DC Motors, Drives and Controls

An Online Continuing Education Course for Engineers

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1. Introduction

DC motors were one of the first types of motors developed and used in the mechanized world. As such, means had to be developed to start and stop these devices. Over the history of DC motors and controls, various methods were developed to do this. This paper is a review of the history of DC motors and the various ways that were devised to control the operation of these motors. A brief review of DC circuit theory will also be given. With that in mind, let's get started.

2. History of DC Motor Development

Motor action was first demonstrated in 1821 by Michael Faraday, a British scientist. Although he had no formal education, he developed many of the concepts of chemistry and electro magnetism that are still used today. The motor he made is called a Homopolar Motor, and is still used today to demonstrate mechanical motion from some salt water, a magnet, and a DC voltage source. Personally, I have never seen one of these work, but it is said that they do. Other than demonstrating that motion can be obtained from the flow of DC current, it has no practical application. Among other things, Faraday invented a device that evolved into the Bunsen Burner, discovered benzene, liquefied chlorine, and reported the first syntheses of the chlorine carbon compounds C_2Cl_6 and C_2Cl_4, and in 1847 discovered that the optical properties of gold colloids are different than the optical properties of the solid metal. This observation could be called the birth of nano science, way before we even had a word for it.

In the electrical field, Faraday built a DC battery in about 1812. Between the years of 1833 and 1839 he discovered the principle of electromagnetic induction, which has led to the development of motors and transformers that have made much of modern life possible. James Clerk Maxwell mathematically modeled Faraday's Law which states that a changing magnetic field produces an electric field. Faraday used that principle to construct an electric dynamo, the predecessor of modern electric generating systems.

During Faraday's lifetime, Hungarian physicist, Anyos Jedlik, started working with devices he called "Electro Magnetic Self Rotors". In 1828 he demonstrated the first device that contains the three major parts of a DC motor, the stator, the rotor, and the commutator. It had no permanent magnets. In 1832, British scientist, William Sturgeon, made the first DC motor that was capable of turning machinery. Unfortunately, it was so far ahead of it's time that it was never widely used. Then in 1837 Americans Emily and Thomas Davenport patented a direct current motor with the intention of powering machine tools and a printing press. Due to the high cost of batteries to make the motors run the devices did not sell well and the Davenports went bankrupt. Then in 1855 Anyos Jedlik built a device that was capable of doing useful work. There is no evidence that it was ever used anywhere except for demonstration purposes. The electric motor did not become useful until 1873, when, by accident, Zenobe Gramme connected a dynamo, (generator) to another dynamo. When the first dynamo was connected to a prime mover, such as a steam driven belt, the second dynamo turned and was capable of delivering useful work. This eliminated the need for expensive batteries.

By 1886 Frank Julian Sprague and his company, Sprague Electric Railway and Motor Company, introduced two important inventions. They were a constant speed, non-sparking motor with fixed brushes, and a method to regulate or return power to the main lines on braking. These motors led to electric motors on trains and elevators. As part of the development of electric train motors, or traction motors as they are commonly known, Thomas Edison experimented with placing a few windings on the stator in series with the armature current in about 1880. These series windings led to the feasibility of using electric motors to run trains.

3. Construction of DC Motors

Most modern DC, brush type, motors are built with a part that stands still, called the stator, and a part that rotates, called the rotor. The stator is a piece of magnetic material formed so that it looks like a magnet with a north and a south pole. Figure 3.1 shows a diagram of a two pole stator. DC motors can have more than two poles, but there will always be an even number of poles, with equal numbers of north and south poles, alternating around the circumference.

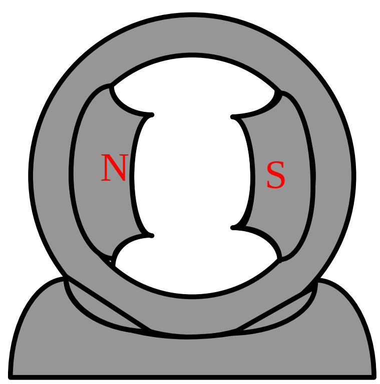


Figure 3.1 End View of a Two Pole Stator

All motors have to have an even number of poles. A four pole motor will have alternating north and south poles. The magnet can be either a permanent magnet, or an electromagnet. If the stator is a permanent magnet, it just sits there with a magnetic field across the north and south poles. If the stator is an electromagnet some turns of wire need to be wound on it so that current flowing through the wires causes a magnet to be formed. This is shown in figure 3.2.

