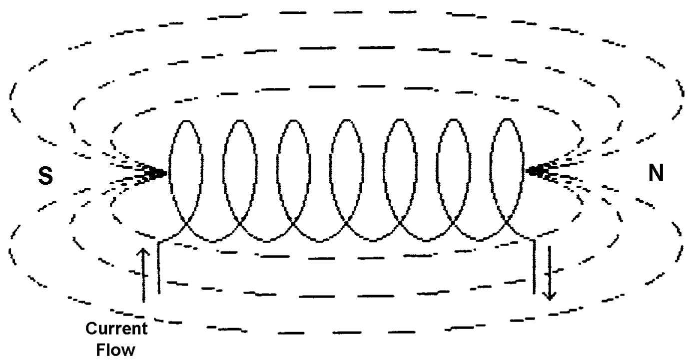
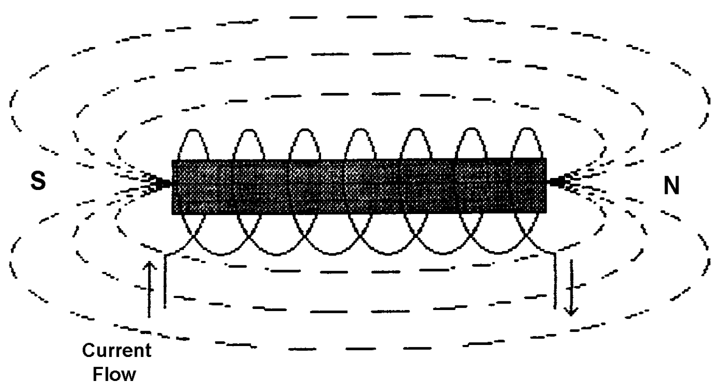
Motor Fundamentals

Before we can examine the function of a drive, we must understand the basic operation of the motor. It is used to convert the electrical energy, supplied by the controller, to mechanical energy to move the load. There are really two types of motors, AC and DC. The basic principles are alike for both. Magnetism is the basis for all electric motor operation. It produces the force required to run the motor. There are two types of magnets the permanent magnet and the electro magnet. Electro magnets have the advantage over permanent magnet in that the magnetic field can be made stronger. Also the polarity of the electro magnet can easily be reversed. The construction of an electro magnet is simple. When a current passes through a coil of wire, a magnetic field is produced.



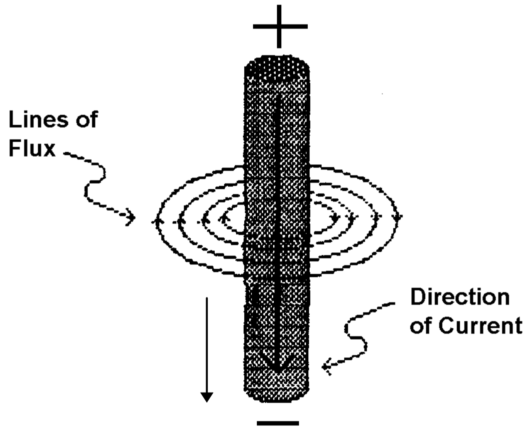
This magnetic field can be made stronger by winding the coil of wire on an iron core.



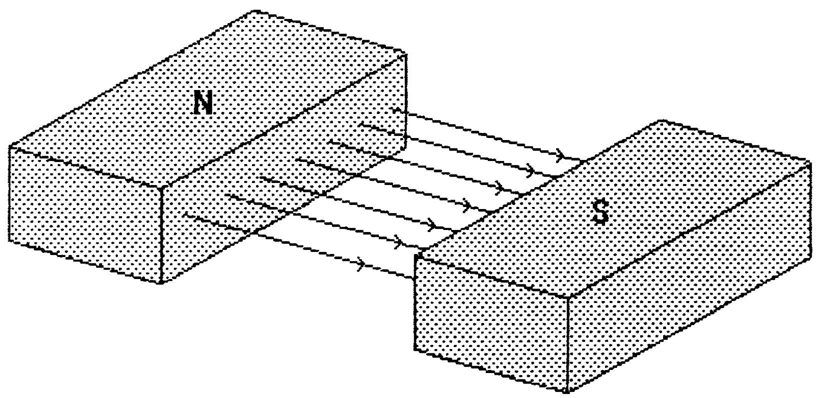
One end of the electro magnet is a north pole and the other end is a south pole The poles can be reversed by reversing the direction of the current in the coil of wire. Likewise, if you pass a coil of wire through a magnetic field, a voltage will be induced into the coil And, if the coil is in a closed circuit, a current will flow.

