Brushless vs. Brushed DC Motors: When and Why to Choose One Over the Other

By Pete Millett, Sr. Technical Marketing Engineer at MPS

Introduction

Many motion control applications use permanent magnet DC motors. Since it is easier to implement control systems using DC motors compared to AC motors, they are often used when speed, torque, or position needs to be controlled.

There are two types of commonly used DC motors: brushed motors and brushless motors (also called BLDC motors). As their names imply, DC brushed motors have brushes, which are used to commutate the motor to cause it to spin. Brushless motors replace the mechanical commutation function with electronic control.

In many applications, either a brushed or brushless DC motor can be used. They function based on the same principles of attraction and repulsion between coils and permanent magnets. Both have advantages and disadvantages that may lead to choosing one over the other, depending on the application's requirements.

Brushed DC Motors

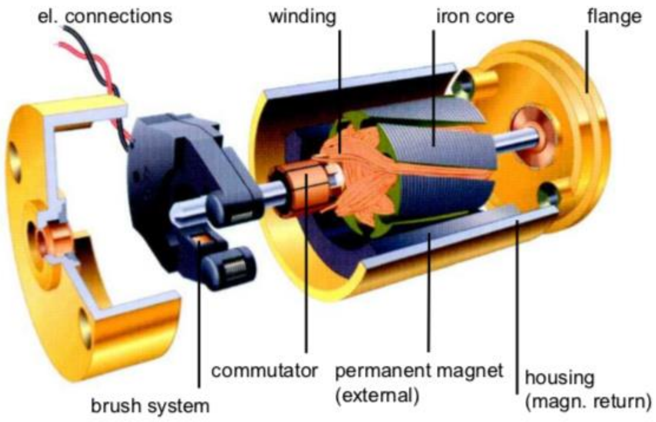


Figure 1: Brushed DC Motor

DC motors use wound coils of wire to create a magnetic field. In a brushed motor, these coils are free to rotate to drive a shaft — they compose the part of the motor called the rotor (see Figure 1). Typically, the coils are wound around an iron core, though there are also brushed motors that are "coreless," where the winding is self-supported.

The fixed part of the motor is called the stator. Permanent magnets are used to provide a stationary magnetic field. These magnets are typically positioned on the inner surface of the stator, outside of the rotor.

In order to create torque, which makes the rotor spin, the magnetic field of the rotor needs to continuously rotate, so that its field attracts and repels the fixed field of the stator. A sliding electrical switch is used to make the field rotate. The switch consists of the commutator (which is typically a segmented contact mounted to the rotor) and fixed brushes that are mounted to the stator (see Figure 2).

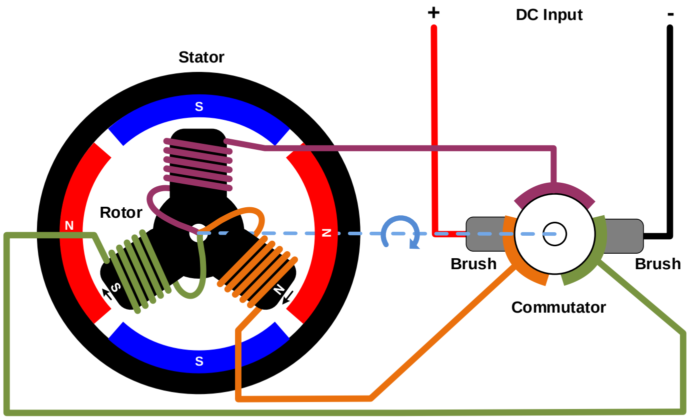


Figure 2: Cross-Sectional View of Brushed DC Motor Functionality

As the rotor turns, different sets of rotor windings are constantly switched on and off by the commutator. This causes the coils of the rotor to be constantly attracted and repelled from the stator's fixed magnets, which makes the rotor spin.

Since there is some mechanical friction between the brushes and the commutator — and given that it is an electrical contact, it generally cannot be lubricated — mechanical wear occurs to the brushes and commutator over the lifetime of the motor. This wear eventually reaches a point where the motor no longer functions. Many brushed motors — especially large ones — have replaceable brushes, typically made of carbon, that are designed to maintain good contact as they wear. These motors require periodic maintenance. Even with replaceable brushes, the commutator also eventually wears to the point that the motor must be replaced.

To drive a brushed motor, a DC voltage is applied across the brushes, which passes current through the rotor windings to make the motor spin.

