

Brushed DC Motor Basics

Hello, My name is John Mouton. I am an Applications Engineer at Microchip Technology in the Security, Microcontroller and Technology Division. Thank you for downloading Brushed DC Motor Basics. This is Part 1 in a 4 part series of web-seminars related to Controlling a Brushed DC Motor using a Microcontroller. This web-seminar will focus on the basics of Brushed DC motor construction and some common characteristics. So let's begin!

Agenda

- Topics discussed in this Web-Seminar:
 - Basics of Brushed DC Motors
 - Four Types of Brushed DC Motors
 - Principles of Operation

During this web-seminar I will discuss the main components of a brushed DC motor and how these components work together to function as a motor. We will also explore four types of brushed DC motors and compare common characteristics between them.

Motor Basics

So let's start off with the brushed DC motor basics.

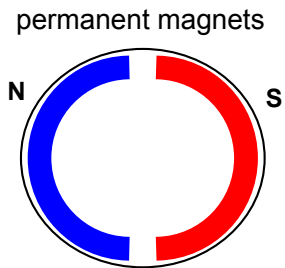
Motor Components

1. Stator
2. Rotor / Armature
3. Brushes
4. Commutator

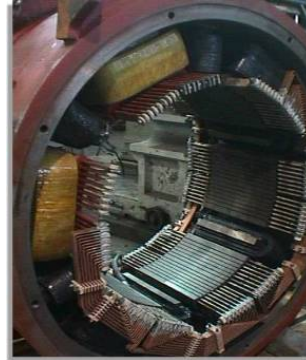
A brushed DC motor is made up of 4 basic components; the stator, the rotor (or armature), brushes, and commutator.

Stator

- **Generates a stationary magnetic field that surrounds the rotor, this field is generated by either:**



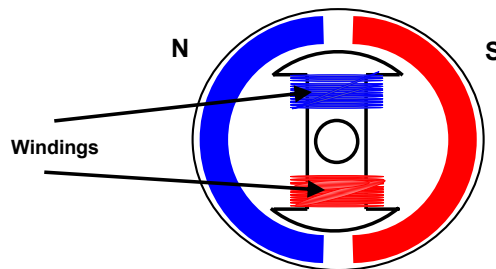
electromagnetic windings



First let us look at the stator. As the name implies, the stator generates a stationary magnetic field that surrounds the rotor and this magnetic field is generated by either permanent magnets or electromagnetic windings.

Rotor

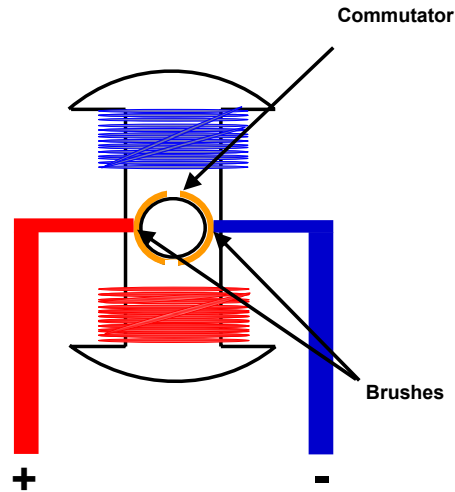
- Made up of one or more windings
- Commutation



Next is the rotor, also known as the armature. The rotor is made up of one or more windings.

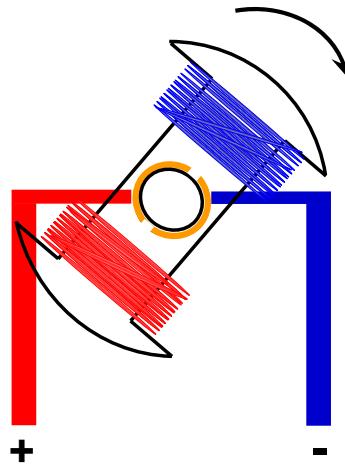
When these windings are energized they produce a magnetic field. The magnetic poles of this rotor field will be attracted to the opposite poles generated by the stator, causing the rotor to turn. As the motor turns, the windings are constantly being energized in a different sequence so that the magnetic poles generated by the rotor do not overrun the poles generated in the stator. This switching of the field in the rotor windings is called Commutation.

