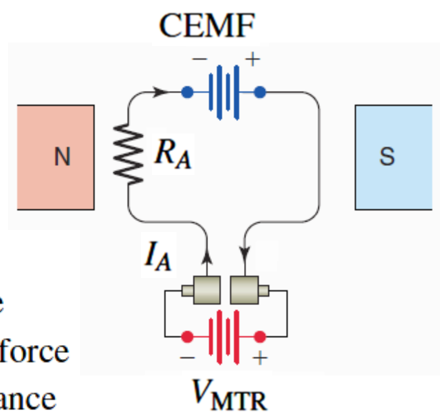
- **As the armature rotates in a DC motor, the armature coils cut the magnetic field of the stator and induce a counter voltage in them.**

- **This occurs in a motor as a by-product of motor rotation and is also referred to as the generator action of a motor.**



The overall effect of the CEMF is that this voltage will be subtracted from the terminal voltage of the motor so that the armature motor winding will see a smaller voltage potential.

$$I_A = \frac{V_{MTR} - CEMF}{R_A}$$



where I_A = armature current
V_{MTR} = motor terminal voltage
CEMF = counter electromotive force
R_A = armature-circuit resistance

EXAMPLE 5-1

Problem: The armature of a 250-V DC motor draws 15 A when operating at full load and has a resistance of 2 Ω. Determine the counter EMF produced by the armature when operating at full load.

Solution:

$$I_A = \frac{V_{MTR} - CEMF}{R_A}$$

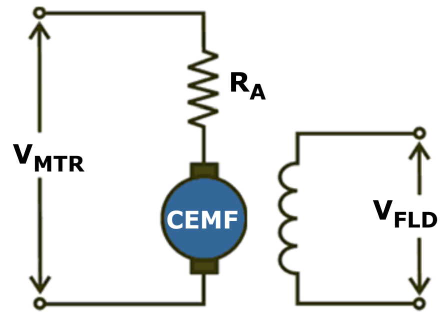
$$CEMF = V_{MTR} - (I_A \times R_A)$$

$$= 250\text{ V} - (15\text{ A} \times 2\ \Omega)$$

$$= 250 - 30$$

$$= 220\text{ V}$$

➢At the moment a motor starts, the armature is not rotating, so there is no CEMF generated in the armature.



➢Only the low resistance of the armature limits the amount of current through the armature.

➢As the motor picks up speed a CEMF is generated in the armature, which opposes the applied terminal voltage and quickly reduces the amount of armature current.

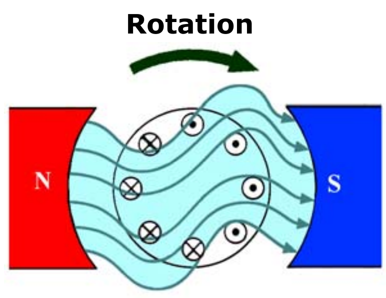
➢At full no-load speed the CEMF nearly equals that of the applied line voltage.

➢When a load is applied to the motor, its speed will be decreased, which will reduce the CEMF, and more current will be drawn by the armature to drive the load.

ARMATURE REACTION

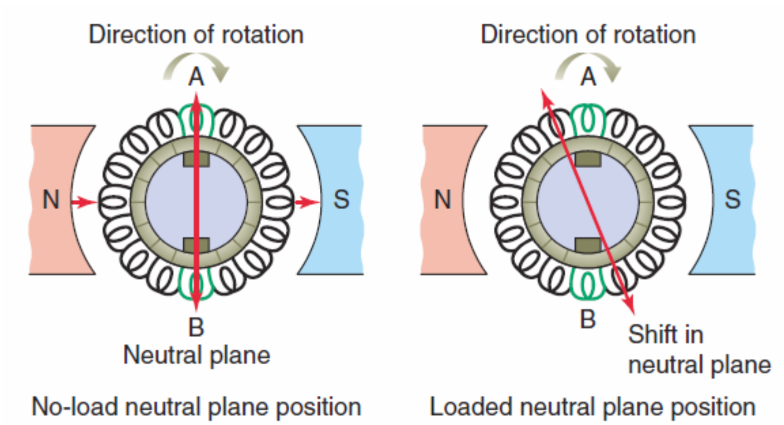
The magnetic field produced by current flow through the armature conductors distorts and weakens that of the main field poles. This distortion and field weakening of the stator field is known as *armature reaction.*

Armature coil



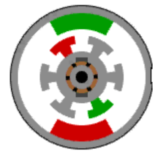
Main Field Distortion

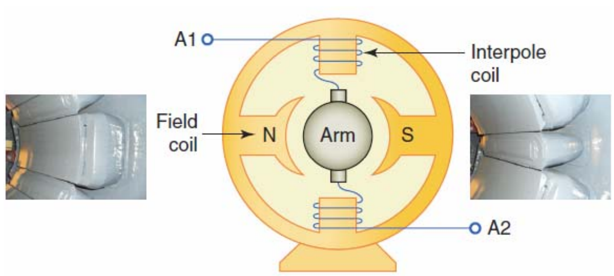
The position of the *neutral plane* is shifted backwards opposing the direction of rotation under no-load and loaded motor operating conditions.



