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Introduction

Welcome to another course in the STEP 2000 series, **S**iemens **T**echnical **E**ducation **P**rogram, designed to prepare our distributors to sell Siemens Energy & Automation products more effectively. This course covers **Basics of DC Drives** and related products.

Upon completion of **Basics of DC Drives** you will be able to:

Explain the concepts of force, inertia, speed, and torque

- Explain the difference between work and power
- Describe the operation of a DC motor
- Identify types of DC motors by their windings
- Identify nameplate information on a DC motor necessary for application to a DC drive
- Identify the differences between a power module and a base drive
- Explain the process of converting AC to DC using thyristors
- Describe the basic construction of a DC drive
- Explain the significant differences between 1- and 4-quadrant operation in a DC drive
- Describe features and operation of the Siemens 6RA70 DC MASTER
- Describe the characteristics of constant torque, constant horsepower, and variable torque applications

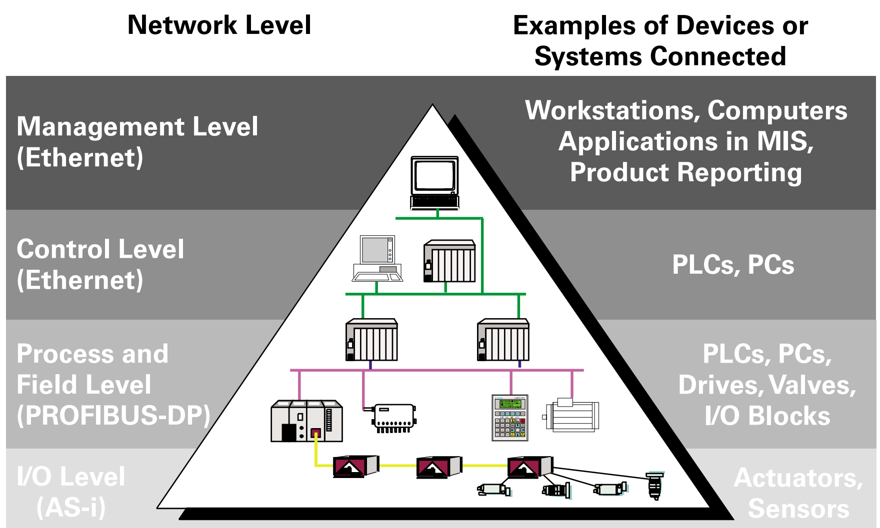
This knowledge will help you better understand customer applications. In addition, you will be better able to describe products to customers and determine important differences between products.

If you are an employee of a Siemens Energy & Automation authorized distributor, fill out the final exam tear-out card and mail in the card. We will mail you a certificate of completion if you score a passing grade. Good luck with your efforts.

Totally Integrated Automation and DC Drives

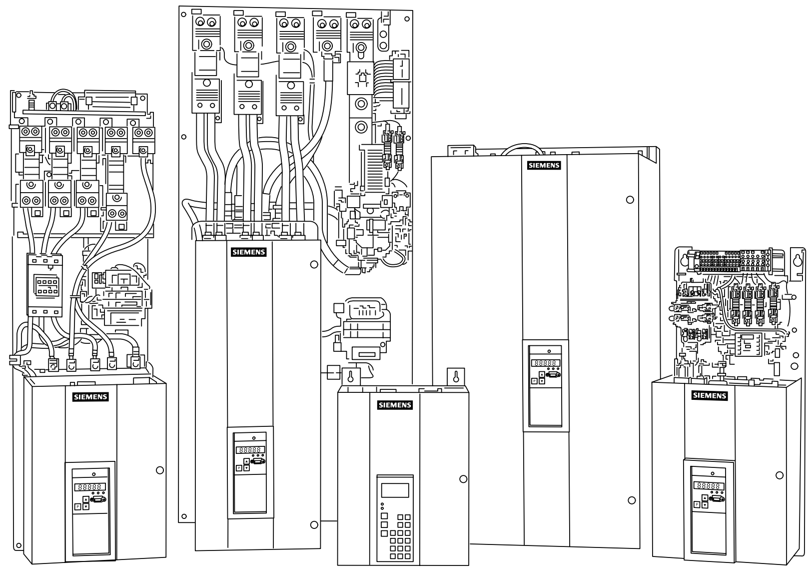
Totally Integrated Automation

Totally Integrated Automation (TIA) is a strategy developed by Siemens that emphasizes the seamless integration of automation products. The TIA strategy incorporates a wide variety of automation products such as programmable controllers, computer numerical controls, Human Machine Interfaces (HMI), and DC drives which are easily connected via open protocol networks. An important aspect of TIA is the ability of devices to communicate with each other over various network protocols such as PROFIBUS-DP.