Brushes and Commutator



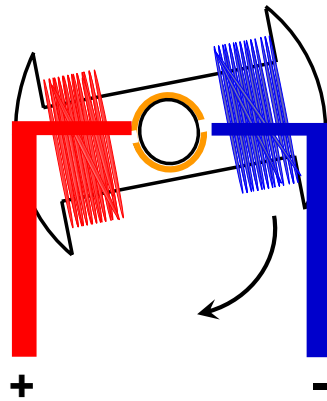
Brushed DC motors do not require a controller to switch current in the motor windings. Instead, it uses a mechanical commutation of the windings. A copper sleeve (commutator), resides on the axle of the rotor. As the motor turns, carbon brushes slide over the commutator, coming in contact with different segments of the commutator. The segments are attached to different rotor windings, therefore, a dynamic magnetic field is generated inside the motor when a voltage is applied across the brushes of the motor. The brushes and commutator are the parts of a brushed DC motor that are most prone to wear.

Brushes and Commutator



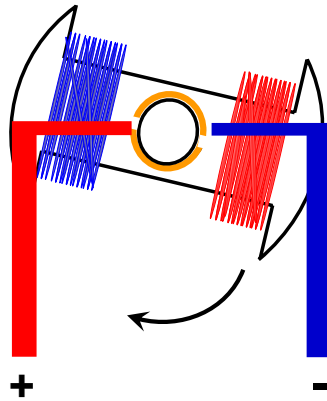
So, as the rotor rotates inside the stator, the brushes rub the different segments of the commutator supplying a charge to that segment and its corresponding winding.

Brushes and Commutator



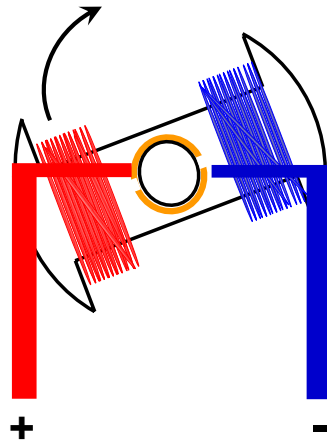
As the brushes pass over the commutator gaps the supplied electrical charge will switch commutator segments.

Brushes and Commutator



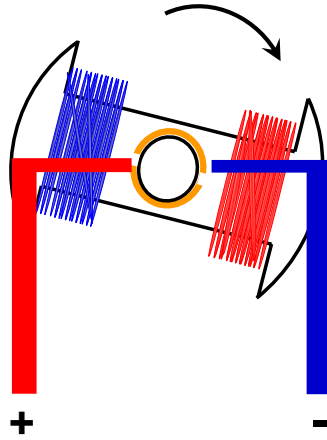
Thus, switching the electrical polarity of the rotor windings. This will create an attraction of the different polarities and keep the rotor rotating within the stator field.

Brushes and Commutator

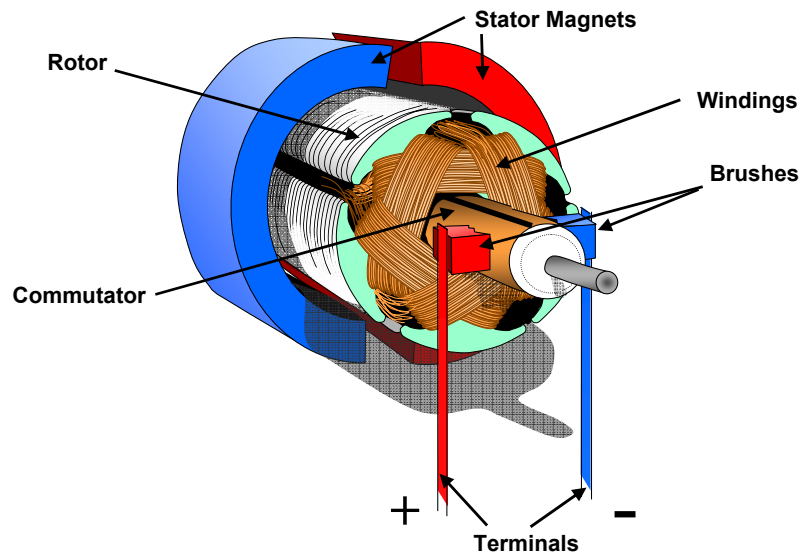


This process will continue as long as a supply voltage is applied.

Brushes and Commutator



Brushed DC Motor Overview.



Finally, here is a complete overview of a brushed DC motor with all components labeled.

Types of Brush DC Motors

Now let us take a look at the different types of brushed DC motors.

Four Types of BDCMs

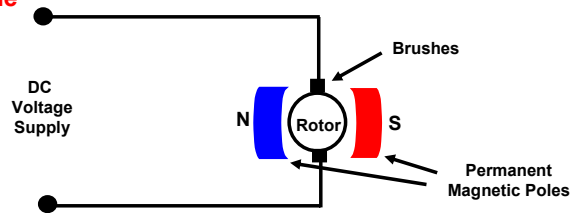
1. Permanent Magnet
2. Shunt - wound
3. Series - wound
4. Compound - wound
 - Shunt + Series

There are four types of brushed DC motors.