In cases where rotation is only needed in one direction, and the speed and torque don't need to be controlled, no drive electronics are required for a brushed motor. In applications like this, the DC voltage is simply switched on and off to make the motor run or stop. This is common in low-cost applications such as motorized toys. If reversal is needed, it can be accomplished by using a double-pole switch.

To facilitate control of speed, torque, and direction, an "H-bridge" composed of electronic switches — transistors, IGBTs, or MOSFETs — is used to allow the motor to be driven in either direction. This allows the voltage to be applied to the motor in either polarity, which makes the motor rotate in opposite directions (see Figure 3). The motor speed and torque can be controlled by pulse width modulation (PWM) on one of the switches.

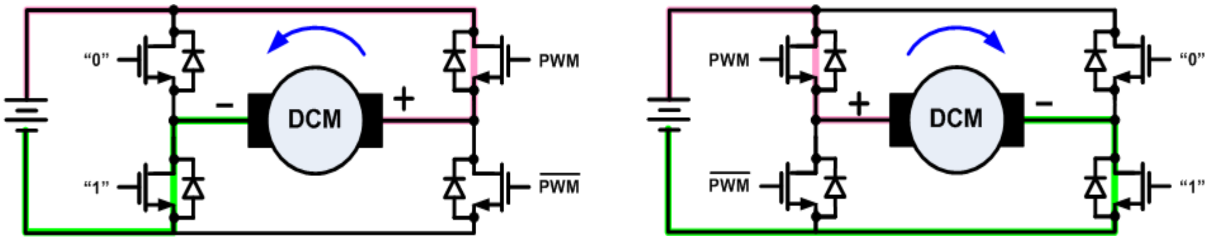


Figure 3: Driving a Motor via an H-Bridge

Brushless DC Motors

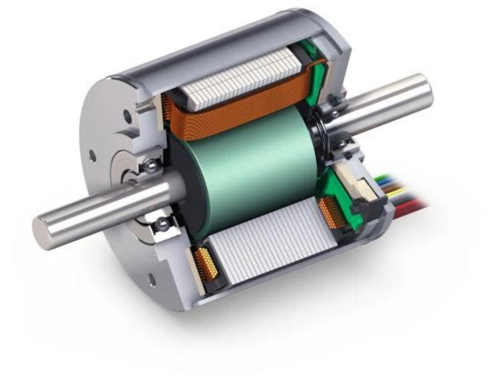


Figure 4: BLDC Motor

Brushless DC motors, or BLDC motors, operate on the same principle of magnetic attraction and repulsion as brushed motors, but are constructed somewhat differently. Instead of a mechanical commutator and brushes, the magnetic field of the stator is rotated using electronic commutation. This requires the use of active control electronics.

In a brushless motor, the rotor has permanent magnets affixed to it, and the stator has windings. Brushless motors can be constructed with the rotor on the inside (see Figure 4), or with the rotor on the outside of the windings, which is sometimes called an “outrunner” motor.

The number of windings used in a brushless motor is called the number of phases. Though BLDC motors can be constructed with different numbers of phases, three-phase brushless motors are the most common. One exception is small cooling fans that may use only one or two phases.

The three windings of a BLDC motor are connected in either a “star” or a “delta” configuration (see Figure 5). In both cases, there are three wires connecting to the motor, and the drive techniques and waveforms are identical.

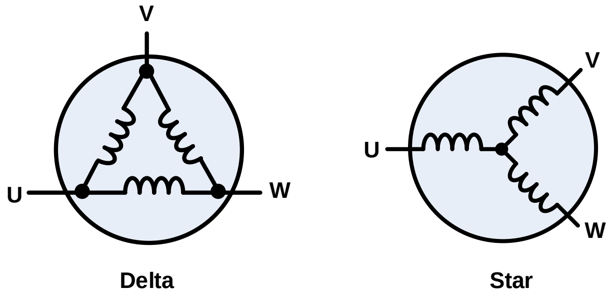
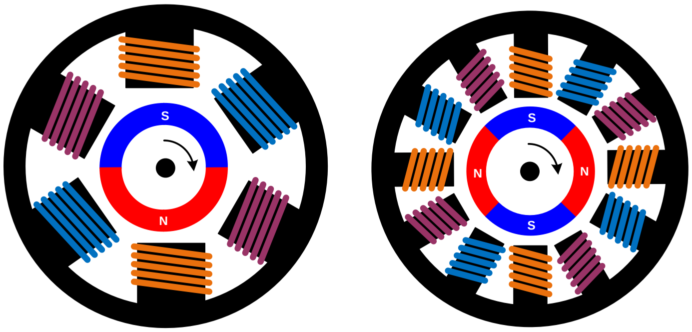


Figure 5: BLDC Motor Configurations

With three phases, motors can be constructed with different magnetic configurations, called poles. The simplest three-phase motors have two poles: The rotor has only one pair of magnetic poles, one north and one south. Motors can also be built with more poles, which require more magnetic sections in the rotor and more windings in the stator (see Figure 6). Higher pole counts can provide improved performance, though very high speeds are better accomplished with lower pole counts.