Armature reaction affects the motor operation by

- Reduction in motor torque due to the weakening of the magnetic field.
- Arcing at the brushes due to short-circuiting of the voltage being induced in the coils undergoing commutation.





In large DC motors interpoles are placed between the main field poles to minimize the effects of armature reaction.

SPEED REGULATION

Motor *speed regulation* is a measure of a motor's ability to maintain its speed from no-load to full-load without a change in the applied voltage to the armature or fields.

$$\text{Percent speed regulation} = \frac{\text{No-load speed} - \text{Full-load speed}}{\text{Full-load speed}} \times 100$$

The lower the percentage the better the speed regulation.

EXAMPLE 5-2

Problem: A DC shunt motor is running with a measured no-load speed of 1775 rpm. When full-load is applied the speed drops slightly to 1725 rpm. Find the percentage speed regulation.

Solution:

Percent speed regulation

$$= \frac{\text{No-load speed} - \text{Full-load speed}}{\text{Full-load speed}} \times 100$$

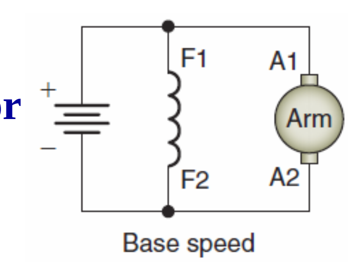
$$= \frac{1775\text{ rpm} - 1725\text{ rpm}}{1725\text{ rpm}} \times 100$$

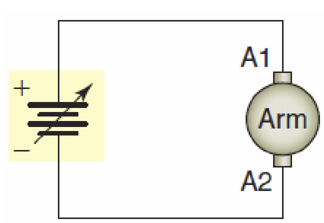
$$= \frac{50}{1{,}725} \times 100$$

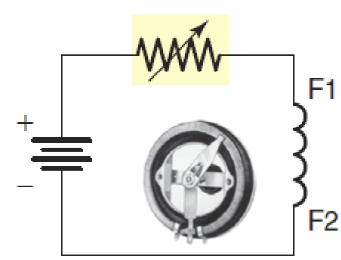
$$= 2.9\%$$

VARYING DC MOTOR SPEED

The *base speed* listed on a DC motor's nameplate is an indication of how fast the motor will run with rated armature voltage and rated load amps at rated field current

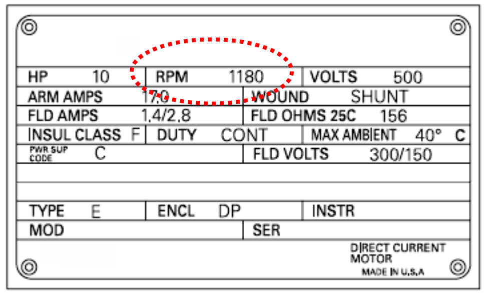






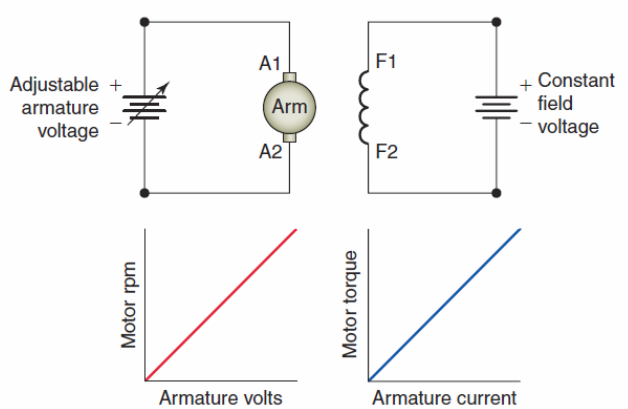
DC motors can be operated below base speed by reducing the amount of voltage applied to the armature and above base speed by reducing the field current.

The maximum motor speed may also be listed on the nameplate.

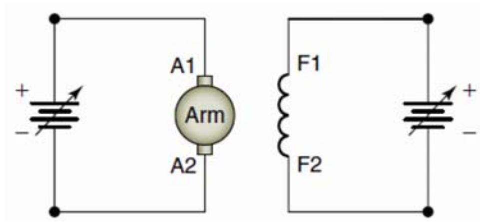


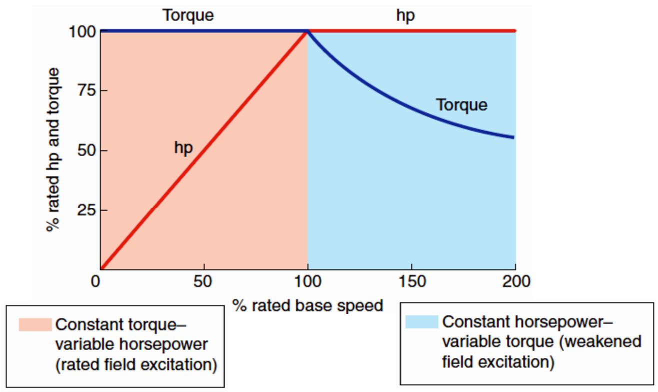
Caution: Operating a motor above its rated maximum speed can cause damage to equipment and personnel. When only base speed is listed check with the vendor before operating it above the specified speed.