DC Motor

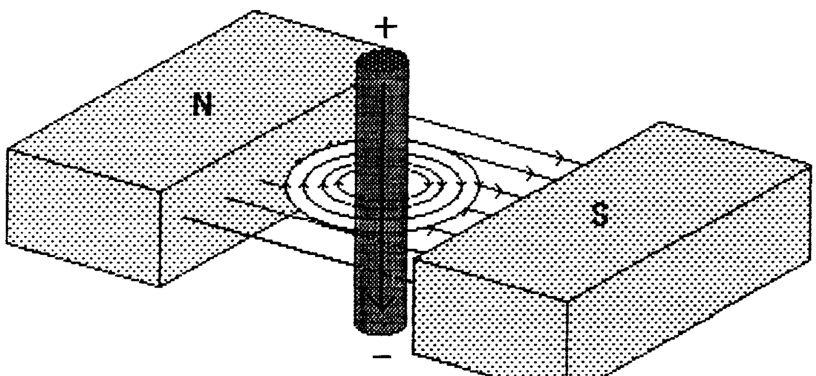
When a current passes through a conductor, lines of magnetic force (flux) are generated around the conductor. The direction of the flux is dependent on the direction of the current flow. If you are thinking in terms of conventional current flow (positive to negative) then, using your right hand point your thumb in the direction of the current flow and your fingers will wrap around the conductor in the same direction of the flux lines.



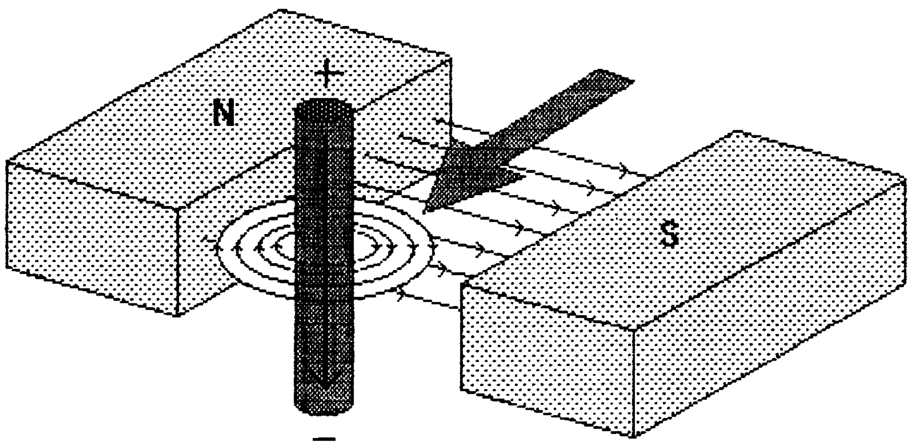
If you are thinking in terms of electron current flow (negative to positive) then you must use your left hand. If we look at the air gap between two magnets that have their opposite poles facing each other, we would see magnetic lines of force (flux) from the N to S poles.



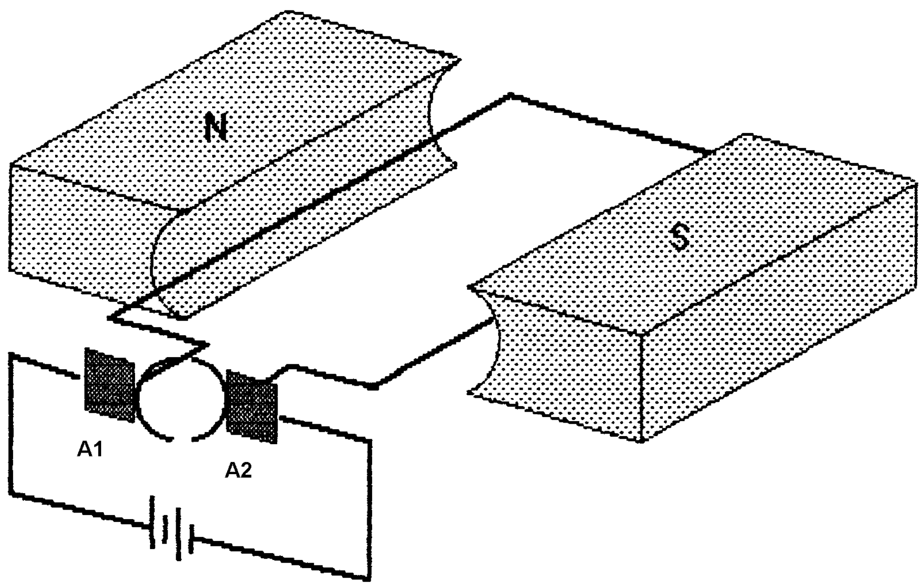
Now, if we place a current carrying conductor in the air gap of two magnets, the lines of flux in the air gap will be affected.