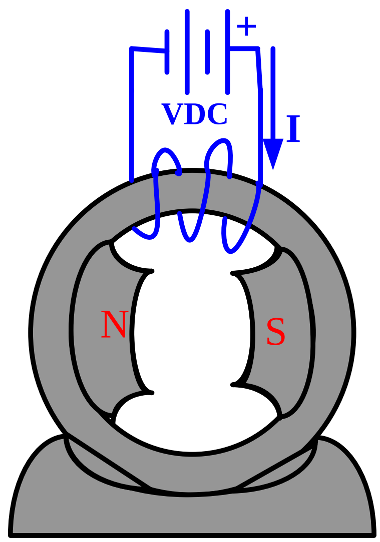


Figure 3.2   Diagram Showing How the Stator of a DC Motor Is Magnetized

The strength of the electro magnet depends on the number of turns and the current. The number of turns times the current is called "Amp Turns" and is referred to as the magnetizing force. The quality of the magnetic material is also important. "Good" magnetic material will make a stronger magnet than ordinary steel or iron with the same number of amp turns of magnetizing force.

The next part of the DC motor is called the rotor or armature. It fits between the north and south poles of the stator shown in Figures 3.1 and 3.2. It rotates on bearings on either end and is connected to a DC power source through a switch called the commutator. The switching is done automatically as the rotor turns. Figure 3.2 shows how a rotor or armature is electrically connected.

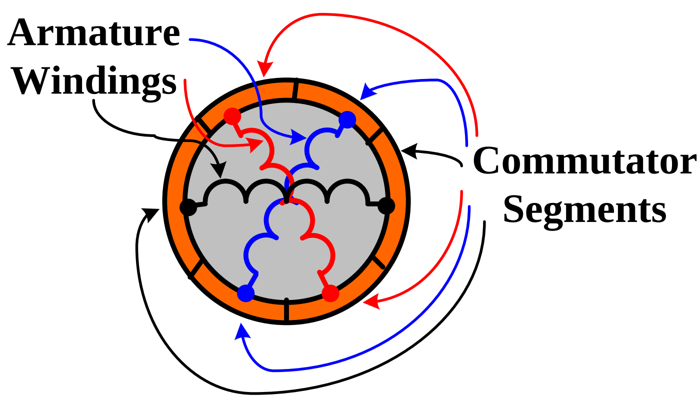


Figure 3.3   Diagram Showing How an Armature Is Electrically Connected

This simple example shows only three windings, but actual motors have many more that are determined by motor size and application. The commutator segments are usually made of copper, and are insulated from each other with a material such as mica. The windings themselves are usually copper, but some lower cost motors have aluminum windings. The rotor itself is made from a good quality magnetic material, similar to the stator material. The rotor and stator are laminated to lower iron losses. When a motor is operating there are two brushes that ideally allow current to flow through one winding at a time. Larger motors can have more sets of brushes, but they will be in sets of two. Actually, as the armature turns, there is a short period of rotation when current will flow through two windings at once. The motor designers have, over the years, figured out how to handle this problem. The brushes have to have a certain length and width to handle the current flow, which can be significant, especially in larger motors. The brushes are usually made of carbon, and the moving carbon copper contact offers a relatively low voltage drop, giving low power losses at this point. Figure 3.4 shows how the brushes will ride on the commentator and cause current to flow in the armature. Sparking and arcing can be a problem, but proper design and maintenance minimizes this problem.

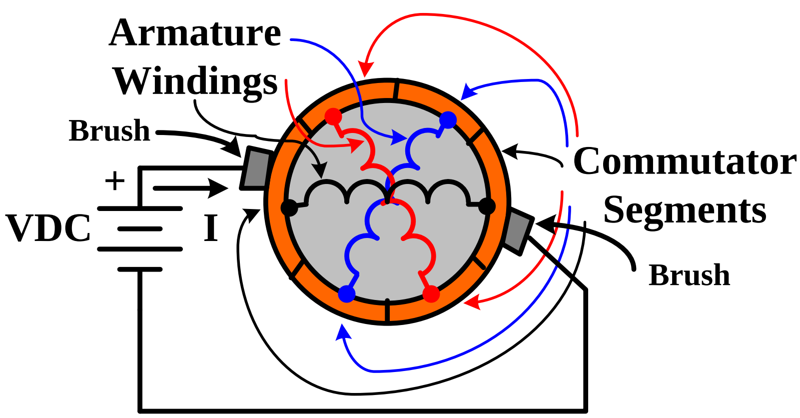


Figure 3.4 Armature Circuit of a DC Motor Showing Brushes and Voltage Supply

If anyone has taken apart a small hand held electric drill or kitchen appliance, you will have seen how this circuit looks physically. Bigger motors just have bigger parts and possibly more commutator segments and more sets of brushes. Now that we have looked at the physical parts of a DC motor, let’s look at how they can be connected.