2 Poles **4 Poles**

Figure 6: 2-Pole Motor vs. 4-Pole Motor

To drive a three-phase brushless motor, each of the three phases needs to be able to be driven to either the input supply voltage or ground. To accomplish this, three half-bridge drive circuits are used, each consisting of two switches. The switches can be bipolar transistors, IGBTs, or MOSFETs, depending on the voltage and current required.

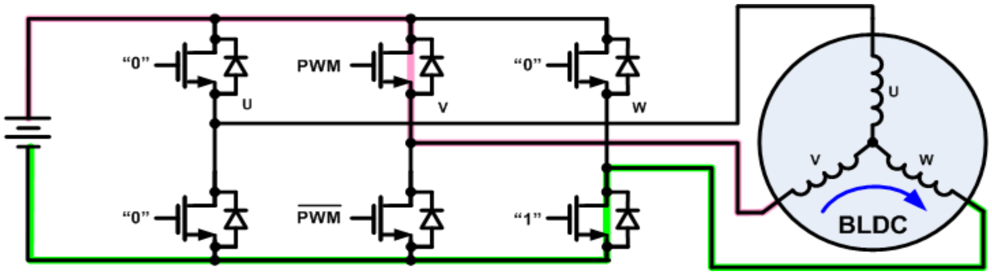


Figure 7: Three-Phase BLDC Motor with Three Half-Bridges

There are a number of drive techniques that can be employed for three-phase brushless motors. The simplest is called trapezoidal commutation (also called block or 120-degree commutation). Trapezoidal commutation is somewhat similar to the commutation method used in a brushed DC motor. In this scheme, at any given time, one of the three phases is connected to ground, one is left open, and the other is driven to the supply voltage. If speed or torque control is needed, the phase connected to the supply is pulse-width modulated. The phases switch abruptly at each commutation point, which means that while the rotor's rotation is constant, there is some torque variation (called torque ripple) as the motor rotates.

For higher performance, other commutation methods can be used. Sine commutation (also called 180-degree commutation) drives current thorough all three motor phases all of the time. The drive electronics generate a sinusoidal current though each phase, each shifted 120 degrees from the other. This drive technique minimizes torque ripple, as well as acoustic noise and vibration, and is often used for high-performance or high-efficiency drives.

To properly rotate the field, the control electronics need to know the physical position of the magnets on the rotor relative to the stator. This position information is often obtained using Hall sensors mounted to the stator. As the magnetic rotor turns, the Hall sensors pick up the rotor's magnetic field (see Figure 8). This information is used by the drive electronics to pass current through the stator windings in a sequence that causes the rotor to spin.

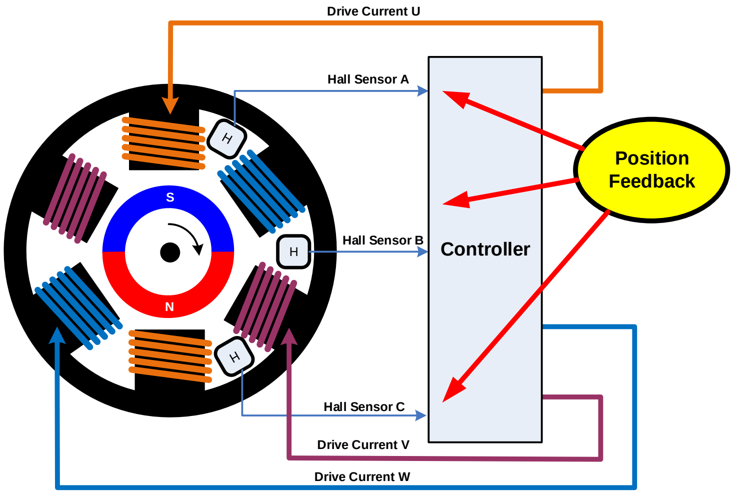


Figure 8: Hall Sensor Functionality

Using three Hall sensors, trapezoidal commutation can be implemented with simple combinational logic, so no sophisticated control electronics are needed. Other commutation methods, such as sine commutation, require more sophisticated control electronics and typically employ a microcontroller.

