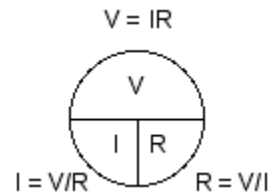


Relationships

Voltage (V), Current (I), and Resistance (R) are all related, by the following formula:

Volts = Amps x Ohms, or

$$V = I \times R$$

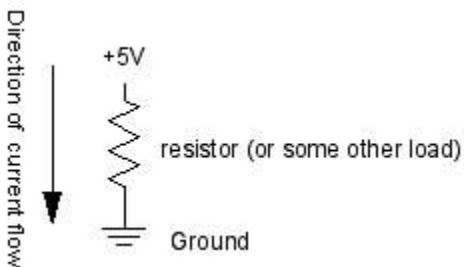


Current (I), voltage (V), and resistance (R) are also related to electrical power (P) (measured in watts), as follows:

Watts = Volts x Amps or

$$W = V \times A$$

Electrical current flows from places of higher potential energy to places of lower potential energy (i.e. from positive to negative).



Ground is the place in a circuit with where the potential energy of the electrons is zero. Sometimes this point is connected to the actual ground, either through a grounded electrical circuit, water pipe, or some other method. Basically, any conductor that goes to the earth will do.

A few important rules:

Current follows the path of least resistance to the ground. So if it has a choice of two paths in a circuit, and one has less resistance, that's the path it'll take.

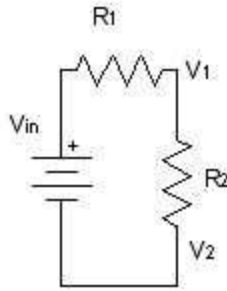
In any given circuit, the total voltage around the path of the circuit is zero. Each component that offers a resistance lowers the voltage, and by the time we reach the end of the circuit loop, there will be no voltage left.

The amount of current going into any point in a circuit is the same as the amount coming out of that point.

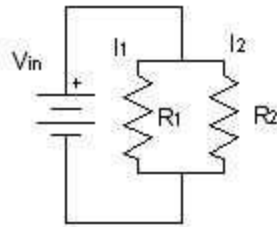
These last two rules give us a way to figure out what's going on when we put components in a circuit. When we look at how components in a circuit are placed in relation to each other, there are two ways we can do it: one in line after another, or side by side. When they are one in line after another, we say the components are in **series** with one another. Side by side, they are in **parallel** with one another.

Let's look at how the current and voltage changes when components are in series or in parallel:

When two components are in series, they are placed one after another, like so:



When resistors are in series, the voltage drops across each resistor, and the total resistance is equal to the sum of all the resistors. We know in the above circuit, the current anywhere is constant. We know the voltage drops across each resistor, and we know that the total of all the voltage drops equals the voltage across the battery. So $V_{in} = V_1 + V_2$. If we know the values of the resistors, we can use the formula $V = I \times R$ to calculate the exact voltages at each point. When two components are in parallel, they are placed beside each other, like this:



For resistors in parallel, the voltage across them is equal, but the current is divided between them. The total current is constant, however, so we know that the divided current across the parallel resistors is equal to the total current. So $I_1 + I_2 = I_{total}$.

Though it's sometimes useful to think about the mathematical relationships of parallel and series circuits, it's often more useful to think about them in terms of practical effects. Again, think of the water metaphor. For the series example, if one resistor lowers the voltage (water pressure), only a smaller voltage (trickle of water) gets through to the next. For the parallel example, the amount of water from the main stream (total current) gets divided into two streams, but the total amount of water flowing through those two streams is equal to the original amount of water. Keeping in mind these basic relationships will help you figure out what the effect of one component is on another when you see them in a circuit together, even if you don't know (or care about) their precise mathematical relationship.

Terminology

Mass is defined as *the measure of how much matter an object or body contains*. Mass is important for calculating how quickly things accelerate when we apply a force to them.

