Pump ED 101

AC Motors Part 1 – Magnetism & the DC Motor

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I received many comments on my four part series on AC Power and most of them were very positive. Several readers, however, thought they were too elementary. I reminded them that the title of my column is Pump Ed 101 not 201 or 301 and its purpose is to introduce people to new and unfamiliar topics. Why do I use this approach? Things have changed quite a bit since I attended high school in the late fifties and early sixties. Back then serious science started in the fourth grade and there was no opting out of physics and chemistry in high school. The physics education I received in high school was conceptual and did not delve into complex mathematical relationships. That made it interesting and understandable - even to a teenage boy with lots of other things on his mind! Had it not been, I doubt that I would have pursued it in college and grad school. High School education changed substantially in the seventies and eighties and I am not sure that our current system achieves what was achieved back then. Because of this a lot of us did not learn how simple physics can allow us to simplify many of the complex topics that we have to deal with on a day to day basis. That is the purpose of Pump ED 101 so this introduction to AC motors will start with the basics. I will also provide you with several references if you would like to further your understanding of this interesting and essential topic.

Magnetism

One of the more neglected subjects taught in science class is magnetism and, like many science topics, it is almost always presented in a boring manner. It is at the heart of both AC and DC motors and is a primary reason that AC power became the dominant power source in the world.

The rudimentary definition of a magnet is an object that attracts iron. Although undoubtedly discovered in prehistoric times, it was not until 600 BC that the Greek philosopher, Thales, reported its properties. He studied a sample of loadstone (iron ore) from the town of Magnesia on the Aegean coast and, because of its attractive properties, called it Magnesian rock. Thales also discovered that amber (a fossilized resin known as elektron), when rubbed, also exhibited an attractive force. It was different though because its attractive forces were not limited to iron but would attract any number of objects including feathers and parchment. In this latter case, he had unknowingly discovered what we call electrostatics or electricity at rest.

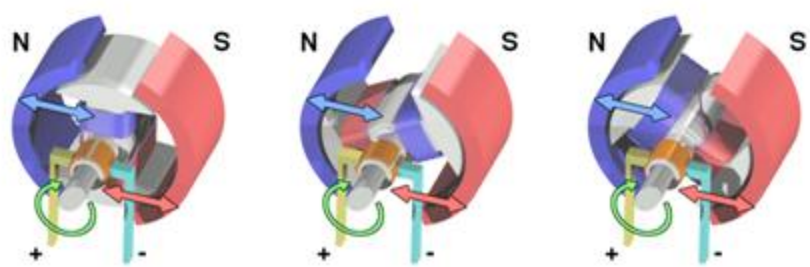
An object that exhibits magnetism without the aid of electricity is called a permanent magnet. These magnets have two areas of maximum attraction which are referred to as their north and south seeking poles. Although a number or rules apply, the most basic is that opposite poles attract and like poles repel one another. A moving electric charge can also give rise to a magnetic field and a magnetic field, regardless of how it was produced, exerts a force on a moving electric charge.

Before the 19th century, electricity and magnetism were thought to be independent forces. In 1819; however, Hans Christian Oersted performed an unplanned experiment that demonstrated they are intimately related. It occurred during a lecture when he accidentally placed a wire that was connected to a battery over the face of a compass and noted that the needle moved to the right. Upon reversing the battery connections, the needle swung to the left. He had accidentally discovered the interaction between electric current and a magnet. The French physicist Andre Ampere, for whom the unit of current intensity is named, went on to demonstrate that a magnetic force generated by an electric current is indistinguishable from that of a permanent magnet. His simple experiment consisted of two parallel wires which were connected to separate batteries (electromagnets). One wire was fixed while the other was free to slide toward or away from the fixed one. When current traveled in the same direction in both wires, the movable wire slid toward the stationary one. When current traveled in opposite directions, the movable wire slid away. His experiment demonstrated that an electric current could exhibit the same attractive and repulsive forces as a permanent magnet. It also showed that reversing the connections to the battery reversed the polarity of the magnetic field by causing current to flow in the opposite direction. The changing polarity of the electromagnet, when combined with permanent magnets, is the basis for the simple DC motor.

