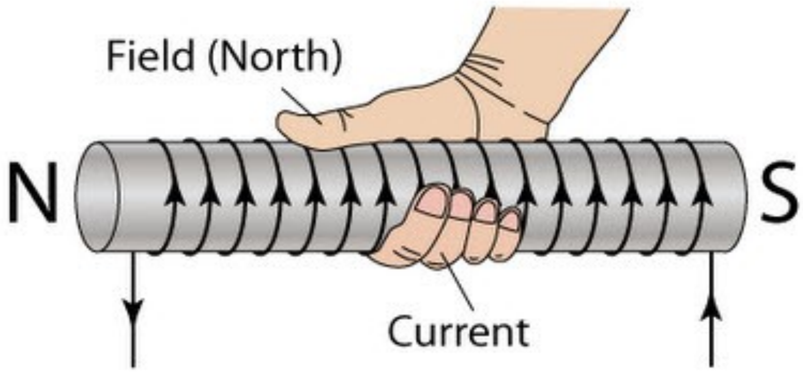
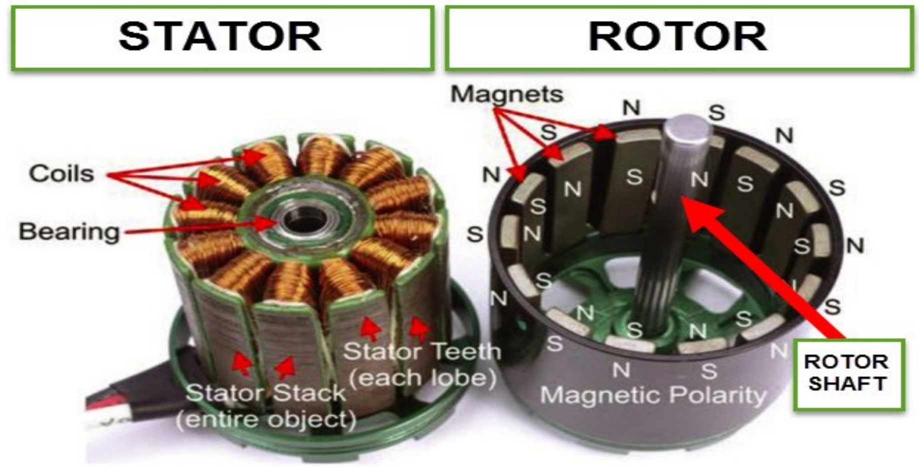
CONTROLLERS, ROTORS & STATORS

How 3-Phase Multi-rotor Motors Work





When **Direct Current** electricity flows in a wire, small particles called **electrons** move down the length of that wire. Electrons in motion cause a **magnetic force** to be projected in a direction perpendicular to the motion of the electron. If the electron ceases to move, the magnetic force disappears. Similarly, if the electron begins moving again, the magnetic force reappears. Therefore, when a wire is wrapped in a circle to make a coil and electricity runs through the wire, the electrified coil causes a magnetic force. We use the **Right-Hand-Rule** to determine the direction of the magnetic force generated by the electrified coil. To determine the **North** direction of the magnetic force, take your right hand and wrap the fingers around the coil with the ends of the fingers pointing in the direction of the electricity flow. When the thumb is extended outward, the thumb will point in the direction of the **North Pole** of the magnetic force.

In an electrical motor, copper wire is wound into a number of coils. When electricity is run through the coils, a magnetic force is created with the **North pole** in the direction as described in the **Right-hand Rule**. If the direction of the current flow is reversed, the direction of the magnetic force will reverse. The coils make up the **Stator**, or the part of the motor that does not move. Mounted on a bell-shaped case are a series of permanent magnets which are magnetized with one pole on one side and the opposite pole on the other side. The magnets are positioned so the pole positions are staggered. The bell-shaped case, a steel shaft, and the magnets make up the **Rotor**, which is free to spin around the **Stator**. As the electricity flows in alternating directions, the coils attract and repel the permanent magnets, causing the **Rotor** to spin. If the electrical pulses are properly sequenced and timed, the **Rotator** will spin in a single direction.