Force can be described as a push or pull that can cause an object with mass to change its velocity (which includes to begin moving from a state of rest). Force causes **acceleration**. Newton's Second Law states that the *acceleration (a) of an object is directly proportional to the force (F) applied, and inversely proportional to the object's mass (m)*.

$$F = ma$$

To honor Newton's achievement, the standard unit of force in the SI system was named the **newton**. One newton (N) of force is enough to accelerate 1 kilogram (kg) of mass at a rate of 1 meter per second squared (m/s^2).

International System of Units (SI)

Gram (g)

$$1 \text{ g} = 0.001 \text{ kg}$$

Kilogram (kg)

$$1 \text{ kg} = 2.2 \text{ lbm}$$

Torque is a *force that tends to rotate or turn things*. You generate a torque any time you apply a force using a wrench. The unit is the Newton-meter, which contains a distance and a force. To calculate the torque, you just multiply the force by the distance from the center.

Ex. Tightening the lug nuts on your wheels is a good example. When you use a wrench, you apply a force to the handle. This force creates a torque on the lug nut, which tends to turn the lug nut. In the case of the lug nuts, if the wrench is a foot long, and you put 200 pounds of force on it, you are generating 200 pound-feet of torque. If you use a 2-foot wrench, you only need to put 100 pounds of force on it to generate the same torque.

Work is the *application of a force over a distance*, with one catch -- the distance only counts if it is in the direction of the force you apply.

Power is a measure of how quickly work can be done. The SI unit for power is the watt.

International System of Units (SI)

Watts (W)

$$1000 \text{ W} = 1 \text{ kW}$$

Kilowatt (kW)

$$1 \text{ kW} = 1.341 \text{ hp}$$

Energy is a *measure of how long we can sustain the output of power*, or how much work we can do. Power is the rate at which we do the work. One common unit of energy is the kilowatt-hour (kWh). If we are using one kW of power, a kWh of energy will last one hour. If we use 10 kW of power, we will use up the kWh in just six minutes.

MOTORS

Most all motors work on the electrical principle of induction. When you put electric current through a wire, it generates a magnetic field around the wire. By placing a charged coil of wire in an existing magnetic field (say, between two magnets), the coil will be either attracted to one magnet and repelled by the other, or vice versa, depending on the current flow. The higher the current, the greater the magnetic field, and therefore the greater the attraction or repulsion. The coil is mounted on a spinning shaft in the middle of the motor. As the coil is alternately attracted to one magnet and repulsed by the other, it spins from one to the other, and we get circular motion.

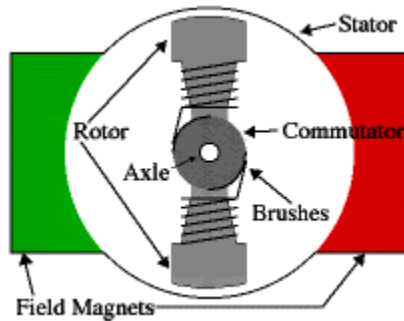
All inductive loads (like motors, electromagnets, and solenoids) work on this same principle: induce a magnetic field by putting current through a wire, use it to attract or repulse a magnetic body. However, the principle works in reverse as well. When you spin a wire in an existing magnetic field, the field induces a current in the wire. So if you've got a motor spinning, and you turn it off, the fact that the motor's coil is spinning in a magnetic field will generate a current in the wire for a brief amount of time. This current comes back in the reverse direction of the current flow you generated to run the motor. It's called blowback, or back voltage, and it can cause damage to your electronics. Usually it's stopped by putting a diode in line with your motor, to stop the back voltage. (Above taken from Igoe's site)

(Above taken from Tom Igoe's site)

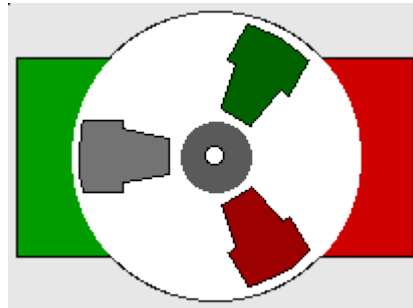
DC Motors



A simple DC motor has a coil of wire that can rotate in a magnetic field. The current in the coil is supplied via two brushes that make moving contact with a split ring. The coil lies in a steady magnetic field. The forces exerted on the current-carrying wires create a torque on the coil. Torque is a measure of how much a force acting on an object causes that object to rotate.