4. Shunt Wound DC Motors

One of the ways that a DC motor can be constructed is called a Shunt Wound Motor. In a shunt wound motor, the field is electrically connected in parallel with the armature. Figure 4.1 shows schematically how this is done.

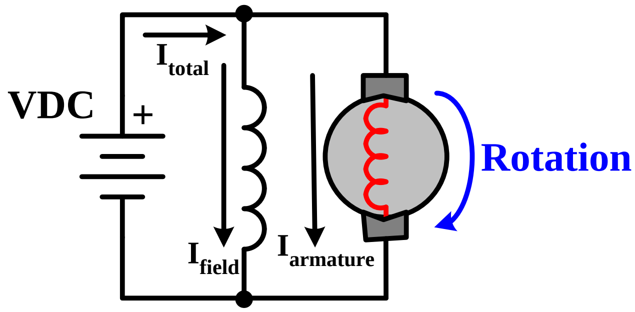
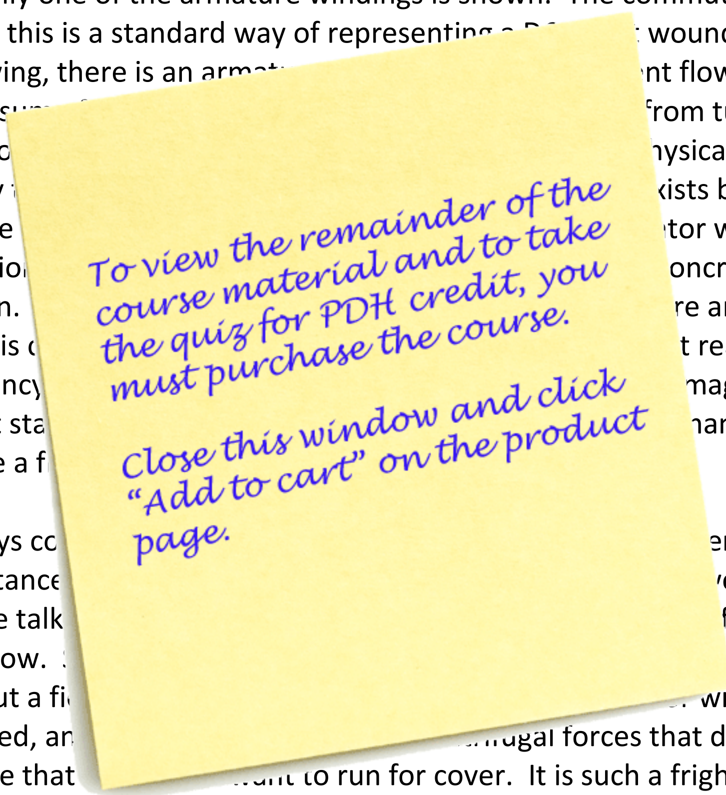


Figure 4.1 Schematic of a Shunt Wound DC Motor

For this drawing, only one of the armature windings is shown. The commutator is also left off
of the drawing, but this is a standard way of representing a D wound motor. As seen by
looking at the drawing, there is an arma nt flowing. The total
current is then the s from turning, or blocked,
rotation will have to hysically located the
magnets formed by xists between them that
makes the armature tor would try to rotate in
the opposite directio oncrete foundations
under this condition. re and has a relatively
high resistance. This t real, power loss,
lowering the efficiency magnet. With a
permanent magnet sta anent magnet DC
motors do not have a f



The armature always co er wire, and thus has
a much lower resistance e will discuss this
issue later when we talk f the motor depends
upon this current flow. If a shunt wound
motor is run without a fi will run at an
extremely high speed, an ugal forces that develop. It also
makes a weird noise that to run for cover. It is such a frightening sound that
you know that there is something absolutely wrong. There are stories from the steel mills of
motors falling apart and throwing large pieces of the armature hundreds of feet. To do that the
pieces of motor would have to make a hole in the roof. A shunt motor (with a good field) is a
relatively constant speed device if the armature voltage is constant. It will slow down a bit
under load, but that is part of its expected operation.

This is a good time to explain Reverse Generated EMF. When the armature rotates in the magnetic field, a voltage is generated in the armature that depends on the strength of the stator magnet, the number of turns in the armature, and how fast it is rotating. This voltage is opposed in direction to the applied voltage. Thus, as the motor speed increases, the armature current decreases. Without this effect, it would be very difficult to control the current that