CONTROLLERS, ROTORS & STATORS

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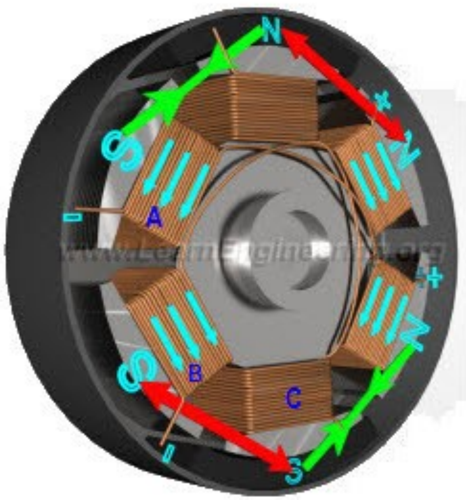


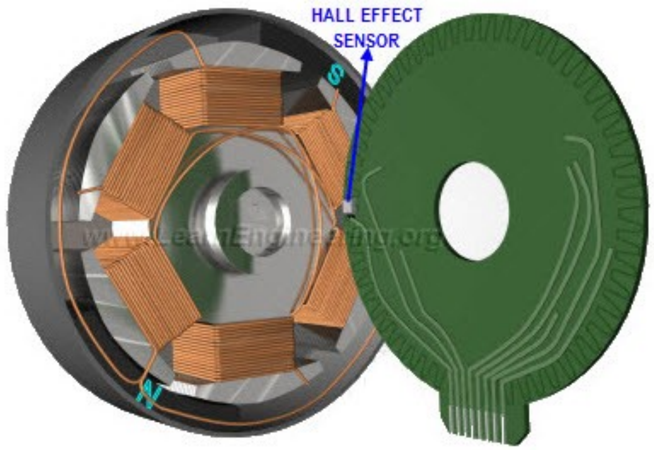
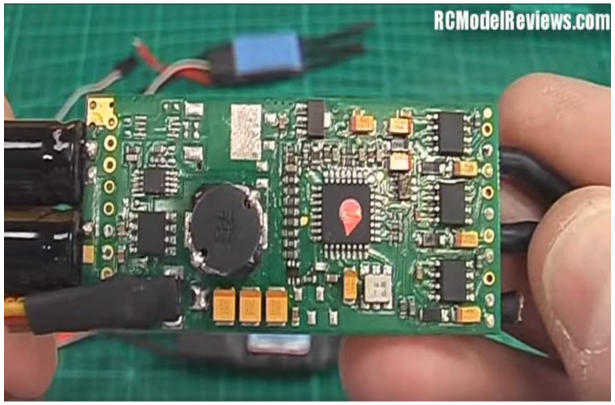


Fig. 15 A Hall effect sensor is used to determine the position of the rotor



In a **3-Phase motor**, the copper coils in the **Stator** are located three regions: A, B and C. A second set of coils is located in three complementary regions: A', B' and C'. The two complementary regions are located on the opposite sides of the cylinder comprising the **Stator**. The magnetic forces in each region push and pull in opposite directions such that one coil is pulling while its counter-part coil is pushing. This increases the speed and circular force (also called **Torque)** on the spinning **Rotor**.

A **Hall Effect Transducer** alters an electrical current based upon the direction (i.e. North or South pole) and the force of a nearby magnetic field. Its senses the position of the **Rotator** as it spins and correspondingly alters the current flow to the magnetic coils in the **Stator**. The location and rate of spin of the **Rotor** is sent to the **Electronic Speed Controller (ESC)** and the **Flight Control Board** on the drone.

The **Electronic Speed Controller (ESC)** controls each of the motors of the drone. It sequentially energizes the various electric coils mounted on the **Stator** to attract and repel the permanent magnets, and cause the **Rotor** to spin. The **ESC** controls the rate and direction of the spin of the motor. If the **ESC** is a **BEC type**, it also provides power to the remaining component boards on the drone. There is one **ESC** for each motor on the drone.