The DC Motor

It is difficult to credit any one person with the development of the DC electric motor. Obviously it started with Oersted's discovery of electromagnetism but many others including Sturgeon, Henry, Ampere, Faraday and Davenport contributed to the development process. Unfortunately none of these early designs had any practical value due to their low output power. It wasn't until 1873, and once again purely by accident, that one appeared on the scene. In 1871 the Belgian inventor, Zénobe Gramme, developed a high output DC generator that utilized 34 poles and produced a waveform that was nearly constant. During a demonstration in Vienna in 1873 his assistant accidentally connected a generator to one that was already running and its shaft began to rotate. The same machine that produced high electrical power as a generator also produced high mechanical power as a motor.

Figure 1 shows the components and magnetic field relationships of a simple two pole, brushed DC motor. The blue and rose colored stationary objects located on the periphery represent the north and south poles of a permanent magnet and give rise to the two pole designation. The rotating "armature", located in the center, contains two sets of windings that are 180 degrees apart and connected in series. When DC power is applied they become an electromagnet and produce north and south poles. Again a blue coil represents a north pole and a rose coil represents a south pole. Located on the motor shaft, just forward of the coils, is a split ring commutator that feeds the two coils. At the nine and three o'clock position are carbon brushes that apply DC power to the two rings of the commutator. The commutator functions as a switch that reverses the flow of current in the armature coils during rotation.



The left hand figure shows the armature in the vertical position. You can also see that the splits in the commutator are similarly aligned. Current flows from the negative brush through the right commutator, into the coils and back to the positive brush through the left commutator. In doing so it creates a north pole in the upper coil and a south pole in the lower coil. This causes the armature to rotate clockwise due to the opposing and attracting forces between the coils and the permanent magnets. The middle figure shows the armature approaching one quarter of a rotation. The same forces are still at play and the split areas of the commutator are approaching each brush. At exactly one quarter rotation the forces cancel one another but rotation continues due to the inertia of the armature. Just as it passes the one quarter mark the brushes come in to contact with the opposite commutator ring and the current flowing through the armature reverses direction. The result is shown by the figure on the right where the coils of the armature have reversed their polarity and the interactive magnetic forces arise again. In a two coil motor this reversal occurs twice during each rotation. Motor speed is directly proportional to voltage and inversely proportional to the magnetic flux produced.

Brushed motors can be designed with any number of poles and coils. Also, the poles can consist of electromagnets rather than permanent magnets. Unlike the example in Figure 1, most two pole motors will have a minimum of three coils and a commutator ring that is split into three separate sections. This eliminates two basic problems. I mentioned that there is an armature position where no rotational force is created. If the motor were to stop there it would not restart on its own. Also when the split portion of the commutator passes the brushes a short circuit will occur that can waste energy and cause damage if the current is high. A minimum of three coils will solve both of these problems.

With the advent of the semiconductor another DC design became available in the early 1960's. Brushless DC (BLDC) motors are synchronous motors that are electronically commutated and overcome many of the limitations of the brushed motor. In this design the components do a complete flip flop. The outer magnet poles are replaced with a stator that consists of a group of stationary coils installed in a circular fashion and the armature is replaced with a rotor that utilizes permanent magnets rather than coils. Some electronic controllers that operate these motors use Hall Effect sensors to monitor the position of the rotor and determine when a particular stator coil should be energized. Other controllers use sensorless control and monitor the back EMF that arises in the uncharged coils and eliminate the need for Hall Effect sensors. BLDC motors are very popular in the electronics industry and tend to dominate many applications including computer hard drives, CD/DVD players and cooling fans. They are also used to power cooling fans in the HVAC industry as well as hybrid vehicles.

For an excellent pictorial presentation on how brush and brushless DC motors work, visit http://www.stefanv.com/rcstuff/qf200212.html . It was written for model airplane enthusiasts but applies to all of us. Next month we will discuss the operation of an AC motor and compare it to the DC motor.

Finally, if you happen to be one of those who missed out on the opportunity to enjoy the benefits of simple physics you still have a chance. Paul Hewitt is the author of Conceptual Physics. http://conceptualphysics.com/ This high school text book first appeared in 1987 and is by far the best I have ever read. The current 11th edition is pretty pricy but older editions are available, inexpensively, at Amazon and Barnes & Noble. Don't be embarrassed by the fact that it is a high school text. I have a copy of the 7th edition and use it whenever I want to make a complex topic more understandable. There are also a couple of links to free, online physics books on my web site. Just go to the "Other Educational Sites" section of www.PumpEd101.com.

Joe Evans is responsible for customer and employee education at PumpTech Inc, a pumps & packaged systems manufacturer & distributor with branches throughout the Pacific Northwest. He can be reached via his website www.PumpEd101.com. If there are topics that you would like to see discussed in future columns, drop him an email.