Motors and Generators

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Ideas to Implementations

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Motors and Generators

1 a). A Simple DC motor

The motor effect is very simple: A wire carrying current in a magnetic field experiences a force. A really simple demo of this can be done with a battery, a magnet and some wire.

![Image of a simple DC motor setup](http://www.exploratorium.edu/nacks/gm_images/stripped_motor_1_400x229.gif)

Wind the wire into a loop, and sit it on top of some contacts (paperclips are good) soldered to the end of a D cell. Blu tack a magnet beneath the loop and away you go.

The looped wire is best if it is enameled (has a clear insulating coating around it). To get a contact you need to strip off this insulation. Of course if you strip off the whole coating then the loop will not rotate but rock back and forth – it needs a commutator.

The trick is that you create a commutator by stripping only 1 side of the wire. Then the loop will only experience force half the time, in only one direction. It can be tricky to get it just right, the loop needs to be pretty well-balanced to rotate easily enough to build up momentum, but when you get it right it goes by itself without even a kick from you.

The ones we use in Kickstart are from Arbor scientific, www.arborsci.com

1 b) Universal motor

Universal motors are a kind of hybrid of the AC and DC motors. AC induction motors are not very efficient for heavy loads, DC is much better. But the power from the wall is AC, so high power motors, like drills are designed to act like a DC motor, but using an AC current.

The universal motor is just like a DC motor, but will run off an AC power source. This is achieved by replacing the permanent magnets in the stator with electromagnets (coils). These coils are wound in such a way as to replace the permanent magnets – if you run the universal motor on a DC source, it will still work, in exactly the same way. However if you connect an AC source of course the poles of the magnet will be constantly varying as the current varies.
But the current through the rotor coil is changing too – in phase with the electromagnets – and so the force be in the same direction.

This is a very useful type of motor, and therefore is very common. With the exception of the fan, most of the appliances in your house will use these: drills, washing machine etc.

2. Lenz’s Law

Simple and very effective demonstrations of Lenz’s law can be made from strong magnets and metal.

a) Falling magnets

Strong Neodymium earth magnets can be bought from http://www.amfmagnetics.com.au/

Buy some 20 mm copper pipe from a hardware store and away you go. Compare with an identical length of 20 mm PVC pipe.

Getting a bit more complex, try some different metals. Aluminium works well – it is a pretty good conductor (26 nΩm as against Cu 17 nΩm), but alloys such as brass are not good conductors (their lattice structure is not as regular as a pure metal.

And hacksaw a slit lengthwise in the copper pipe. You might expect the magnet would not be slowed then, but Lo! it still lingers in the pipe. This shows that eddy currents are not only in one plane of rotation. They are at all kinds of angles – they will form in any way they can to oppose the magnet’s motion. The important part is that the pipe has a non-uniform magnetic field. The part of the pipe closest to the magnet will have the strongest field, and therefore will have eddy currents flowing as expected. Away from the magnet (above or below) the change in flux is smaller, so the EMF will still be in the same direction, however the EMF caused by the adjacent piece of the conductor which is closer to the magnet will overcome this, so the electrons will flow away from the magnet and then back across to where they started from.

To clarify this, think about a small piece of metal falling through an even magnetic field. There is a EMF induced in the metal: all the electrons will flow to one side (as defined by the right hand rule/Fleming’s rule/FBI) but there will be no circular current induced. Every part of the conductor is experiencing the same EMF, so there is no way back; that is until the bottom piece of the metal begins to emerge, this area of lower field will allow a return path for the electrons. The same situation will have occurred as the metal entered the magnetic field.

Note that only where the current moves (and therefore induces a magnetic field) is there an opposing force. Hence in the above example (which I think came from a recent Catholic education trial paper) the metal is slowed as it enters the field, but once it is fully in the field, no current is induced so no opposing force is experienced, so it will fall at 9.8 m/s². Then as it begins to exit the field, it will be slowed again by Lenz’s law.

So for the same magnet which metal has the highest EMF?

Lenz’s Law (or Faraday’s Law) tells us that the EMF is proportional to the change in flux – it is nothing to do with the pipe it is falling through! They all have the same EMF! However because of the different resistances, the currents induced are different – hence the different opposing forces. Even the PVC has an EMF induced, but no current flows at all.

b) Rolling Magnets

Another form of the same experiment is to roll the magnet down a sheet of metal. Experiment with different metals, different thicknesses, and different angles.

c) Jumping rings

The jumping ring apparatus is a very dramatic demonstration of the opposition due to Lenz’s law. But it goes further than that, because of the AC current. If we divide the AC current in the coil into four sections – increasing North, decreasing North, increasing South, decreasing South – we see that the ring is not always repelled; whenever the field is decreasing the ring should attract. But it never does!

The reality of the situation is that there is a phase lag. As the coil induces a current, the ring reacts, but not immediately. (In electronics this is known as inductance). If you do the maths – which is not trivial (see attached paper) – then you can prove that there will always be opposition due to this effect.
3. Induction motors

AC induction motors are tricky to explain conceptually. The heart of it is a rotating magnetic field. Lenz’s law tells us that there will be an opposition to the moving magnetic field. The rotation of the field will cause rotation of the rotor – it’s trying to minimize their relative rotational speeds.