CONTROLLERS, ROTORS & STATORS

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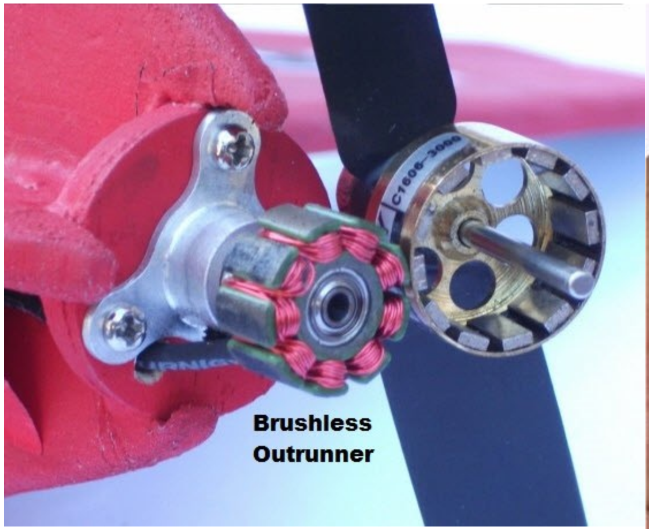

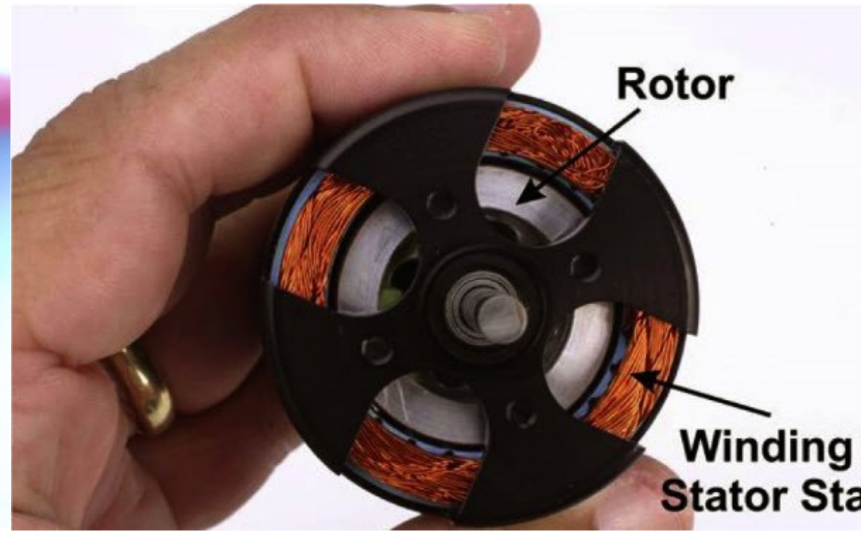

The **Outrunner** brushless motor has magnets outside the **Stator** coils. Since the magnets are relatively heavy and are further from the center of the motor, it takes more power to get them spinning. Therefore, **Outrunner** type motors have more **Torque** and tend to spin at slower speeds. With more **Torque**, a motor can handle larger propeller blades.

The **Inrunner** brushless motor has the permanent magnets mounted on a rotating shaft (the **Rotor**) at the center. The **Stator** copper coils are around the outside and are mounted to the fixed outside case. In this configuration, the heavier magnets are closer to the center; therefore, it takes less power to rotate them at speed. **Inrunner** brushless motors are designed to deliver less **Torque** but more speed. Their use is more common on smaller and faster drones that utilize smaller propellers.

Definition: KVR

A motor rating where 1 **Volt** of power applied will result in X revolutions per minute (rpm), under no load. For example, **KVR** = 2,400 says a motor will spin at 2,400 rpm when 1 **Volt** is applied.

Definition: Commutate

The amount of force created by a magnetic coil is at its maximum when the angle between the axis of the coil is 90° to the center plane of the permanent magnet. As the angle declines, the force declines. The **Sine function** in Trigonometry describes this rate of decline. For example, Sine 90° = 1, conversely, Sine 0° = 0. In order to produce a constant magnetic force on the permanent magnets on the **Rotor**, one can vary the voltages in a sinusoidal wave pattern that is complementary to the angles between the axes of the coils and the mid-planes of the permanent magnets. This is done by the **ESC** and it is referred to as a **Commutator**. Those that have studied Trigonometry, know that the complement of **Sine** is **Cosine**.