On the side of the conductor where the lines of flux oppose each other, the magnetic field will be made weaker. On the side of the conductor where the lines of flux are not opposing each other, the magnetic field will be made stronger. Because of the strong field on one side of the conductor and a weak field or, the other side, the conductor will be pushed into the weaker field.

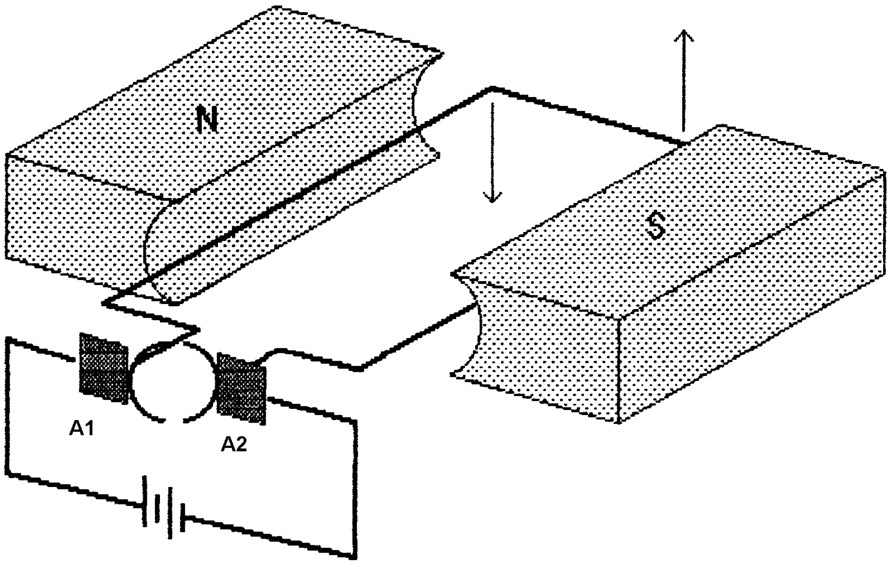


Now, lets apply this principle to the operation of the DC motor. The armature of the motor is a loop of wire (current carrying conductor) which is free to rotate. The field magnets are permanent or electro magnets with their N and S poles facing each other to set up the lines of flux in the air gap.



The armature is connected to the commutator which rides along the brushes which are connected to a DC power source. The current from the DC power source flows from the positive lead, through the brush labeled A1 through one commutator section, through the armature coil, through the other commutator section, through the brush labeled A2 and back to the negative lead.

This current will generate lines of flux around the armature and affect the lines of flux in the air gap. On the side of the coil where the lines of flux oppose each other, the magnetic field will be made weaker. On the side of the coil where the lines of flux are riot opposing each other, the magnetic field is made stronger. Because of the strong field on one side of the coil and the weak field on the other side, the coil will be pushed into the weaker field and, because the armature coil is free to rotate, it will rotate.



