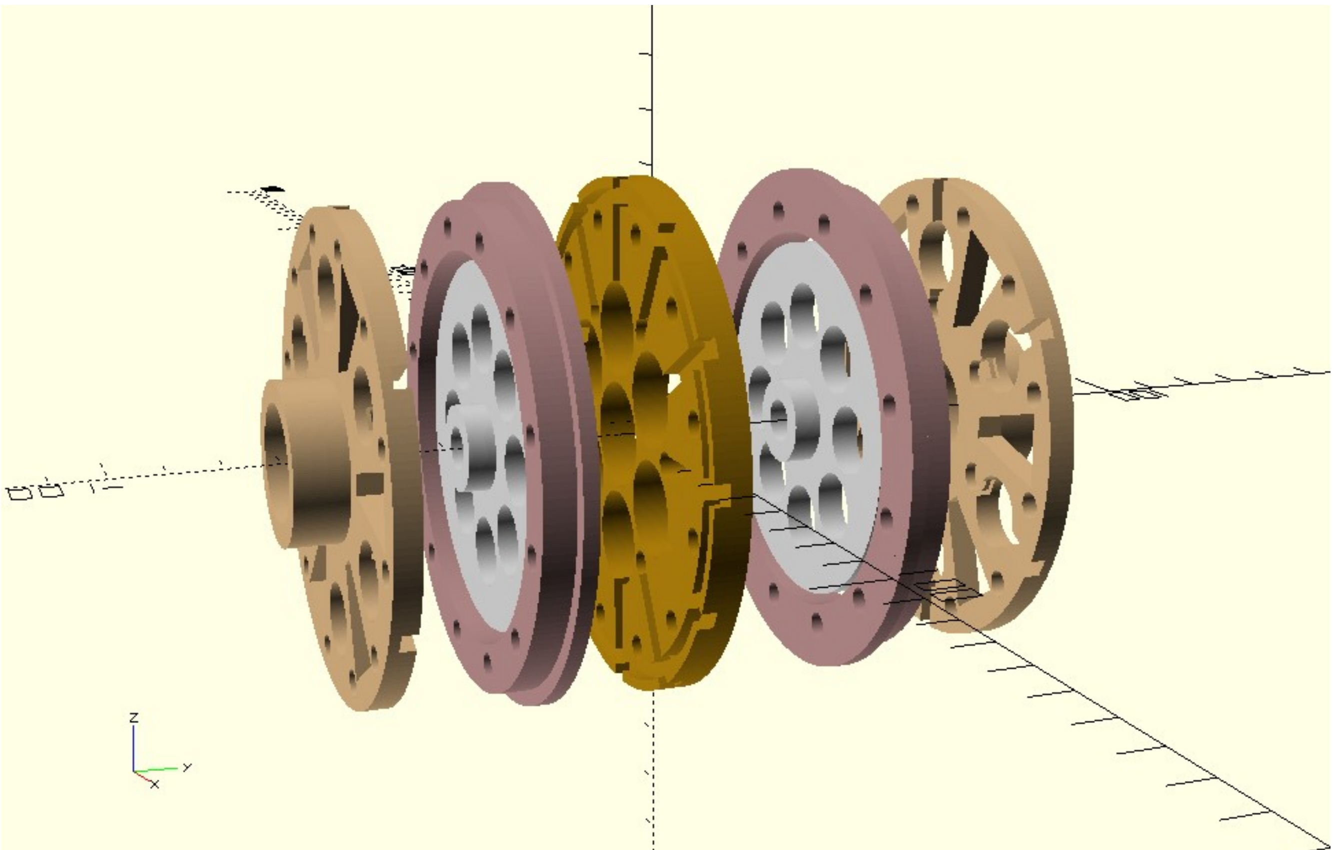
# 3d Printed Axial Flux BLDC Motor



by Richard Randazzo
2020 / 09 / 23

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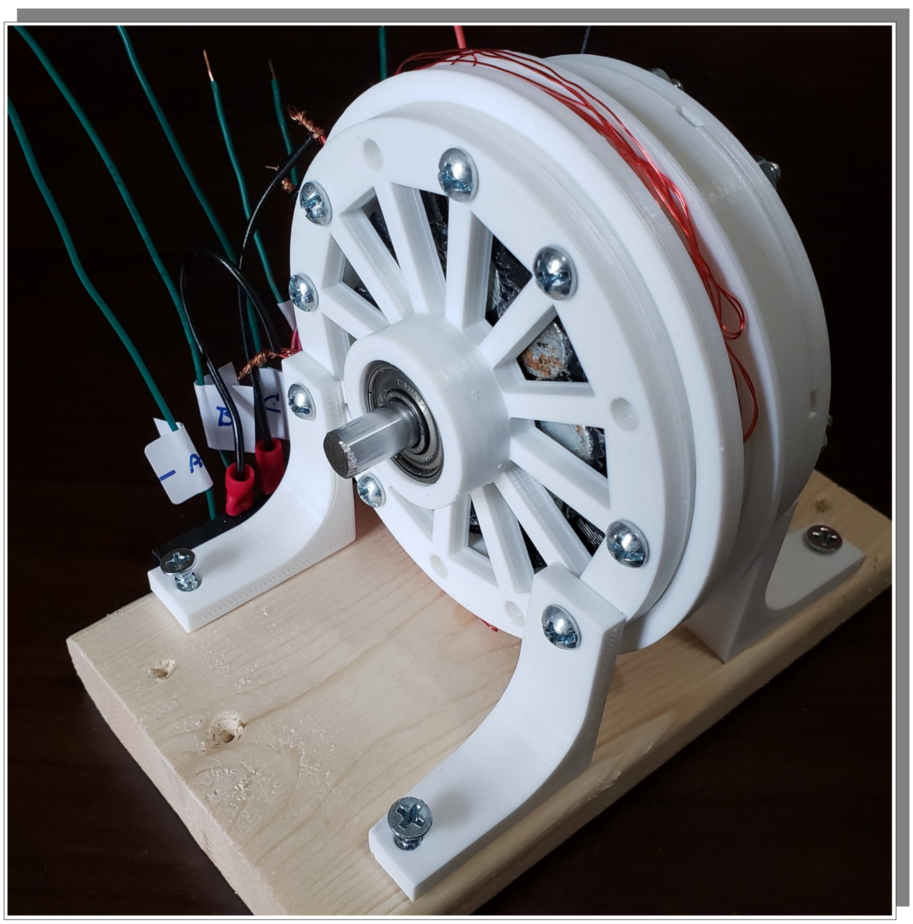


**Introduction:**

Though I have tried to make this document as accurate as possible, this is a work in progress. A lot of things may require modification along the way and changes made to improve the build or performance. Some of the photos may be of earlier builds so the parts may look a little different. The rotor is a good example as there have been fan blades added for cooling. I have added as many photos as I could, to try to explain the build process and functionality, but no doubt some things do get overlooked.

What's the point of building a brushless direct current motor? Why axial flux? And why 3d printing? Electric motors are becoming more important in our every day life. Especially in our daily mode of transportation and concerns about the effects on our environment. The move to electric vehicles is becoming a major factor in all modes of transportation from bicycles to dump trucks. One of the major breakthroughs in motor design came with the introduction of the BLDC motor. Now almost all small electric vehicles, especially bicycles, utilize BLDC motors. As these motors become more popular it is important that we understand them and the required electronics to control them. The first part of my goal with this project is to help others understand the current ways these motors are designed and operate. The second part is to give people who are interested a good basic platform to learn to build controllers.

I present some basic electronics and formulas to help anyone who may be new to the subject and I will try to be clear and explain components as best as I can. Some of the calculations I use make basic assumptions but tend to work out well in practice.

Though my design is quite different I began with using a how-to document much like this I purchased from http://amazingdiyprojects.com/electric_motor.html. He is a northern European and does quite a few amazing projects. His YouTube is https://www.youtube.com/user/amazingdiyprojects and worth watching as he demonstrates some pretty powerful axial flux motors.

