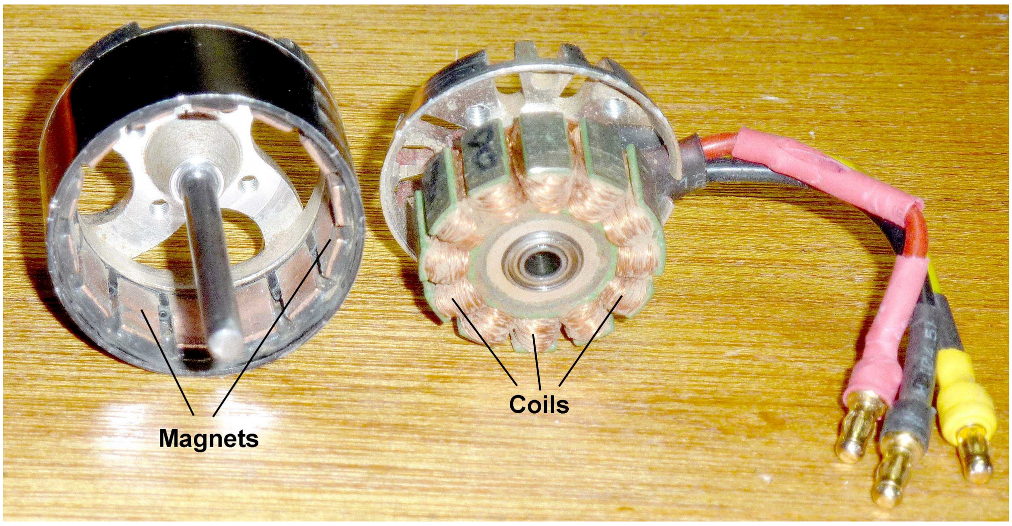
How brushless motors work

Magnetic fields

We have all played with magnets and know that north attracts south and north repels north. To make a force we need two magnets or fields. A magnet may be permanent, where a solid object has magnetism built in by lining up its atoms, or made by an electric coil, called an electromagnet. Modern permanent magnets use rare earth elements, such as neodymium or samarium, to make very strong fields. Electromagnets have many turns of insulated or lacquered wire, usually copper, wrapped round an iron core. The iron greatly increases and concentrates the field but does not hold the magnetism when the current stops. The iron core is in thin sheets (laminated) to reduce induced currents.

Fields in motors

An electric motor has two sets of magnets in it. Both might be electromagnets or one might be permanent. Brushless motors are the latter. Electric motors have a rotating part called a rotor and a fixed part called a stator. The outrunner motors that we mostly use have the electromagnet coils in the central stator. The permanent magnets are on the spinning outer case, hence the name outrunner. This has the advantage that the outer case holds the magnets firmly even at high speeds and acts as a flywheel.



Picture 1

Photo Peter Scott

The reason that brushless motors are more difficult to explain is that the coils produce a magnetic field that effectively rotates around the shaft axis. This field drags and pushes on the permanent magnets on the rotor to turn it. To reverse the rotation you simply reverse two of the wires.

So how is the rotating field produced? There are three sets of coils connected as a three-pointed star or a delta shape. This is similar to the three-phase motors used in industry. Industrial ones connect to the three mains phase wires (red, green, blue). The alternating currents in these run 120° out of step (phase) to each other. These produce the rotating field. The rotating field creates (induces) currents in heavy wires in the rotor and then pushes on them. That is why they are called induction motors. In our brushless motors it is the permanent magnets that are pushed. The difference between mains and our motors is that in mains there is a fourth wire for a neutral return.

The relevant wiki is https://en.wikipedia.org/wiki/Three-phase_electric_power

If you stop the rotor the field rushes past and the largest torque (rotational force) is produced. That is why our motors need caution. A finger in the propellor will not permanently stop it but actually give it more force, so after chopping off one finger it will move on to remove the next.