The torque available at the motor shaft (turing effort) is determined by the magnetic force (flux) acting on the armature coil and the distance from the renter of rotation that force is**.** The flux is determined by the current flowing through the armature coil and strength of the field magnets

By mathematics:

$$T = K_t \phi_F I_A$$

Where:

T = Torque
K_t = Torque constant
ϕ_F = % of field flux
I_A = Armature current

The rotational speed (N) of the motor is determined by the voltage applied to the armature coil**.**

By mathematics:

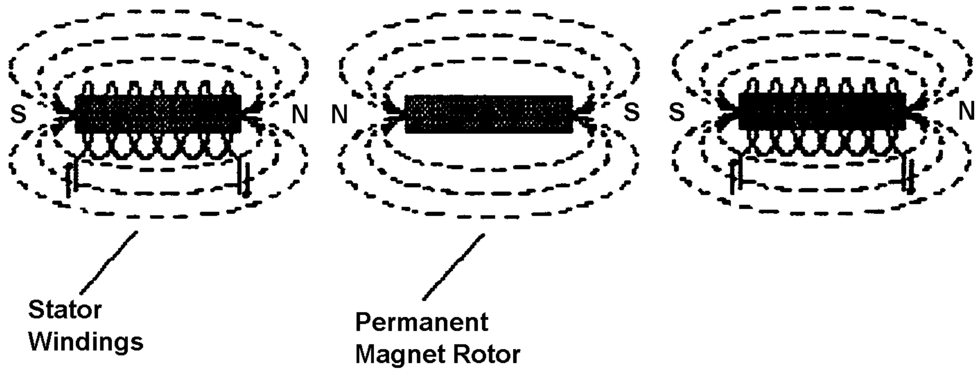
$$N = \frac{E_T - I_A R_A}{K_V \phi_F}$$

Where:

N = speed (rpm)
E_T = terminal voltage
I_A = amature current
R_A = armature resistance
K_V =voltage constant
ϕ_F = % of field flux

AC Motor

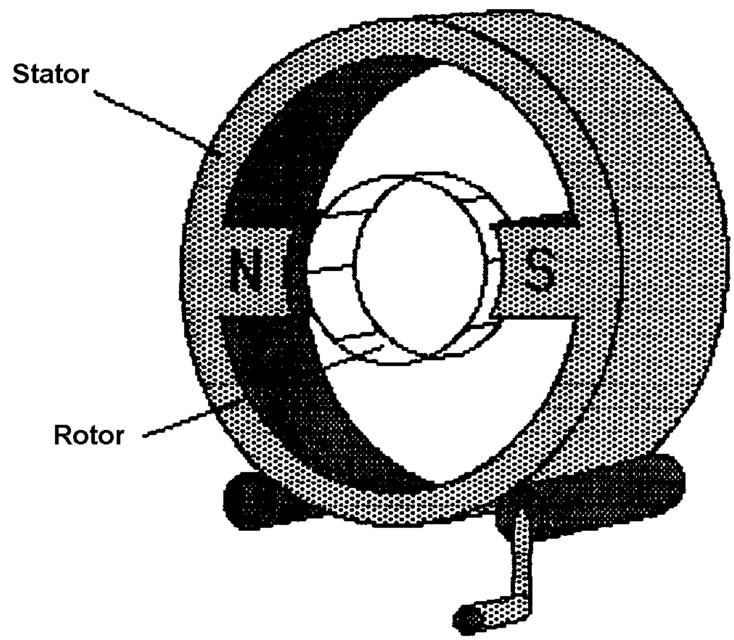
The AC motor operates on the same principle of the OC motor (interaction between magnetic lines of flux). One major difference is the OC motor requires DC current and the AC motor requires AC current. There are basically two types of AC motors: synchronous and induction. The basic principle for synchronous motors can be shown using two electro magnets and a permanent magnet.



We can pass current through the coils in a direction so the north and south poles are aligned with the permanent magnet. The permanent magnet is free to rotate and is therefore called the rotor. The electro magnets are stationary and are therefore called the stator. Initially if the north and south poles are aligned in the motor and, because like poles repel and unlike poles attract, the rotor will be pushed by the magnetic force of the like poles. As it rotates, it will be pulled by the magnetic force of the unlike poles.