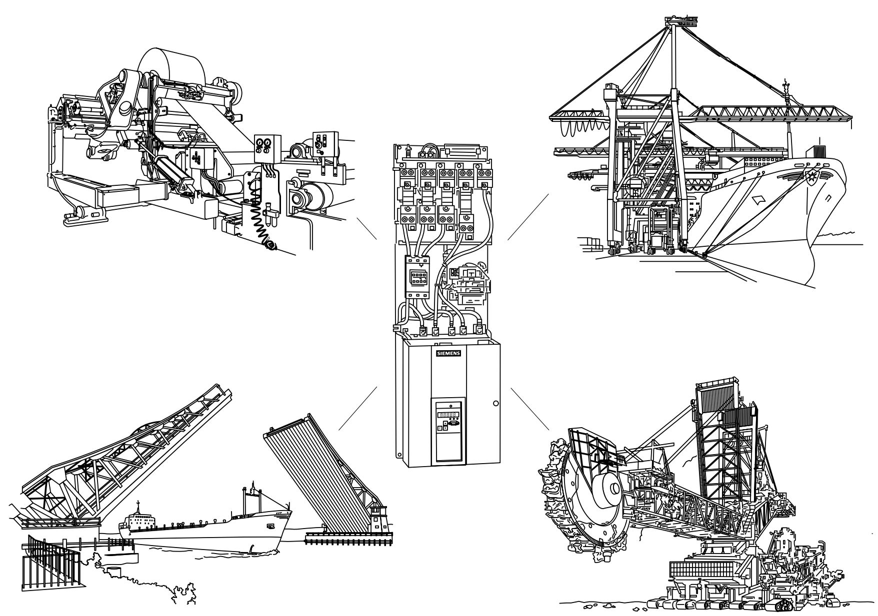


Siemens DC Drives

SIMOREG® is the trade name for Siemens adjustable speed DC Drives. SIMOREG stands for **SI**emens **MO**tor **REG**ulator. Siemens DC drives are an important element of the TIA strategy. DC motors were the first practical device to convert electrical energy into mechanical energy. DC motors, coupled with DC drives such as the Siemens SIMOREG 6RA70, have been widely used in industrial drive applications for years, offering very precise control.



Although AC motors and vector-control drives now offer alternatives to DC, there are many applications where DC drives offer advantages in operator friendliness, reliability, cost effectiveness, and performance. We will discuss applications later in the course.



Mechanical Basics

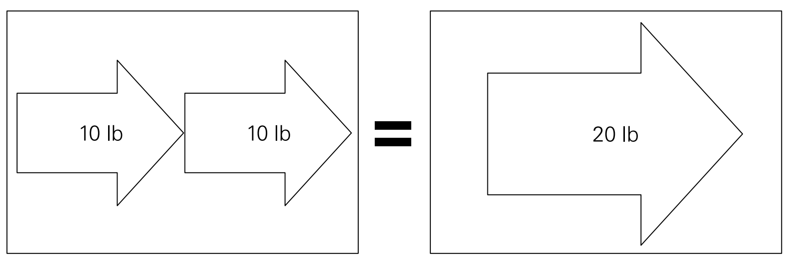
Before discussing Siemens DC drives it is necessary to understand some of the basic terminology associated with the mechanics of DC drive operation. Many of these terms are familiar to us in some other context. Later in the course we will see how these terms apply to DC drives.

Force

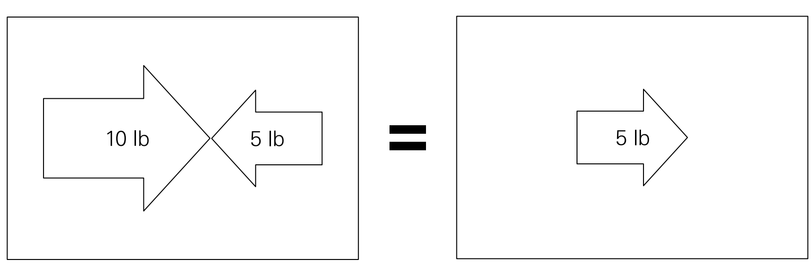
In simple terms, a force is a push or a pull. Force may be caused by electromagnetism, gravity, or a combination of physical means. The English unit of measurement for force is pounds (lb).

Net Force

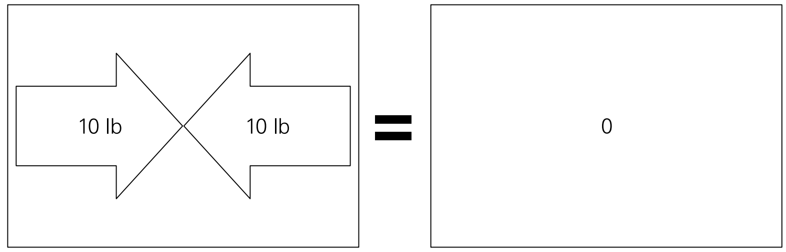
Net force is the vector sum of all forces that act on an object, including friction and gravity. When forces are applied in the same direction they are added. For example, if two 10 lb forces were applied in the same direction the net force would be 20 lb.



If 10 lb of force were applied in one direction and 5 lb of force applied in the opposite direction, the net force would be 5 lb and the object would move in the direction of the greater force.



If 10 lb of force were applied equally in both directions, the net force would be zero and the object would not move.



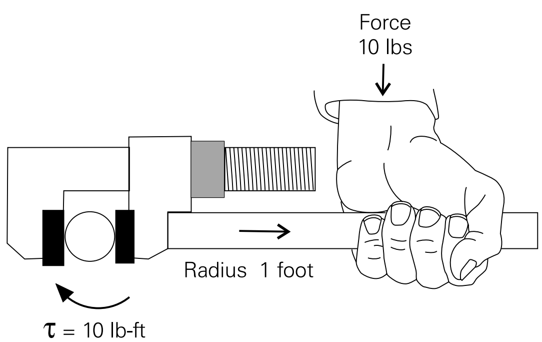
Torque

Torque is a twisting or turning force that tends to cause an object to rotate. A force applied to the end of a lever, for example, causes a turning effect or torque at the pivot point.

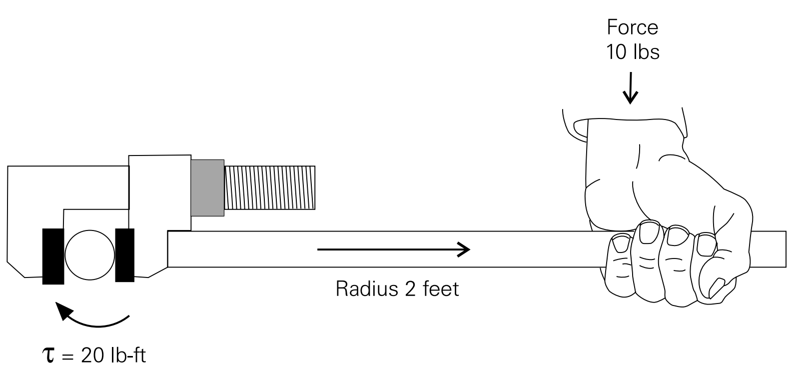
Torque (τ) is the product of force and radius (lever distance).