In *armature controlled adjustable speed* applications, the field is connected across a constant-voltage supply and the armature is connected across an independent adjustable-voltage source

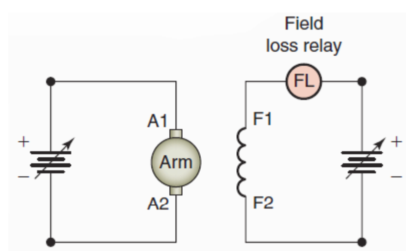


Coordinated *armature and field control* for extended speed range of a DC motor.





First the motor is armature voltage controlled for constant torque-variable HP operation up to base speed. Once base speed is reached field-weakening control is applied for constant HP-variable torque operation to motor's maximum rated speed.

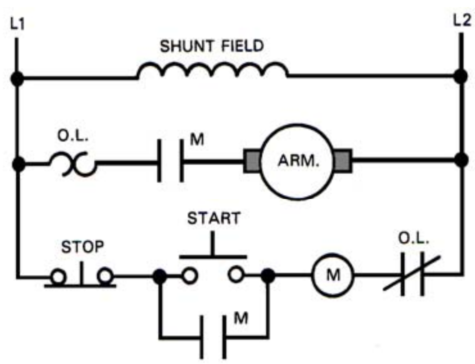


Caution: If a DC motor suffers a loss of field excitation current while operating, the motor will immediately begin to accelerate to the top speed, which the loading will allow. This can result in the motor virtually flying apart if it is lightly loaded. For this reason some form of field lost protection must be provided in the motor control circuit that will automatically stop the motor in the event that current to the field circuit is lost or drops below a safe value.

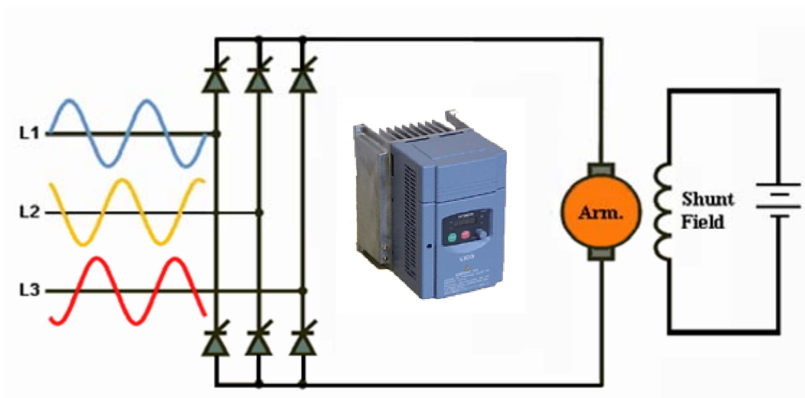
Field Loss relay

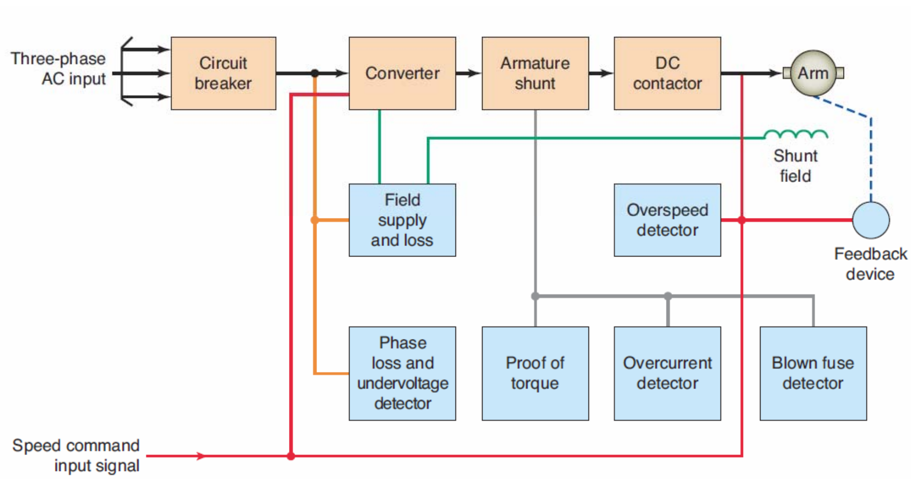
DC MOTOR DRIVES

In general DC magnetic ***motor starters*** **are intended to start and accelerate motors to normal speed and to provide protection against overloads.**



In addition to protection, ***electronic motor drives*** are designed to control the speed, torque, acceleration, deceleration and direction of rotation of motors.





- ***Power section*** consists of the main circuit breaker, converter, armature shunt, and DC contactor.
- ***Control section*** consists of the speed command input signal as well as various feedback, and errors signals.

Typical DC motor drive unit used to provide control over the operation of a conveyor system. In addition to motor speed and torque, it provides controlled acceleration and deceleration as well as forward and reverse motor operation.