The first type, is the Permanent Magnet Brush DC Motor. Second, the shunt-wound brushed DC motor. Third is the series-wound DC motor and fourth is the compound-wound brushed DC motor which is a combination of both the shunt and series wound brushed DC motors.

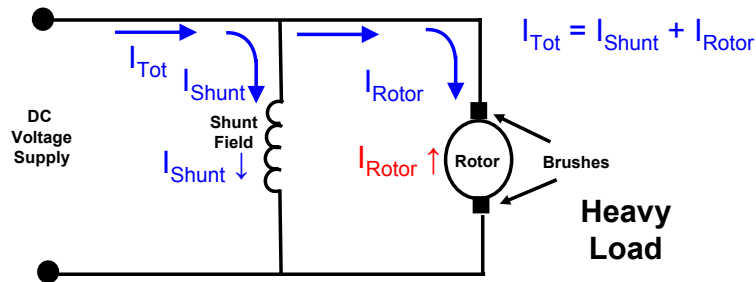
Permanent Magnet (PMDC)

- Most common
- Used in fractional horsepower applications
Examples: Toys, RC app., Slot cars, Appliances, etc...
- More cost effective than wound stators
- Torque, limited b/c of stator field
 - Good low end (low speed) torque
 - Limited high end (high speed) torque
- Responds very quickly to voltage changes due to constant stator field (good speed control)
- **Drawback, Magnets lose their magnetic properties over time**



Permanent magnet brushed DC motors are the most common. These motors use permanent magnets to produce the stator field. They are generally used in applications needing fractional horsepower such as; Toys, Radio Control hobby applications, electric slot cars, appliances, etc. It is more cost effective to use permanent magnets than wound stators because they are cheaper to manufacture. The torque from a permanent magnet brushed DC motor is limited by its stator field, which gives it good low end (low speed) torque and a limited high end (high speed) torque. The permanent magnet brushed DC motor responds very quickly to changes in voltage. This is due to its constant stator field, thus giving it good speed control capabilities. But, they do have a drawback. Permanent magnet brushed DC motors will loose their magnetic properties over time, thus degrading its stator field and causing the motors performance to decline.

Shunt-Wound (SHWDC)



- As $V_{Supply} \uparrow$, $I_{Tot} \uparrow$, speed \uparrow , stator/rotor field \uparrow , thus Torque \downarrow
- As motor load \uparrow , $I_{Rotor} \uparrow$, $I_{Shunt} \downarrow$, stator field \downarrow , rotor field \uparrow , speed \downarrow , thus Torque \uparrow

Shunt-wound brushed DC motors have the field coil in parallel (shunt) with the rotor. The current in the field coil and in the rotor are independent of one another, thus, the total current of the motor is equal to the sum of the shunt current (or stator current) and the rotor current. So, during normal operation, as the supplied voltage is increased the total current of the motor will increase causing the stator and rotor fields to increase. As total current increases motor speed will increase, thus motor torque will decrease.

However, once you put a load on the motor the rotor current will increase causing the rotor field to increase. If the rotor current increases then the shunt current will decrease causing the stator field to decrease. This will cause the motor speed to decrease, thus the motor torque will increase.

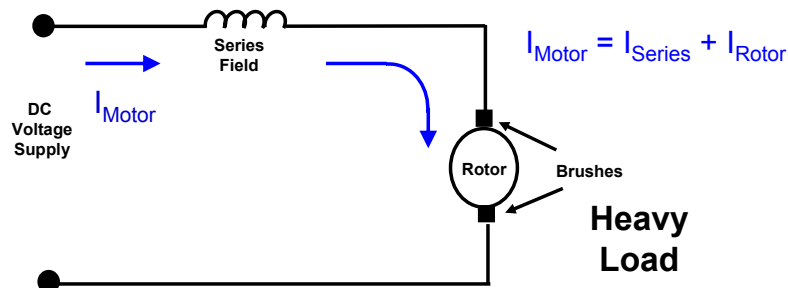
Shunt-Wound

(SHWDC)

- Decreasing torque at high speed
- At low speed, higher more consistent torque
- Excellent speed control
- Typically used in Industrial and automotive applications
- No loss of magnetism over time as with PMDC motors
- **More expensive than PMDC motors**
- **Motor Runaway, if the shunt current goes to zero**

Shunt-wound brushed DC motors have the performance characteristics of decreasing torque at high speeds and a high but more consistent torque at low speeds. The current in the field coil and in the rotor are independent of one another, thus, the total current of the motor is equal to the sum of the shunt current (or stator current) and the rotor current. As a result, these motors have excellent speed control characteristics. Shunt-wound brushed DC motors are typically used in applications that require 5 or more HP such as industrial and automotive applications. As compared to permanent magnet brushed DC motors, shunt wound brushed DC motors have no loss of magnetism and are more robust. Some drawbacks are that shunt wound brushed DC motors are more expensive than permanent magnet brushed DC motors and have the potential of motor runaway if the shunt current decreases to zero. This is a very dangerous condition that can lead the motor to literally brake apart.