Torque (τ) = Force x Radius

In the English system torque is measured in pound-feet (lb-ft) or pound-inches (lb-in). If 10 lbs of force were applied to a lever 1 foot long, for example, there would be 10 lb-ft of torque.



An increase in force or radius would result in a corresponding increase in torque. Increasing the radius to 2 feet, for example, results in 20 lb-ft of torque.



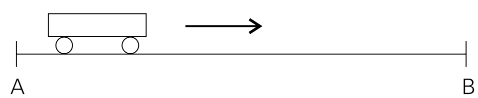
Speed

An object in motion travels a given distance in a given time. Speed is the ratio of the distance traveled to the time it takes to travel the distance.

$$\text{Speed} = \frac{\text{Distance}}{\text{Time}}$$

Linear Speed

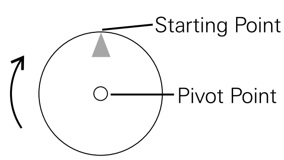
The linear speed of an object is a measure of how long it takes the object to get from point A to point B. Linear speed is usually given in a form such as feet per second (f/s). For example, if the distance between point A and point B were 10 feet, and it took 2 seconds to travel the distance, the speed would be 5 f/s.



Linear Motion

Angular (Rotational) Speed

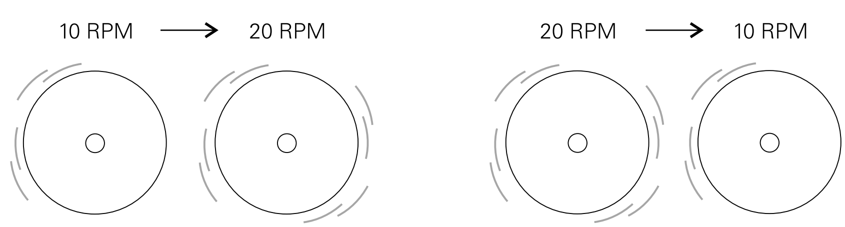
The angular speed of a rotating object is a measurement of how long it takes a given point on the object to make one complete revolution from its starting point. Angular speed is generally given in revolutions per minute (RPM). An object that makes ten complete revolutions in one minute, for example, has a speed of 10 RPM.



Rotational Motion

Acceleration

An object can change speed. An increase in speed is called acceleration. Acceleration occurs when there is a change in the force acting upon the object. An object can also change from a higher to a lower speed. This is known as deceleration (negative acceleration). A rotating object, for example, can accelerate from 10 RPM to 20 RPM, or decelerate from 20 RPM to 10 RPM.



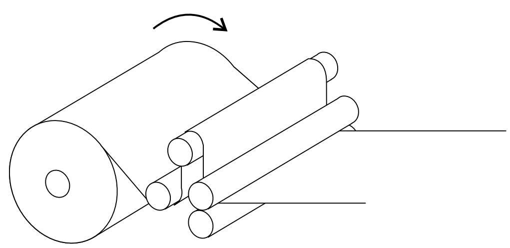
Acceleration

Deceleration

Law of Inertia

Mechanical systems are subject to the law of inertia. The law of inertia states that an object will tend to remain in its current state of rest or motion unless acted upon by an external force. This property of resistance to acceleration/deceleration is referred to as the moment of inertia. The English system of measurement is pound-feet squared (lb-ft^2).

If we look at a continuous roll of paper, as it unwinds, we know that when the roll is stopped, it would take a certain amount of force to overcome the inertia of the roll to get it rolling. The force required to overcome this inertia can come from a source of energy such as a motor. Once rolling, the paper will continue unwinding until another force acts on it to bring it to a stop.



Friction

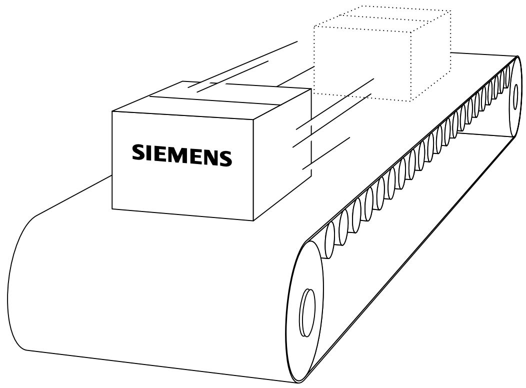
A large amount of force is applied to overcome the inertia of the system at rest to start it moving. Because friction removes energy from a mechanical system, a continual force must be applied to keep an object in motion. The law of inertia is still valid, however, since the force applied is needed only to compensate for the energy lost.

Once the system is in motion, only the energy required to compensate for various losses need be applied to keep it in motion. In the previous illustration, for example: these losses include:

- Friction within motor and driven equipment bearings
- Windage losses in the motor and driven equipment
- Friction between material on winder and rollers

Work

Whenever a force of any kind causes motion, work is accomplished. For example, work is accomplished when an object on a conveyor is moved from one point to another.



Work is defined by the product of the net force (F) applied and the distance (d) moved. If twice the force is applied, twice the work is done. If an object moves twice the distance, twice the work is done.