The fact that the magnetic field is rotating is easily understood in the case of a three-phase (three-pole) motor. The phases of the current are out of phase by 120 degrees, just the right amount to make the fields of the electromagnets staggered.

In the case of a single-phase motor it is not so clear. Once the rotor is spinning, it will see a rotating magnetic field, so it will continue to spin. However from a standing start, it should only experience attraction to or repulsion from the electromagnets. The key is the loop of copper on one side of the electromagnet’s soft iron core, known as the shaded pole. This creates torque in the rotor because it makes the magnetic field asymmetric. Also the copper, because it is a loop will induce its own magnetic field, slightly out of phase with the main field. In technospeak the inductance of the loop has a phase lag associated with it. The shaded pole is marked S in the diagram at left.

An important part of the AC induction motor is the squirrel cage. I don’t know what it has to do with squirrels (should be possums in Australia!) but the idea is that you are trying to maximize the eddy currents to get the most interaction between the rotor and the magnetic fields. Often there are laminations to minimize eddy currents (and the soft iron core of the rotor may well be laminated) but in this case we are doing the opposite. Often the squirrel cage is not visible in the rotor, because it is embedded in the soft iron core for more effective interactions with magnetic field.

In Kickstart we have a demo motor pictured at right. Available from Christensen (local dealer Mike Walsh)

**Squirrel Cage**

The most common type of rotor is the “squirrel cage.” It consists of a stack of steel laminations with evenly spaced conductor bars around its circumference. The conductor bars are electrically and mechanically connected with end rings. A slight skewing of the bars helps to reduce audible hum caused by vibrations. The rotor and its shaft constitute an integral rotor assembly.

4. The Oscilloscope

An oscilloscope is an essential tool for showing signals and pulses, such as AC power or the output from a generator. However, like all flexible tools, it can be tricky to get the trace you want.
The basic concept of an oscilloscope (or CRO – Cathode Ray Oscilloscope) is that the beam sweeps across the screen at a speed determined by the timebase. The beam will be deflected up and down by the signal, a voltage between the core and shielding of the BNC cable.

To get a picture on the screen there are a few things you need to get all working at once.

1. **Horizontal (X) axis.** This is (usually) the time scale, how fast the beam sweeps across the screen.
   a) **Triggering.** The triggering determines when the beam begins its sweep.
      - Automatic triggering means it continuously sweeps across the screen, beginning a new sweep as soon as finishes the previous one. Good for monitoring a continuous signal.
      - If auto is off, the sweep will only start when a voltage of a certain level is detected. This is the setting you would use when monitoring a non-continuous signal, (e.g. pulses from a detector) or a signal where you want the pulse synchronised with the sweep. The signal level required to kick off the sweep is determined by the triggering level knob. Too high and the sweep will never begin, too low and it will trigger too often, from tiny pulses of electrical noise.
   b) **Position.** There is usually a knob to move the trace left or right. If you have no signal the trace could be too far off to one side. This is useful to align the pulse to the grid to make measurements of the length of a trace.
   c) **Speed (or timebase).** This is the speed at which the beam sweeps across the screen. Too fast and it becomes very faint, and you may not be able to see the shape of your pulse. Too slow and the trace will creep across the screen, squishing your signal into a vertical line.

2. **Vertical (Y) axis.** This is the voltage of the signal.
   a) **Choose the right input.** Many CROs have two inputs (channels). Look for a switch to choose the right one Channel 1 or Channel 2 (i.e. the one that you have plugged your cable into.)
   b) **Check the zero position.** Unplug the cable or switch it to zero or GND(ground) and you should see a flat line. Adjust the position knob to bring it back onto the screen.
   c) **Get the right scale - too big and it will disappear off the top of the screen, too small and you will have a flat line.**

3. **AC/DC coupling.** The coupling switch determines what kind of input circuitry is used to detect the signal. Often you are measuring a fast (AC) signal, but there may be a DC offset on your trace. If you switch to AC it will remove that offset, but if you want to see the offset leave it switched to DC and it will display both signals (NOT just the DC). In most cases this switch makes very little difference to the trace. Sometimes this has the GND setting (or ground) on the same switch. Setting the switch to GND is the same as unplugging the cable; i.e. it sets the input to zero volts.

### 5 Generators and commutators

We all know that the DC motor relies on the split-ring commutator to reverse the polarity to keep the motor spinning. And we know a generator is a motor in reverse – but there are some subtleties to the commutators between motors and generators.

A DC motor needs a split in the commutator, but running that in reverse doesn’t give smooth DC current. It gives a **rectified** current, in other words the negative part of the cycle is flipped over to be positive. (or vice versa if you go the other way).

To smooth this out you can add more splits into the ring. In the lab here we have a generator with 8 splits, and a historic generator with 32 slits. Each pair of splits is connected to a separate winding on the rotor. This way, as the coil rotates away from the 90 degree position (i.e. maximum current generated) the brushes pass over a split, so the commutator switches to the next coil, which is just about to enter the maximum position. This way the current is always close to maximum, and you get a smooth DC output. Unfortunately some of the windings are broken, so there are gaps in the DC!