Series-Wound (SWDC)



- As $V_{Supply} \uparrow$, $I_{Motor} \uparrow$, Stator/Rotor field \uparrow , speed \uparrow , thus torque \downarrow
- As motor load \uparrow , $I_{Motor} \uparrow$, Stator/Rotor field \uparrow , speed \downarrow , thus torque \uparrow

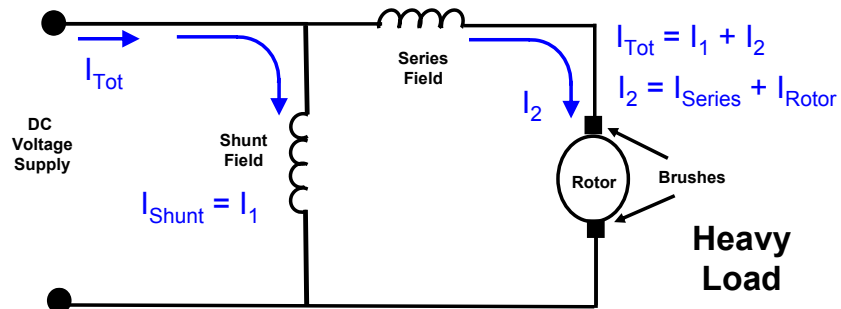
Series-wound brushed DC motors have the field coil in series with the rotor, thus, their field currents become identical. So, the motor current is equal to the sum of the stator (series) current and the rotor current. Thus, during normal operation without a load, as the supply voltage is increased the motor current increases. This causes the stator and rotor fields to increase and the motor speed increases with a decrease in torque. But, as a load is placed on the motor, motor current will increase also causing the stator and rotor fields to increase. Now the motor speed will decrease and torque will increase to overcome the load.

Series-Wound (SWDC)

- **Great slow speed torque (low end)**
 - But, as load is removed, speed increases sharply
- **Ideally suited for heavy loads, examples: cranes and winches**
- **Poor high speed torque (high end)**
- **More expensive than PMDC**
- **Poor speed control due to the series stator field**
- **Motor Runaway, if the series field is shorted**

Series wound brushed DC motors have great slow speed (low end) torque, but if the load is removed, speed will sharply increase. This makes these motors ideally suited for high-torque applications, such as cranes and winches because the current in both the stator and rotor increases under load. Some drawbacks are that they have poor high speed (high end) torque characteristics ,thus they must have a load connected to prevent damage under high speed conditions. They are more expensive than permanent magnet brushed DC motors, they do not have precise speed control characteristics like permanent magnet brushed DC and shunt wound brushed DC motors, and they can potentially go into motor runaway if the series stator field is shorted. Again, this is a very dangerous condition that can lead the motor to literally brake apart.

Compound-Wound (CWDC)



- As motor load \uparrow , $I_{Shunt} \downarrow$, shunt field \downarrow , $I_2 \uparrow$, Series field/Rotor field \uparrow , speed \downarrow , thus torque \uparrow

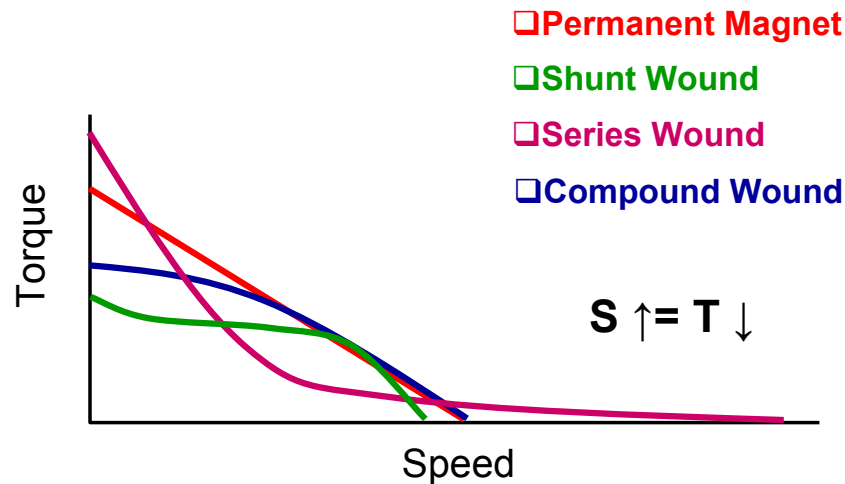
A compound wound brushed DC motor is a combination of both the shunt wound and series wound brushed DC motors. As you can see, the total current in the motor is the sum of the currents through the shunt field and the series field coils. The current through the series field coil is the same as the current through the rotor field. So, as a load is placed on the motor, the current through the rotor and series fields will increase. Thus, the current through the shunt field will decrease, the speed of the motor will decrease, and the motor torque will increase.