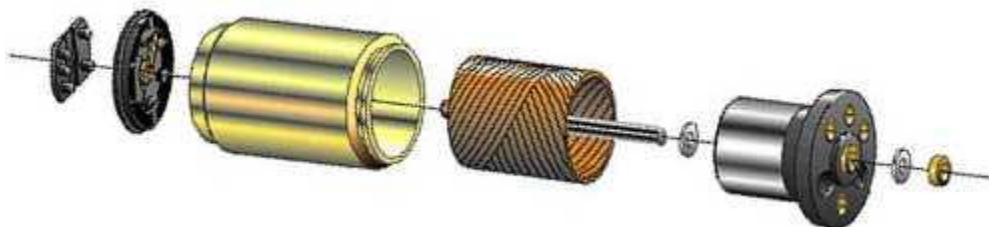
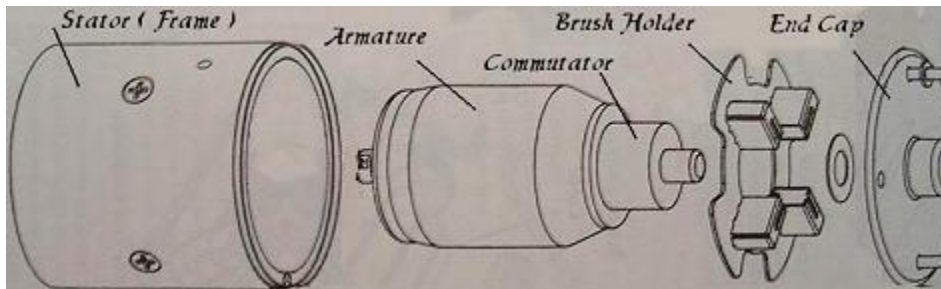
2 pole DC



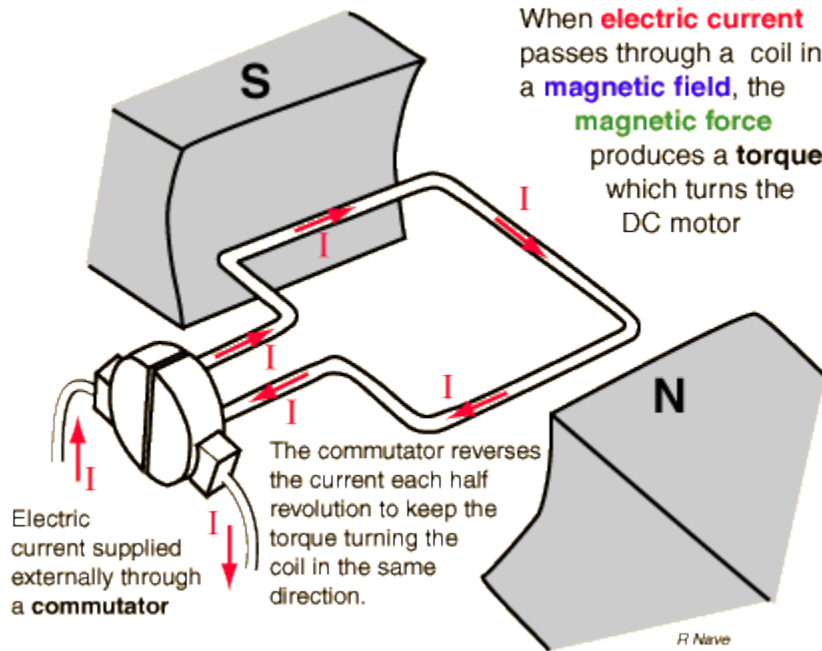
3 pole DC

A simple motor has six parts:

- **Armature or rotor**
- **Commutator**
- **Brushes**
- **Axle**
- **Field magnet**
- **DC power supply** of some sort



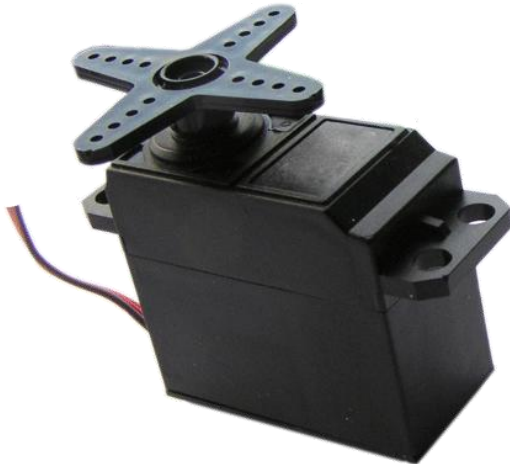
See animation of motors: [http://en.wikibooks.org/wiki/A-level_Physics_\(Advancing_Physics\)/Motors](http://en.wikibooks.org/wiki/A-level_Physics_(Advancing_Physics)/Motors)



Current in DC Motor Diagram

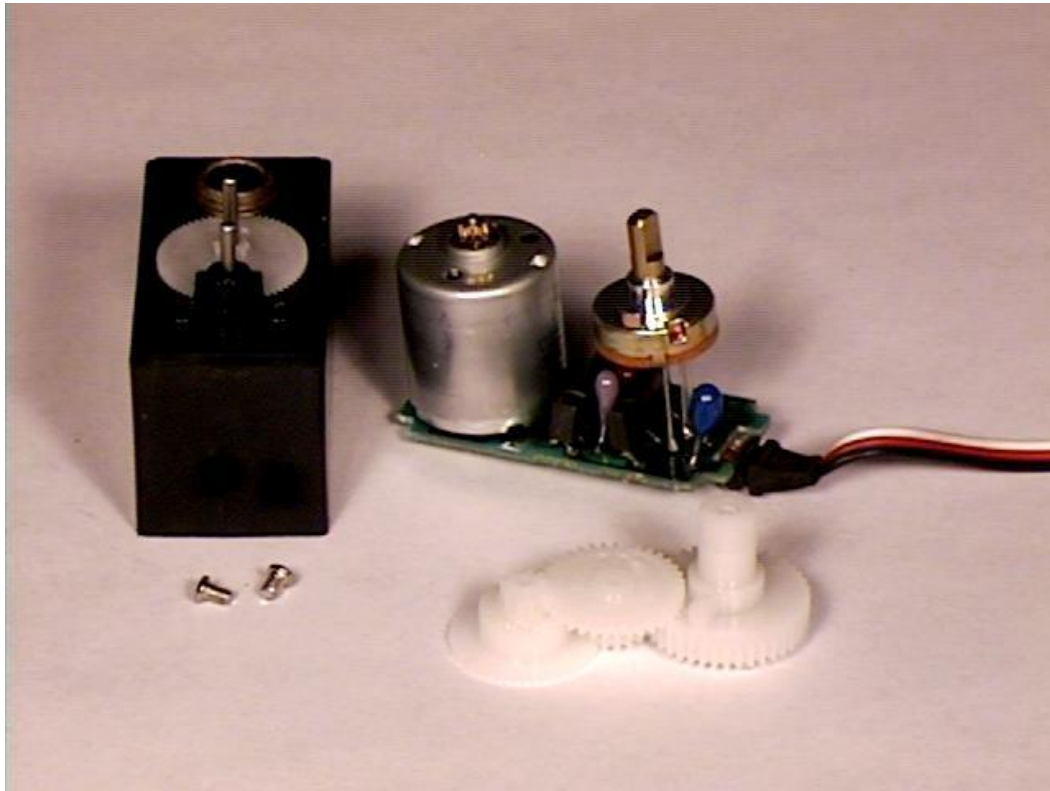
Servo Motors

- DC or AC (We will be dealing with DC)
- Brushed or Brushless type
- Used in Radio Controlled (RC) planes, cars, puppets, robots



- Small and extremely powerful for their size
- the speed and current draw is affected by the load. when lightly loaded it doesn't consume much energy

The control circuitry to perform good servoing of a DC motor is MUCH more complex than the circuitry that controls a stepper motor.