CONTROLLERS, ROTORS & STATORS

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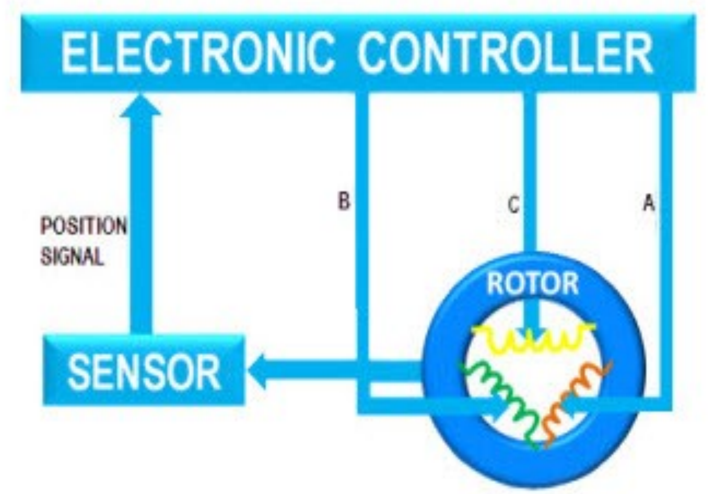
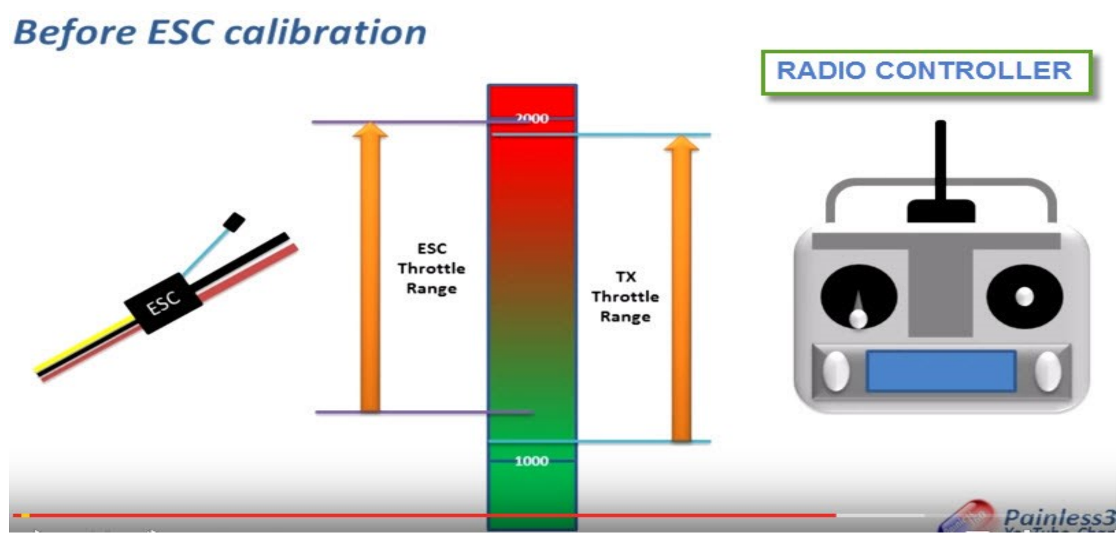


Fig. 14 The ECU determines which coil to energize and when to energize it



The **Electronic Speed Controller (ESC)** energizes each of the **3-phase regions** of the motor. The **ESC** reads and interprets the input from the **Hall Effect Sensor** to determine the rate and direction of spin of the **Rotor**.

The **Electronic Speed Controller (ESC)** senses the positions of the **Throttle/Yaw** and **Pitch/Roll** sticks on the **Radio Controller**. Based upon the sticks' positions, the **ESC** modulates the power (in volts) it sends to each motor.