Compound-Wound (CWDC)

- Has the performance properties of both SHWDC and SWDC motors
- High torque at low speed w/ heavy loads, SWDC motors
- Great speed control, SHWDC motors
- Great for Industrial and automotive applications, example: generators
- Motor Runaway, less likely b/c shunt current must go to zero and series field must short
- **More expensive than PMDC, SHWDC, and SWDC**

The compound wound brushed DC motor has the performance characteristics of both the shunt wound and the series wound brushed DC motors. It has the high torque at low speeds with heavy loads as seen with series wound brushed DC motors and has great speed control as with the shunt wound brushed DC motors. Compound wound brushed DC motors are great for industrial and automotive applications such as generators. With compound wound brushed DC motors the problem of motor runaway is less likely because the shunt current must go to zero and the series field must be shorted, thus the chances of both of these conditions occurring at the same time or very small. However, a compound wound brushed DC motor is more expensive than a permanent magnet, shunt wound, or a series wound brushed DC motors.

Performance Comparison



As we compare the performance characteristics of all four types of brushed DC motors we see that they all show the same basic characteristic, as speed increases torque decreases. For a permanent magnet brushed DC motor this is a very linear process. With the shunt wound brushed DC motor you can see that there is a high but more consistent torque at low speeds which gives it excellent speed control characteristics. The series wound brushed DC motor graph shows its great low speed torque and a very drastic decrease in torque with higher speed, thus if the load was removed, speed would increase very sharply. Finally, with a compound wound brushed DC motor we see a great combination of both the shunt and series wound brushed DC motors. The graph shows good low speed torque but with a more linear or gradual decrease of torque as speed increases, thus showing that it is well suited for lifting heavy loads with great speed control.

Brushed DC Motor Type Comparison

Characteristic	Permanent Magnet	Shunt	Series	Compound
COST	Low	Moderate	Moderate	High
Loss of Magnetism	Worst	None	None	None
Torque vs. Speed	Good at low speed Less at high speed	Good, consistent at low speed.	Great at low speed	Best at low speed
Safety (Motor Runaway)	No chance	High chance	High chance	Low chance
Speed Control	Excellent	Excellent	Poor	Great

Here is a table summarizing the various aspects of each motor type that may make it easier for you to decide which motor suits your application needs.

Comparison with Other Motor Types

Type	Advantages	Disadvantages	Typical Application	Typical Drive
AC Induction	Long life High power high starting torque Rotation in-sync with freq. long-life (alternator)	Rotation slips from frequency Low starting torque More expensive	Fans Appliances Clocks Audio turntables tape drives	Uni/Poly-phase AC
Stepper DC	Precision positioning High holding torque	Slow speed Requires a controller	Positioning in printers and floppy drives	Multiphase DC
Brushless DC electric motor	Long lifespan low maintenance High efficiency	High initial cost Requires a controller	Hard drives CD/DVD players Electric vehicles	Multiphase DC
Brushed DC electric motor	Low initial cost Simple speed control	High maintenance (brushes) Limited lifespan	Treadmill exercisers Automotive starters Toys and some appliances	Direct (PWM)

Now, see how brushed DC motors compare to other types of motors, such as brushless DC motors, stepper DC motors, and AC induction motors.

Summary

- Basics of Brush DC motors.
- 4 Types and how they operate.
 - Permanent Magnet
 - Shunt wound
 - Series wound
 - Compound wound

In summary, we covered the basic components of a brushed DC motor, the four types of brushed DC motors (Permanent magnet, shunt wound, series wound, and compound wound) and how they operate.

Additional Reading

- **AN905 – Brushed DC Motor Fundamentals**

For an additional source of information, refer to applications note # AN905 “Brushed DC Motor Fundamentals.” available at Microchip.com.

Thank You

Again my name is John Mouton and I thank you for downloading this web seminar.