$W = F \times d$

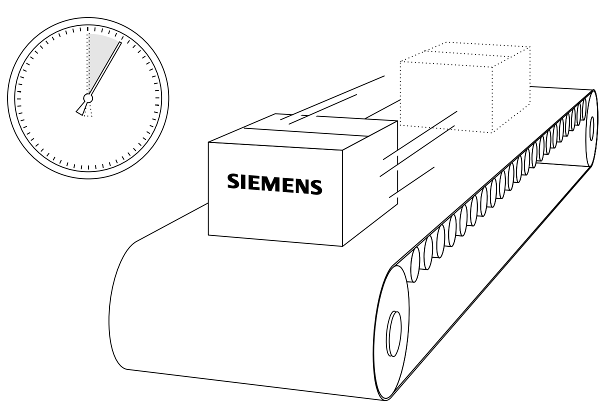
Power

Power is the rate of doing work, or work divided by time.

$$\text{Power} = \frac{\text{Force x Distance}}{\text{Time}}$$

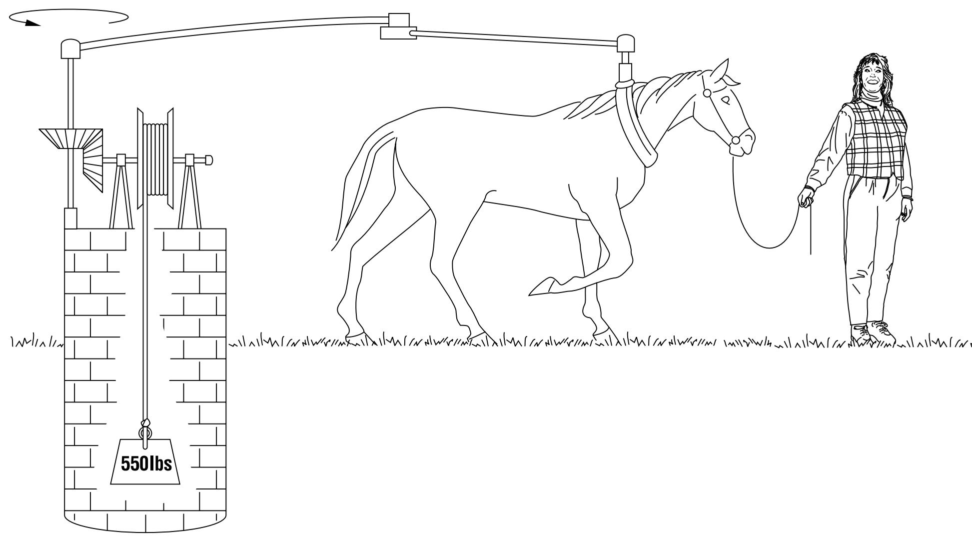
$$\text{Power} = \frac{\text{Work}}{\text{Time}}$$

In other words, power is the amount of work it takes to move the package from one point to another point, divided by the time.



Horsepower

Power can be expressed in foot-pounds per second, but is often expressed in horsepower (HP). This unit was defined in the 18th century by James Watt. Watt sold steam engines and was asked how many horses one steam engine would replace. He had horses walk around a wheel that would lift a weight. He found that each horse would average about 550 foot-pounds of work per second. One horsepower is equivalent to 500 foot-pounds per second or 33,000 foot-pounds per minute.



The following formula can be used to calculate horsepower when torque (lb-ft) and speed (RPM) are known. It can be seen from the formula that an increase of torque, speed, or both will cause a corresponding increase in horsepower.

$$HP = \frac{\text{Torque x RPM}}{5250}$$

Power in an electrical circuit is measured in watts (W) or kilowatts (kW). Variable speed drives and motors manufactured in the United States are generally rated in horsepower (HP); however, it is becoming common practice to rate equipment using the International System of Units (SI units) of watts and kilowatts.

Review 1

1. ___________ is the trade name for Siemens motor generators (DC drives).

2. If 20 lb of force where applied in one direction and 5 lb of force applied in the opposite direction, the net force would be ___________ lb.

3. If 5 lb of force were applied to a radius of 3 feet, the torque would be ___________ lb-ft.

4. Speed is determined by __________ .

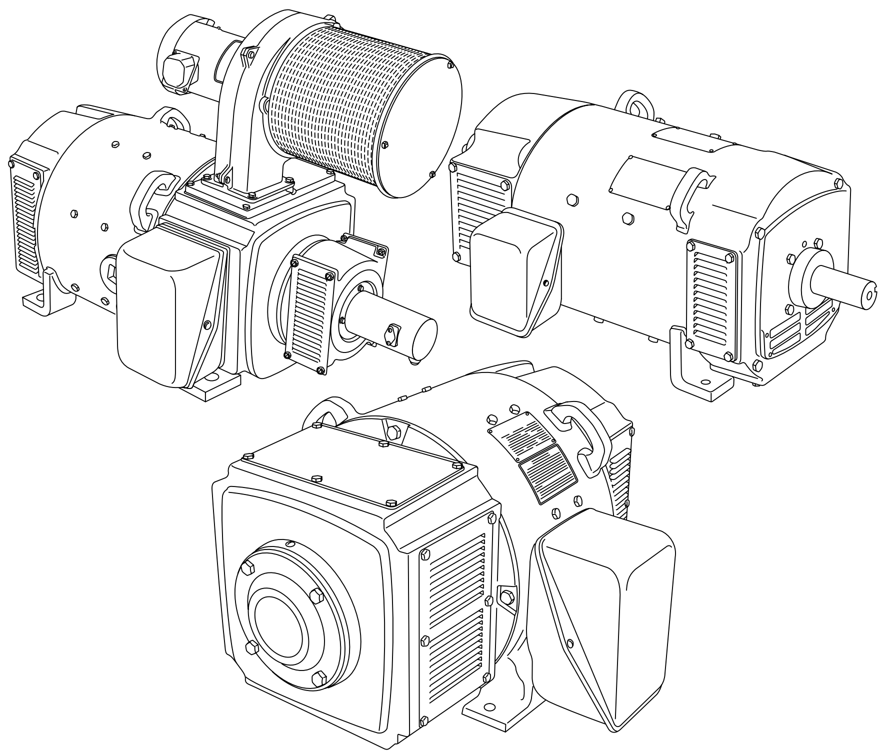
   a. dividing Time by Distance
   b. dividing Distance by Time
   c. multiplying Distance x Time
   d. subtracting Distance from Time

5. Work is accomplished whenever ___________ causes motion.

6. The law of inertia states that an object will tend to remain in its current state of rest or motion unless acted upon by an ___________ ___________ .