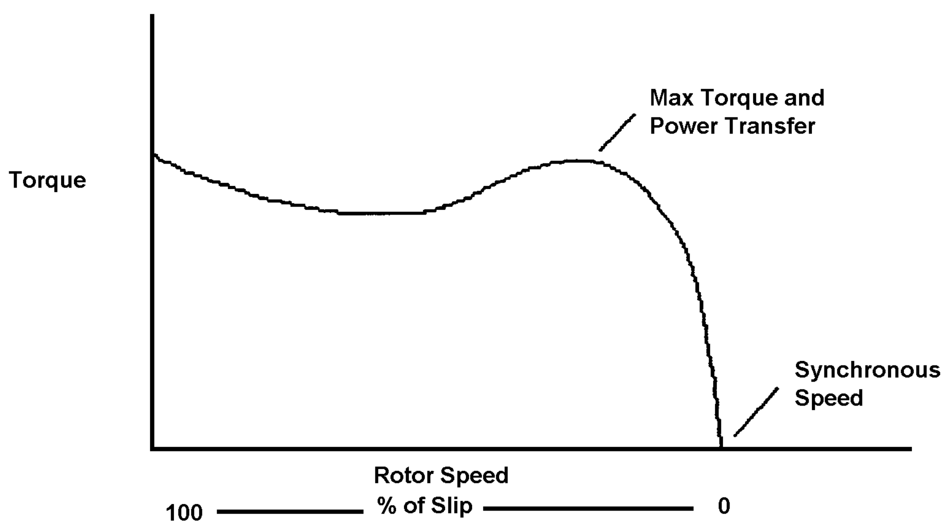
Once the rotor's north and south poles line up with the stator's south and north poles the stator current is reversed, thus changing the south and north pole orientation in the stator and the rotor is pushed again. This process repeats until the current in the stator stops alternating or stops flowing. In a three phase (30) motor, the stator flux (magnetic force) does not just alternate back and forth but it actually rotates around the motor and the rotator actually follows this rotating magnetic field. This type of motor is called a synchronous motor because it always runs at synchronous speed (rotor and magnetic field of stator are rotating at exactly the same speed). Maximum torque is achieved when the stator flux vector and the rotor flux vector are 90° apart.

The induction motor operates much the same way that the synchronous motor does It uses the same magnetic principles to couple the stator and the rotor. However, one major difference is the synchronous motor uses a permanent magnet rotor and the induction motor uses iron bars arranged to resemble a squirrel cage.



As the stator magnetic field rotates in the motor, the lines of flux produced will cut the iron bars and induce a voltage in the rotor. This induced voltage will cause a current to flow in the rotor and will generate a magnetic field. This magnetic field will interact with the stator magnetic field and will produce torque to rotate the motor shaft; which is connected to the rotor. The torque available at the motor shaft is determined by the magnetic force (flux) acting on the rotor and the distance from the center of rotation that force is.

The flux is determined by the current flowing through the stator windings. Another factor determining torque and another difference between the induction motor and the synchronous motor is slip. Slip is the difference between the stator magnetic field speed and the rotor speed. As implied earlier, in order for a voltage to be induced into a conductor, there must be a relative motion between the conductor and the magnetic lines of flux. Slip is the relative motion needed in the induction motor to induce a voltage into the rotor. If the induction motor ran at synchronous speed, there would be no relative motion and no torque would be produced. This implies that the greater the slip, the greater the torque. This is true to a limit. (Please see speed/torque curve below)



The above curve shows the speed/torque characteristics that the typical induction motor would follow, excited by a given voltage and frequency. We can see by this curve that the motor produces zero torque at synchronous speed because there is no slip. As we apply a load, the rotor begins to slow down which creates slip. At about 1 0E slip (at the knee of the curve) we get maximum torque and power transfer from the motor. This is really the best place on the curve to operate the motor.

Vector control (slip control) from a closed loop drive system can be used to keep the motor operating at this optimum point on the curve. Vector control is implemented using a microprocessor based system that has a mathematical model of the motor in memory and a position transducer on the motor to indicate rotor.

The mathematical model allows the microprocessor to determine what the speed/torque curve the motor will follow with any applied voltage and frequency, will be. This will allow the system to control the slip in the motor to keep it operating at the knee of the speed/torque curve. This technology achieves extremely high performance. Now that we have a basic understanding of the operation of the motor, we can better understand the function and operation of the high performance drive.

By mathematics:

$$T = K_t I_{rms}$$

$$N = \frac{120 f}{P}$$

Where:

T = Torque
K_t = Torque constant
I_{rms} = rms motor current
N = Speed (rpm)
f = Frequency of stator current
P = Number of poles