There are also various methods that can be used to determine the rotor position without sensors. The simplest of these methods is to monitor the back electromotive force (EMF) on an undriven phase to sense the magnetic field relative to the stator. A more sophisticated control algorithm, called field-oriented control (FOC), calculates the position based on rotor currents and other parameters. FOC typically requires a fairly powerful processor, as there are many calculations that must be performed very quickly. This, of course, is costlier than a simple trapezoidal control method.

Brushed and Brushless Motors: Advantages and Disadvantages

Depending on the application, there are reasons why an engineer might choose to use a brushless motor over a brushed motor. Table 1 summarizes the main advantages and disadvantages of each motor type.

Table 1: Brushed DC Motor vs. BLDC Motor

	Brushed DC Motor	**Brushless DC Motor**
Lifetime	Short (brushes wear out)	Long (no brushes to wear)
Speed and Acceleration	Medium	High
Efficiency	Medium	High
Electrical Noise	Noisy (brush arcing)	Quiet
Acoustic Noise & Torque Ripple	Poor	Medium (trapezoidal) or good (sine)
Cost	Lowest	Medium (added electronics)

Lifetime

As previously mentioned, one of the disadvantages of brushed motors is that there is mechanical wear to the brushes and commutator over time. For example, in many motors carbon brushes are designed to be replaced periodically as part of a maintenance program. The soft copper of the commutator is also slowly worn away by the brushes, and eventually reach a point where the motor will no longer operate. Since brushless motors have no moving contacts, they do not suffer from this wear.

Speed and Acceleration

Brushed motors' rotational speed can be limited by the brushes and commutator, as well as the mass of the rotor. At very high speeds, the brush-to-commutator contact can become erratic, and brush arcing increases. Most brushed motors also use a core of laminated iron in the rotor, which gives them large rotational inertia. This limits the acceleration and deceleration rates of the motor. It is possible to build a brushless motor with very powerful rare earth magnets on the rotor, which minimizes the rotational inertia. Of course, that also increases the total solution cost.

Electrical Noise

The brushes and commutator form a kind of electrical switch. As the motor turns, the switches are opened and closed, while significant current is flowing through the inductive rotor windings. This results in arcing at the contacts. This generates a large amount of electrical noise, which can get coupled into sensitive circuits. Arcing can be somewhat mitigated by adding capacitors or RC snubbers across the brushes, but the instantaneous switching of the commutator always generates some electrical noise.

Acoustic Noise

Brushed motors are "hard switched" — that is, current is abruptly moved from one winding to another. The torque generated varies over the rotation of the rotor as the windings get switched on and off. With a brushless motor, it is possible to control the winding currents in a way that gradually transitions current from one winding to another. This lowers torque ripple, or the mechanical pulsation of energy onto the rotor. Torque ripple causes vibration and mechanical noise, especially at low rotor speeds.

Cost

Since brushless motors require more sophisticated electronics, the overall cost of a BLDC motor drive is higher than that of a brushed motor. A brushless motor is simpler to manufacture than a brushed motor given that it lacks brushes and a commutator, but brushed motor technology is very well-understood and manufacturing costs are low. However, this is changing as brushless motors become more popular, especially in high-volume applications like automotive motors. Additionally, as the cost of electronics such as microcontrollers continues to decline, making brushless motors more attractive.

Summary

Due to declining costs and better performance, brushless DC motors are gaining in popularity in many applications. But there are still places where brushed motors make more sense.

Much can be learned by looking at the adoption of BLDC motors in automobiles. As of 2020, most motors that run anytime the car is running — things like pumps and fans — have moved from brushed motors to brushless motors for their increased reliability. The added cost of the motor and electronics more than makes up for the lower rate of field failures and decreased maintenance requirements.

On the other hand, motors that are operated infrequently — for example, motors that move power seats and power windows — have remained predominantly brushed motors. Because the total runtime over the life of the car is very small, it is very unlikely that the motors will fail over the life of the car. As another example from the automotive world, seat adjustment motors in high-end cars have been adopting brushless motors because they generate less acoustic noise.

As the cost of brushless motors and their associated electronics continues to decrease, brushless motors are finding their way into applications that have traditionally been dominated by brushed motors. Ultimately, the best motor for a given design is up to the priorities and requirements of the end application.