DC Motors

DC motors have been used in industrial applications for years. Coupled with a DC drive, DC motors provide very precise control. DC motors can be used with conveyors, elevators, extruders, marine applications, material handling, paper, plastics, rubber, steel, and textile applications to name a few.

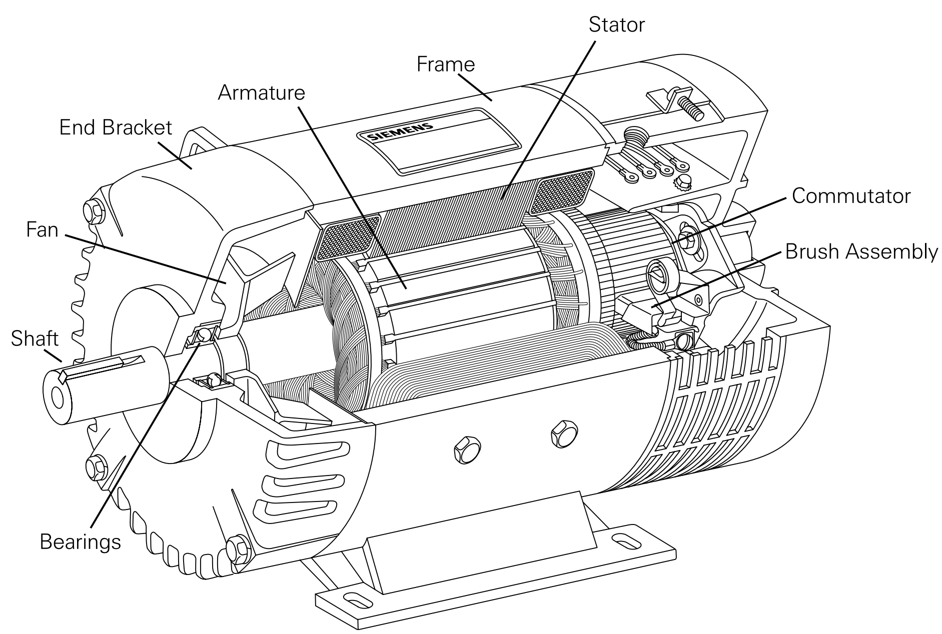


Construction

DC motors are made up of several major components which include the following:

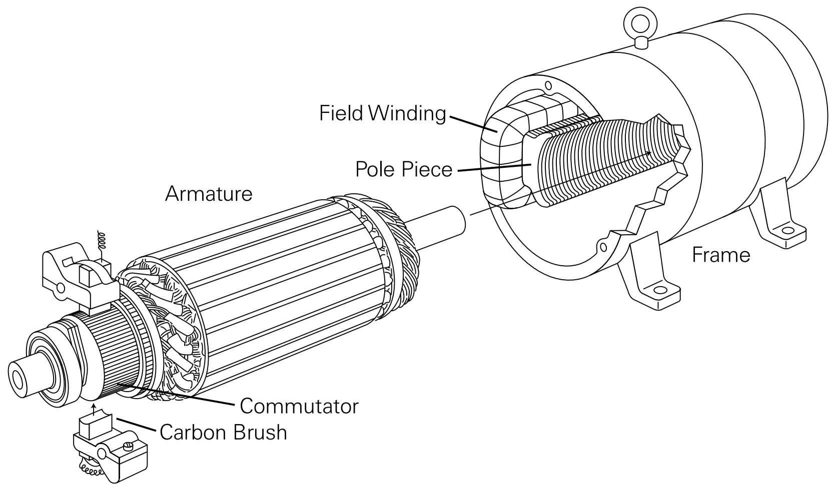
- Frame
- Shaft
- Bearings
- Main Field Windings (Stator)
- Armature (Rotor)
- Commutator
- Brush Assembly

Of these components, it is important to understand the electrical characteristics of the main field windings, known as the stator, and the rotating windings, known as the armature. An understanding of these two components will help with the understanding of various functions of a DC Drive.



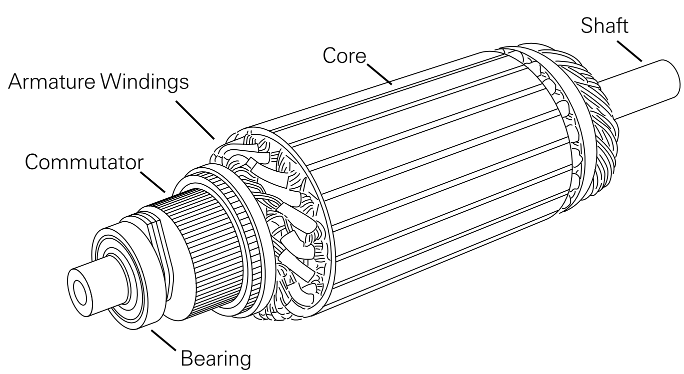
Basic Construction

The relationship of the electrical components of a DC motor is shown in the following illustration. Field windings are mounted on pole pieces to form electromagnets. In smaller DC motors the field may be a permanent magnet. However, in larger DC fields the field is typically an electromagnet. Field windings and pole pieces are bolted to the frame. The armature is inserted between the field windings. The armature is supported by bearings and end brackets (not shown). Carbon brushes are held against the commutator.



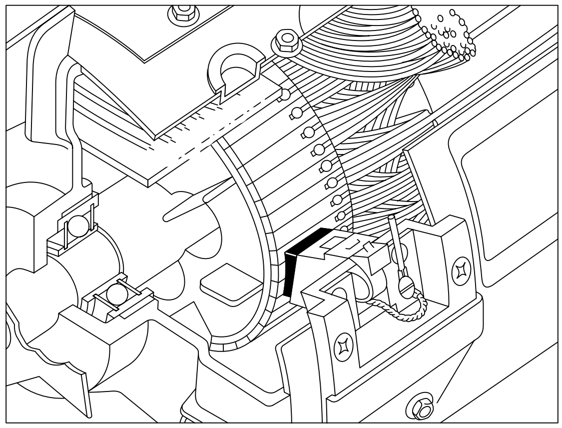
Armature

The armature rotates between the poles of the field windings. The armature is made up of a shaft, core, armature windings, and a commutator. The armature windings are usually form wound and then placed in slots in the core.