Interior of a servo: motor, set of gears, potentiometer, built in control circuitry

Notice the 3 wires:

RED: power (+5V)

BLACK: ground

WHITE: the control wire

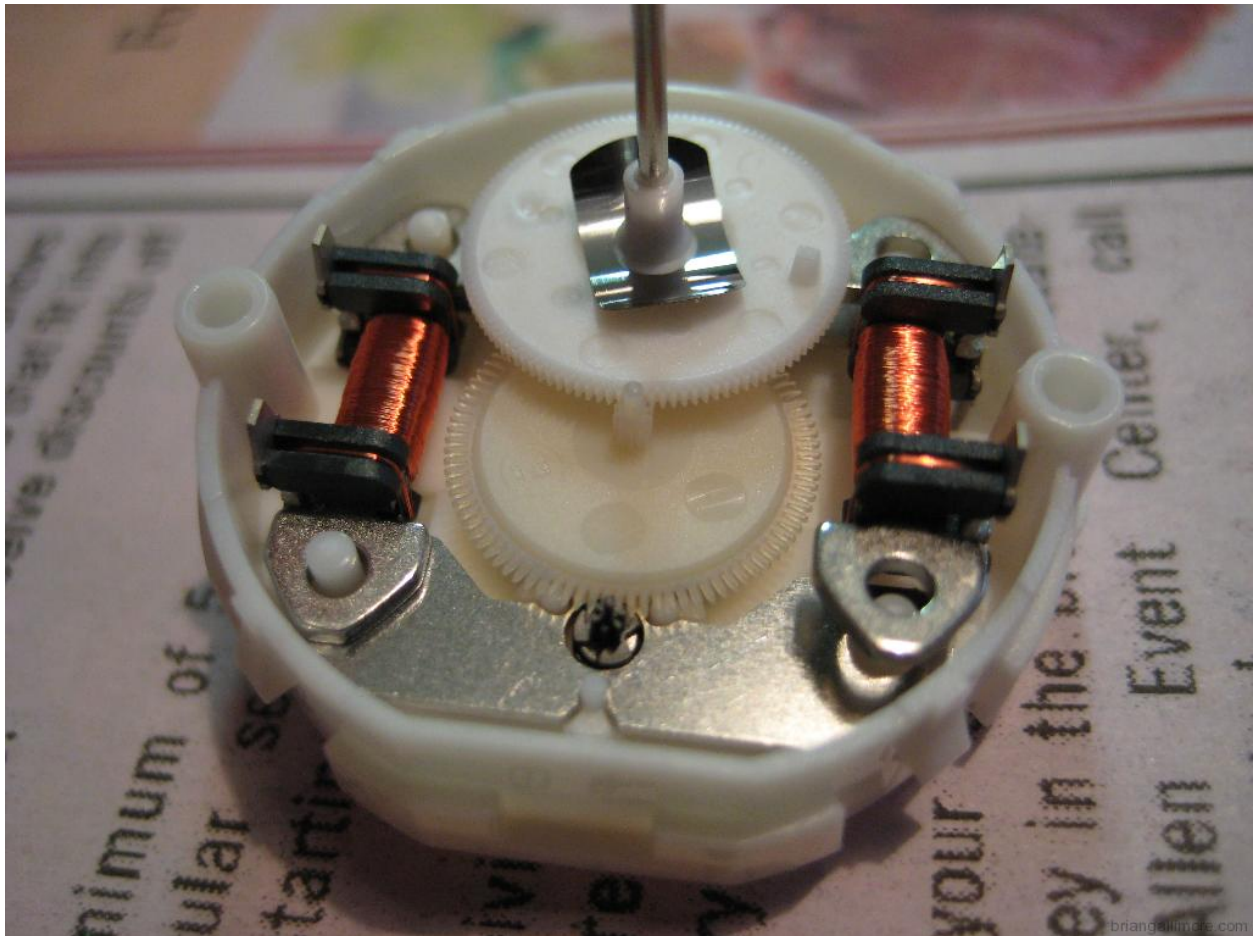
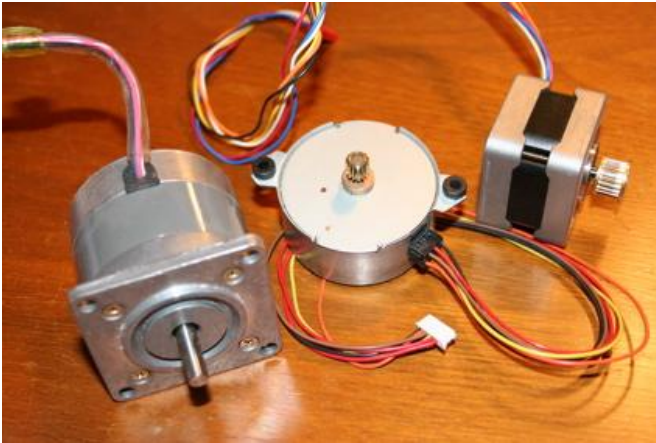
The servo motor has some control circuits and a potentiometer (a variable resistor, aka pot) that is connected to the output shaft. In the picture above, the pot can be seen on the right side of the circuit board. This pot allows the control circuitry to monitor the current angle of the servo motor. If the shaft is at the correct angle, then the motor shuts off. If the circuit finds that the angle is not correct, it will turn the motor the correct direction until the angle is correct. The output shaft of the servo is capable of travelling somewhere around 180 degrees. Usually, its somewhere in the 210 degree range, but it varies by manufacturer. A normal servo is used to control an angular motion of between 0 and 180 degrees. A normal servo is mechanically not capable of turning any farther due to a mechanical stop built on to the main output gear.