Types of brushless motor

There are two types of brushless motor. Sometimes the permanent magnet rotor is inside a static outer casing looking more like a conventional motor. These are called inrunners and are most common in gliders. More common are outrunners where the magnets are on the inside of the outer casing which rotates. The picture above is of an outrunner. Brushless motors are sometimes referred to as BLDC (**B**rush**L**ess **DC**) motors.

Numbers of coils

Figure 1 is the standard simple diagram of a brushless motor. The Ns and Ss show the magnetic pole on the inside of the magnet.

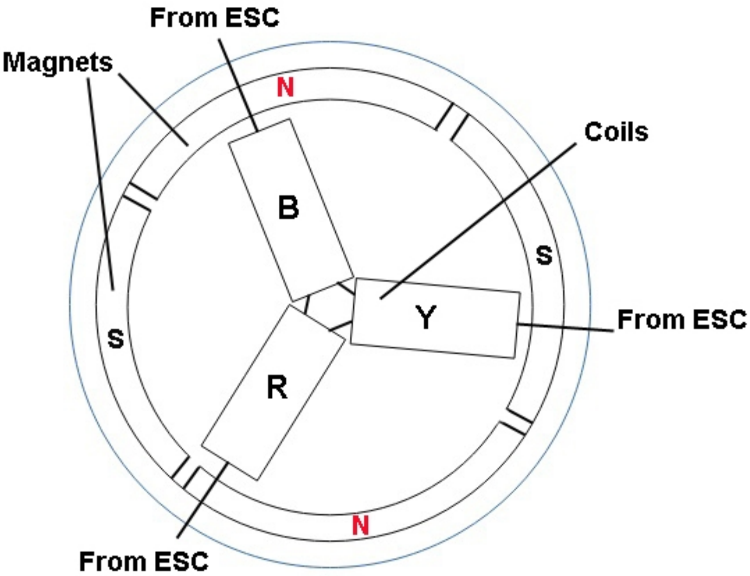


Figure 1

Diagram Peter Scott

In the picture there is a single set of three coils. Such a motor would work but it would probably run roughly. It is shown in this way to make it easier to understand how they work. In practice there are several sets of coils, usually between six and fourteen, and many magnets. You can see this in the photograph above – Picture 1.

Our motors are not connected to the mains. Something has to produce the three phases from the direct current battery, known as an Electronic Speed Controller (ESC). That is why there are three wires coming out of the ESC. If you swap two of the wires the field rotates the other way round, which is how you reverse the motor.

To learn more about ESCs read the next article about them but here is a short account.

Electronic speed controllers (ESCs)

ESCs are clever devices. They don’t produce pure sine waves like the mains but switch the three coil sets on and off in six combinations to give the greatest force. However the idea of a rotating field is correct. Two coil sets are switched on and one is switched off at any one time. The one that is off has a reverse voltage, called back electromotive force (back-EMF), induced in it by its collapsing magnetic field. The ESC senses these voltages and therefore ‘knows’ the speed and direction of the rotor. In-runner brushless motors sometimes use one of two different sensors called magnetic Hall Effect or optical detectors. Not only do ESCs do this switching many thousands of time a second but can handle huge currents, as much as 300 A. For aircraft, 120 A at 24 V is usually enough, producing 2.9 kW or 3.9 HP.

What size electric motor do I need?

You need to know the weight and flying style for the model. Provided you have fitted the right propeller – which will be the subject of a later article - the following table gives you a guide to the power needed for your model. For aerobatic models you also need to know the thrust but that must be measured in a test rig or on a tethered model using a luggage scale.

Watts per kilogram

Slow and park flyer	110 - 149
Trainers, light gliders and slow scale	150 - 199
Sport aerobatic, heavier gliders and fast scale	200 - 239
Advance aerobatic and high-speed	240 - 289
Light loaded 3D and ducted fan	290 - 329
Unlimited 3D and aerobatic	330 upwards

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