Brushes

Brushes ride on the side of the commutator to provide supply voltage to the motor. The DC motor is mechanically complex which can cause problems for them in certain adverse environments. Dirt on the commutator, for example, can inhibit supply voltage from reaching the armature. A certain amount of care is required when using DC motors in certain industrial applications. Corrosives can damage the commutator. In addition, the action of the carbon brush against the commutator causes sparks which may be problematic in hazardous environments.

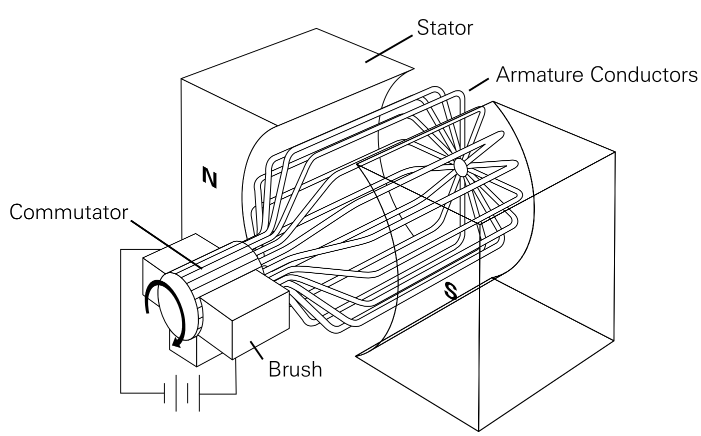


Basic DC Motor Operation

Magnetic Fields

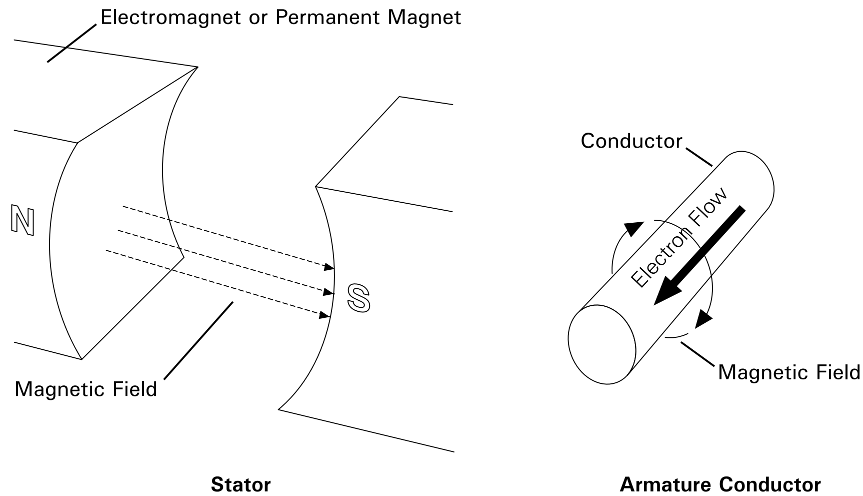
You will recall from the previous section that there are two electrical elements of a DC motor, the field windings and the armature. The armature windings are made up of current carrying conductors that terminate at a commutator. DC voltage is applied to the armature windings through carbon brushes which ride on the commutator.

In small DC motors, permanent magnets can be used for the stator. However, in large motors used in industrial applications the stator is an electromagnet. When voltage is applied to stator windings an electromagnet with north and south poles is established. The resultant magnetic field is static (non-rotational). For simplicity of explanation, the stator will be represented by permanent magnets in the following illustrations.



Magnetic Fields

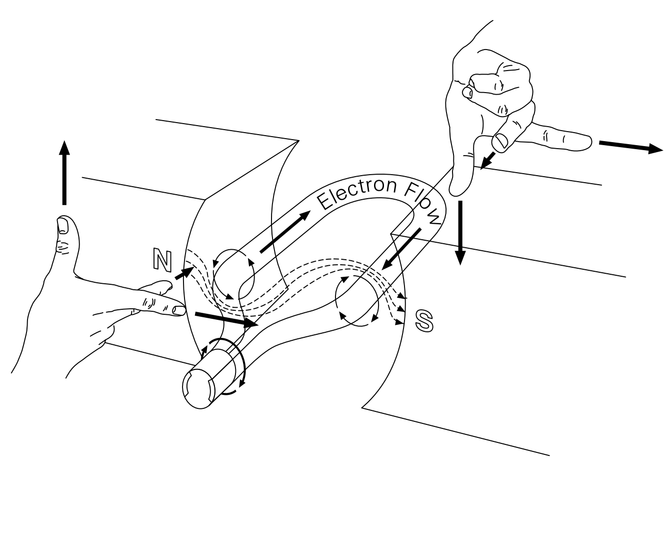
A DC motor rotates as a result of two magnetic fields interacting with each other. The first field is the main field that exists in the stator windings. The second field exists in the armature. Whenever current flows through a conductor a magnetic field is generated around the conductor.



Right-Hand Rule for Motors

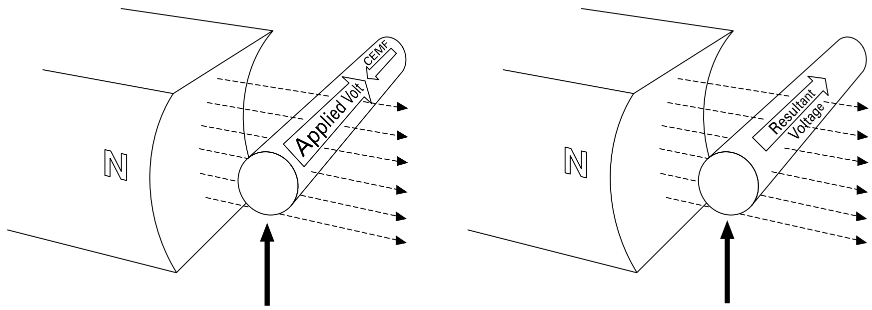
A relationship, known as the right-hand rule for motors, exists between the main field, the field around a conductor, and the direction the conductor tends to move.