The amount of power applied to the motor is proportional to the distance it needs to travel. So, if the shaft needs to turn a large distance, the motor will run at full speed. If it needs to turn only a small amount, the motor will run at a slower speed. This is called proportional control.

(Above taken from: <http://www.seattlerobotics.org/guide/servos.html>)

Stepper Motors

- Unipolar: 4,5,6, and even 8 wires
- Bipolar: 4 wires



- there are many integrated circuits (ICs) dedicated to driving them (ex. L397/L398)
- the stepper motor can move only in steps, or even a microstep
- it steps thru 360 degrees = 1 rotation
- very useful when you desire a particular angular position from a motor

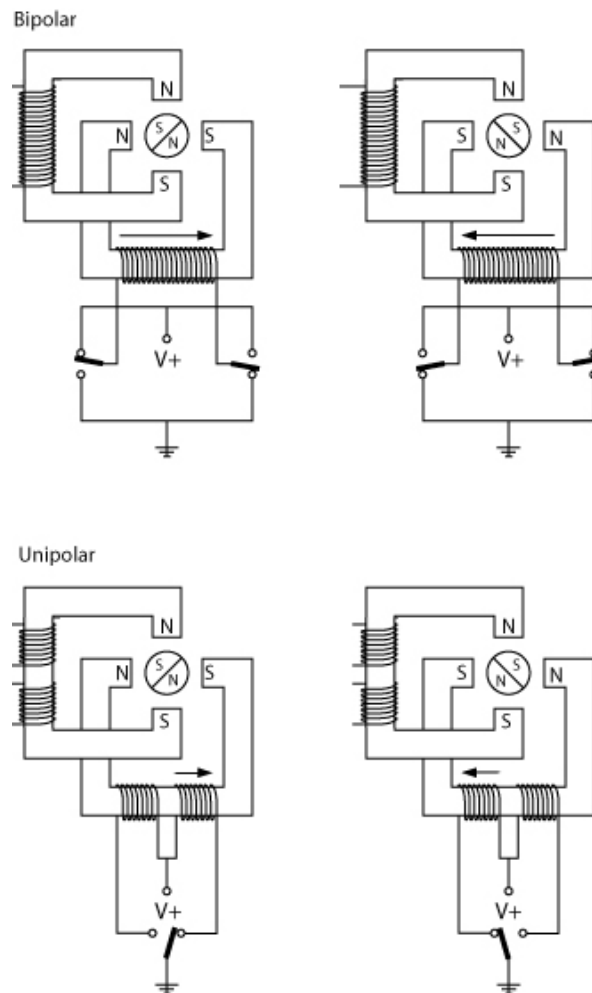
A stepper motor's shaft has permanent magnets attached to it. Around the body of the motor is a series of coils that create a magnetic field that interacts with the permanent magnets. When these coils are turned on and off the