Videos showing the motor built in this instructional :
https://www.youtube.com/watch?v=luVKK2BJHXs

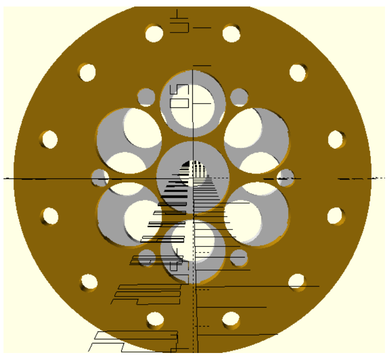
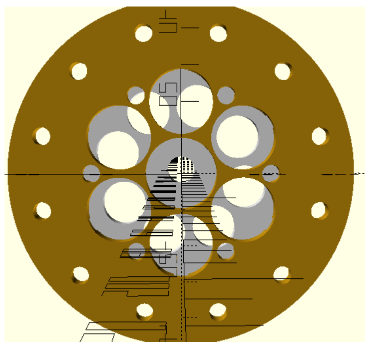
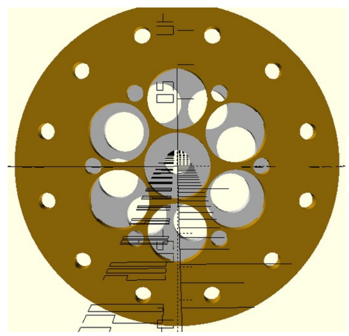
For some amusement you can see the first motor I built with wood and hand tools:
https://www.youtube.com/watch?v=m_aT_dPUWRg

**BLDC Basics:**

There are many good videos on YouTube with explanation of how BLDC motors work so I will only give a short overview.

There are two types of windings: Delta and Wye. Delta being in the configuration of the Greek letter Delta or a triangle and the Wye configuration which is in the shape of a capital letter Y. This instructional uses the Delta configuration. Again I will cop out with the fact that there is much information on the internet describing the difference in these two winding styles. I will say that the delta configuration provides higher starting torque.

The BLDC motor build in this motor uses a ratio of 4 magnets to 3 coils. In this combination the magnets can be moved smoothly around the motor. As stated above, the motor uses a Delta configuration. It has three wires connected to it from the controller. The controller provides one of three conditions to each wire. On, off or neutral. So in essence is it a sort of alternating current (AC) sine wave. Each of these voltages is timed to be 120 degrees out from each other. What this does is cause the motor to be under constant current and constant power.

The images above show the stator in brown and rotor in grey. The series of images are shown in 30 degree steps. If you notice in the first picture the top magnet is aligned perfectly with the coil. If the rotor is turning in a clockwise direction then at this point the coil would switch polarity to repulse the magnet to cause it to move away. In the next picture it can be see that a magnet is aligned to the stator in the right of the top. So that coil would change polarity to force the magnet to keep moving. The third picture shows how this process continues. The hall transistors are used to keep tract of the magnet location and trigger the coils when to switch polarity. This is an extremely over simplified example of how the BLDC motor operates, but again, it is a complex process that requires a complete paper of its own. Please watch some YouTube videos to get a much better treatise on this process.

**Basic Electronics:**

Some basic electronic calculations will be helpful to know.

V is the applied voltage
I is current measured in amperage
R is resistance measured in Ohms

voltage = current x resistance : $V = IR$
useful manipulations are: $I = V/R$ and $R = V/I$

P is power measured in watts
power = voltage times current: $P = VI$
and manipulations are: $V = P / I$ and $I = P / V$

As an example we can use a 1000 watt bicycle motor that uses 48 volts.

To determine the current we can use $I = P / V$

$I = 1000w / 48v = 20.83$ amps

This is useful in determining the batter we want to use. Batteries are rated by amp hours (Ah). That is how many amps it can supply in one hour. Since the motor uses 48 volts and draws 20 amp, from our calculations we can see that if we use a 48v battery rated at 20Ah the battery should last for one hour. If we had a battery that was 10Ah then it would only last for half an hour.

As a quick discussion on batteries (biased toward lithium) I will say that batteries are also rated by how much current they can provide above the rated Ah. 1C is the rated Ah. 2C is twice the rated Ah. 3C – 3times … etc. So a 10Ah battery can provide 20Ah but for only 30 minutes. Also, most batteries will only charge at 1/3 C. That would be 20/3 = 6.67 amps. Most battery chargers are only going to supply 5 amps max so you can expect as long as three hours to charge the 20Ah battery. Though the 10Ah battery does not last as long, the charge time is less and the cost is less. This is meant to give you an idea of what to expect working with electric motors.