If the thumb, index finger, and third finger are held at right angles to each other and placed as shown in the following illustration so that the index finger points in the direction of the main field flux and the third finger points in the direction of electron flow in the conductor, the thumb will indicate direction of conductor motion. As can be seen from the following illustration, conductors on the left side tend to be pushed up. Conductors on the right side tend to be pushed down. This results in a motor that is rotating in a clockwise direction. You will see later that the amount of force acting on the conductor to produce rotation is directly proportional to the field strength and the amount of current flowing in the conductor.



CEMF

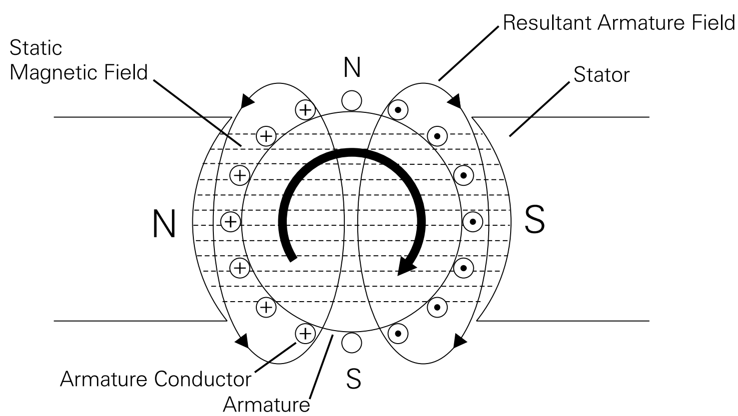
Whenever a conductor cuts through lines of flux a voltage is induced in the conductor. In a DC motor the armature conductors cut through the lines of flux of the main field. The voltage induced into the armature conductors is always in opposition to the applied DC voltage. Since the voltage induced into the conductor is in opposition to the applied voltage it is known as CEMF (counter electromotive force). CEMF reduces the applied armature voltage.



The amount of induced CEMF depends on many factors such as the number of turns in the coils, flux density, and the speed which the flux lines are cut.

Armature Field

An armature, as we have learned, is made up of many coils and conductors. The magnetic fields of these conductors combine to form a resultant armature field with a north and south pole. The north pole of the armature is attracted to the south pole of the main field. The south pole of the armature is attracted to the north pole of the main field. This attraction exerts a continuous torque on the armature. Even though the armature is continuously moving, the resultant field appears to be fixed. This is due to commutation, which will be discussed next.

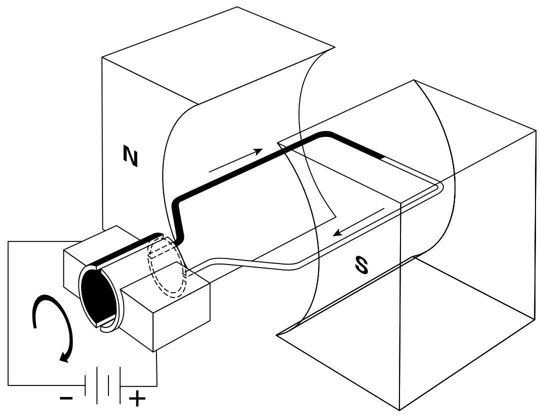


Commutation

In the following illustration of a DC motor only one armature conductor is shown. Half of the conductor has been shaded black, the other half white. The conductor is connected to two segments of the commutator.

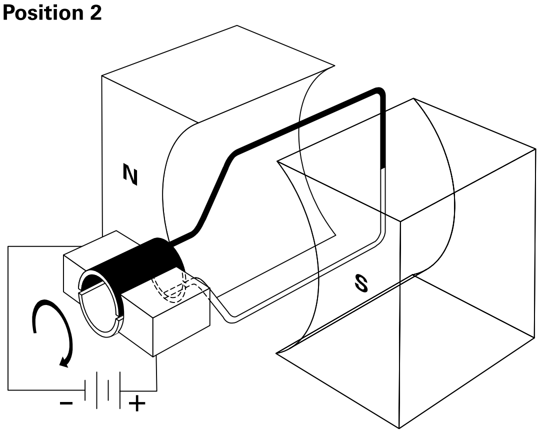
In position 1 the black half of the conductor is in contact with the negative side of the DC applied voltage. Current flows away from the commutator on the black half of the conductor and returns to the positive side, flowing towards the commutator on the white half.

Position 1



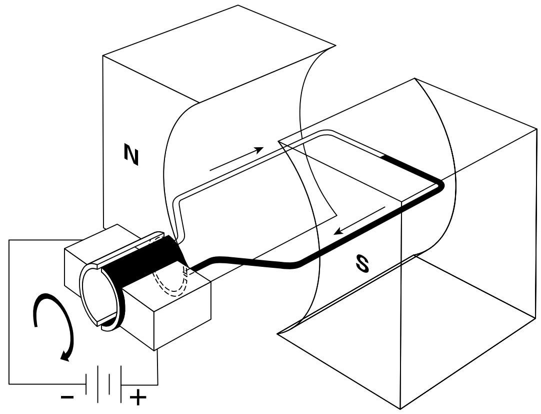
In position 2 the conductor has rotated 90°. At this position the conductor is lined up with the main field. This conductor is no longer cutting main field magnetic lines of flux; therefore, no voltage is being induced into the conductor. Only applied voltage is present. The conductor coil is short-circuited by the brush spanning the two adjacent commutator segments. This allows current to reverse as the black commutator segment makes contact with the positive side of the applied DC voltage and the white commutator segment makes contact with the negative side of the applied DC voltage.