magnetic field causes the rotor to move. As the coils are turned on and off in sequence the motor will rotate forward or reverse. This sequence is called the phase pattern and there are several types of patterns that will cause the motor to turn. Common types are full-double phase, full-single phase, and half step. To make a stepper motor rotate, you must constantly turn on and off the coils. If you simply energize one coil the motor will just jump to that position and stay there resisting change. This energized coil pulls full current even though the motor is not turning. The stepper motor will generate a lot of heat at standstill. The ability to stay put at one position rigidly is often an advantage of stepper motors. The torque at standstill is called the holding torque.

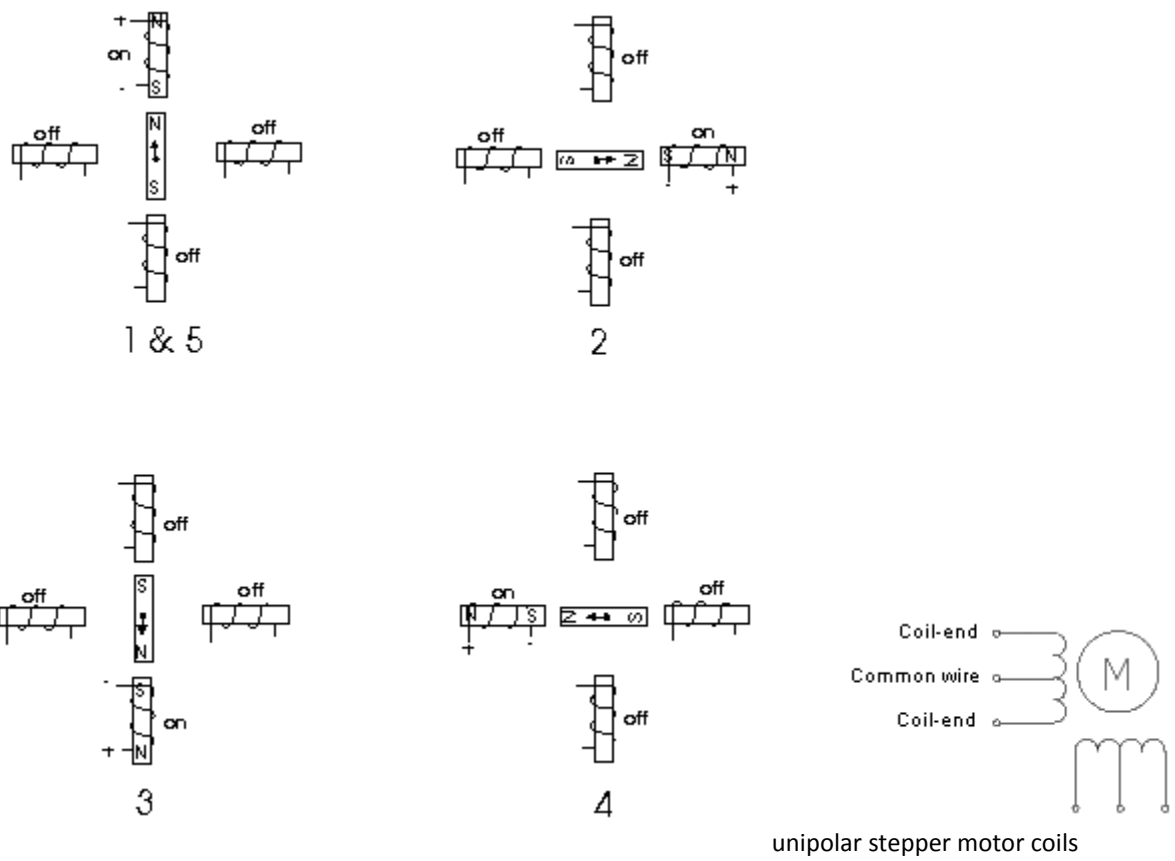
Because steppers can be controlled by turning coils on and off, they are easy to control using digital circuitry and microcontroller chips. The controller simply energizes the coils in a certain pattern and the motor will move accordingly. At any given time the computer will know the position of the motor since the number of steps given can be tracked. This is true only if some outside force of greater strength than the motor has not interfered with the motion.