Position 2



As the conductor continues to rotate from position 2 to position 3 current flows away from the commutator in the white half and toward the commutator in the black half. Current has reversed direction in the conductor. This is known as commutation.

Position 3

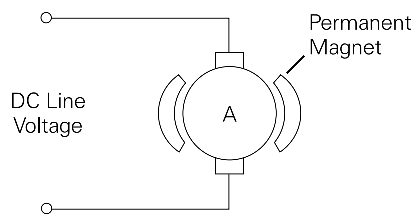


Types of DC Motors

The field of DC motors can be a permanent magnet, or electromagnets connected in series, shunt, or compound.

Permanent Magnet Motors

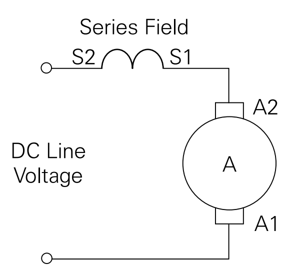
The permanent magnet motor uses a magnet to supply field flux. Permanent magnet DC motors have excellent starting torque capability with good speed regulation. A disadvantage of permanent magnet DC motors is they are limited to the amount of load they can drive. These motors can be found on low horsepower applications. Another disadvantage is that torque is usually limited to 150% of rated torque to prevent demagnetization of the permanent magnets.



Series Motors

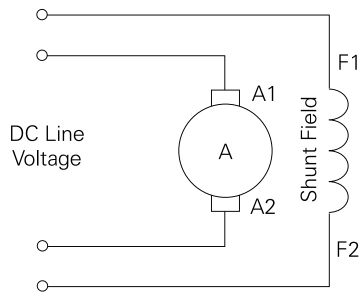
In a series DC motor the field is connected in series with the armature. The field is wound with a few turns of large wire because it must carry the full armature current.

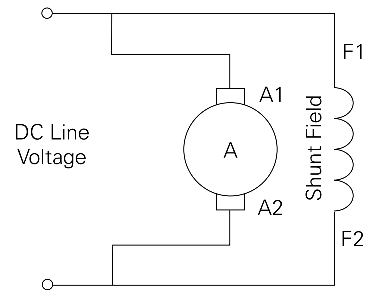
A characteristic of series motors is the motor develops a large amount of starting torque. However, speed varies widely between no load and full load. Series motors cannot be used where a constant speed is required under varying loads. Additionally, the speed of a series motor with no load increases to the point where the motor can become damaged. Some load must always be connected to a series-connected motor. Series-connected motors generally are not suitable for use on most variable speed drive applications.



Shunt Motors

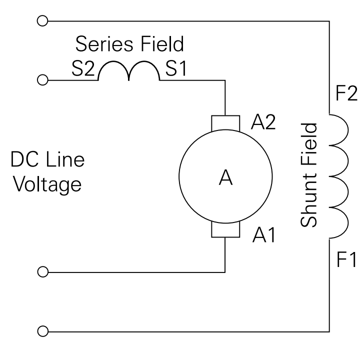
In a shunt motor the field is connected in parallel (shunt) with the armature windings. The shunt-connected motor offers good speed regulation. The field winding can be separately excited or connected to the same source as the armature. An advantage to a separately excited shunt field is the ability of a variable speed drive to provide independent control of the armature and field. The shunt-connected motor offers simplified control for reversing. This is especially beneficial in regenerative drives.





Compound Motors

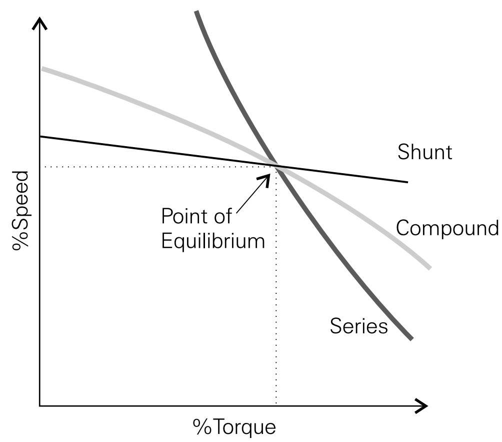
Compound motors have a field connected in series with the armature and a separately excited shunt field. The series field provides better starting torque and the shunt field provides better speed regulation. However, the series field can cause control problems in variable speed drive applications and is generally not used in four quadrant drives.



Speed/Torque Curves

The following chart compares speed/torque characteristics of DC motors.

At the point of equilibrium, the torque produced by the motor is equal to the amount of torque required to turn the load at a constant speed. At lower speeds, such as might happen when load is added, motor torque is higher than load torque and the motor will accelerate back to the point of equilibrium. At speeds above the point of equilibrium, such as might happen when load is removed, the motor's driving torque is less than required load torque and the motor will decelerate back to the point of equilibrium.



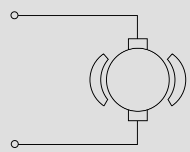
Review 2

1. The field in larger DC motors is typically an ____________ .

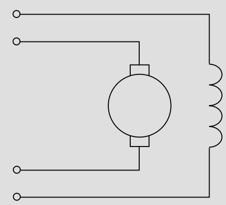
2. Whenever ____________ flows through a conductor a magnetic field is generated around the conductor.

3. Voltage induced into the conductors of an armature that is in opposition to the applied voltage is known as ____________ .

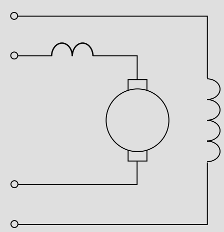
4. Identify the following motor types.



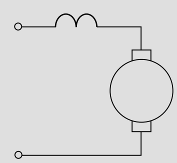
a ________________



c ________________



b ________________



d ________________