An optical encoder could be attached to the motor to verify its position but steppers are usually used open-loop (without feedback). Most stepper motor control systems will have a home switch associated with each motor that will allow the software to determine the starting or reference "home" position.

Unipolar motors were at one time much cheaper to use because they needed less complicated circuitry. Rather than switching the direction of current through its coils, a unipolar motor simply has two sets of coils dedicated to the 2 possible directions of current flow. Bipolar motors have only one coil and depend on external circuitry to switch the current through them. Unipolar motors can only dedicate half their coil toward motion in one direction, whereas bipolar motors can devote all. **The end result is that bipolar motors, with essentially the same coil mass, deliver about 40% higher torque.**



Bipolar vs. Unipolar Stepper Motors



Comparison of motor types^[13]

Type	Advantages	Disadvantages	Typical Application	Typical Drive
Stepper DC	Precision positioning High holding torque	Requires a controller	Positioning in printers and floppy drives	DC
Brushless DC	Long lifespan low maintenance High efficiency	High initial cost Requires a controller	Hard drives CD/DVD players electric vehicles	DC
Brushed DC	Low initial cost Simple speed control	High maintenance (brushes) Low lifespan	Treadmill exercisers automotive starters	Direct DC or PWM (Pulse Width Modulation)

Looking for motors keep in mind the following

Voltage

The rated voltage of a motor is the voltage at which it operates at peak efficiency. Most DC motors can be operated somewhat above or below their range, but it's best to plan to operate them at their rated voltage. Dropping below rated voltage reduces the motor's power, and operating above the rated voltage may burn the motor out. Plan on the motor's top speed being at rated voltage, and slowest speed at no more than 50% less than the rated voltage.

Current

Motors draw current depending on the load they're pulling. Usually more load means more current. Every motor has a *stall current*, which is the current it draws when it's stopped by an opposing force. This stall current is much greater than the *running current*, or current that it draws under no load. Your power supply for a motor should be able to handle the stall current with extra amperage to spare. Motors may draw near the stall current for a brief period of time when starting up, to overcome their inertia.

Speed

Motor speed is given in revolutions per minute (RPM's).

Torque

Torque is the measure of a motor's pulling force. It's measured by the force a motor can pull when the opposing force is attached to a shaft attached to its center rod. If the shaft sticks out a foot from the motor's center, and the motor can pull one pound on that shaft, the motor's torque is one foot-pound. Motor manufacturers haven't standardized this measurement, so sometimes you will see it as ft.-lb., lb-ft., oz.-in, in.-oz., g-cm (gram-centimeter), and any other weight to length variation you can think of.

Resistance

Often you'll see a motor rated in ohms. This just gives you the resistance that the motor's coil offers. Using Ohm's Law (voltage = current x resistance), you can calculate the motor's current draw if you know the rated voltage and the coil resistance.

Links:

<http://www.tigoe.net/pcomp/code/motors>

<http://www.epanorama.net/links/motorcontrol.html>