**Axial Flux:**

The orientation of this motor is different than most motors. The stator and rotor are perpendicular to the axle of the motor. Therefore the flux is parallel to the axle. Historically these motors were called “pancake” motors. The stator is sandwiched between two rotors providing more torque. A compound motor could consist of multiple stators and rotors. Using the axial flux design makes it easier to compound these motors together and use much less space.

**Air Core:**

Most motor and solenoid coils have iron ferrite cores. This is used to focus the magnetic flux. The problem with an iron core is that it creates what is known as a hysteresis curve or a delay in the switching of current direction and magnetic polarity change. There is a white paper comparing the efficiency of the iron core coils to air coils and the air core coil proves more efficient. If for any reason you doubt this please feel free to build your coils using an iron core. Using an iron core increases weight, creates more heat, and makes for a more complicated and therefore a more difficult build. Another problem with using an iron core is at low speed you can feel what is known as a “cogging effect”. This is where the magnets can be felt jerking from one iron core to the next as they move around the motor. The cogging effect is the reason that American electric vehicle builders prefer AC motors.  But if there is no iron core, this effect is eliminated. Therefore this motor design does not have a problem of cogging.

**Magnets:**

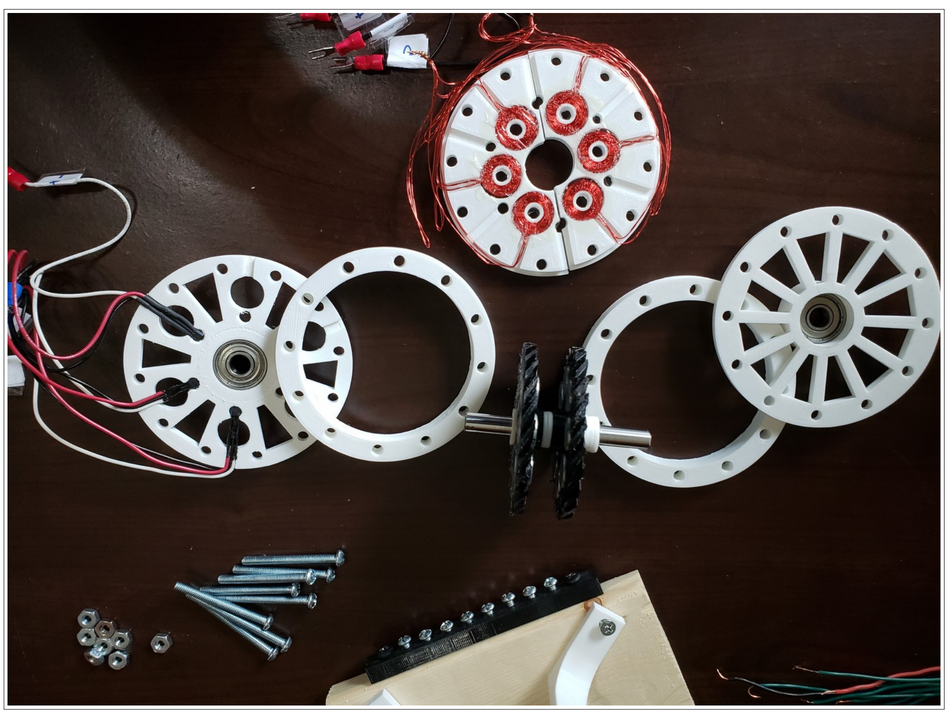
Neodymium magnets are used on most BLDC motors these days. The “pull” strength of these magnets range from a low measured at n32 to a high of n52. As the number increases so does the cost. Also, as the size increases, so does the cost. So the magnets used in the prototype seen in this document were n32 .5” x .25” (approximately 12x6mm). Ceramic magnets are cheap but their strength is low when compared to neodymium. But they could be used and would work well for prototyping and may even work for certain applications.  Caution should be used in handling magnets as they can cause damage or injury.

**3d Printing:**

With the introduction and improvements of 3d printing it has become very popular for use in rapid prototyping. Using the 3d printer removes a lot of the skill necessary in building items and devices that would historically take a craftsman or a machinist to build. If you can draw the item, using one of the many CAD (computer aided design) programs available today, it can most likely be printed. Some CAD programs are quite sophisticated and are geared more toward artist. OpenSCAD is a freeware program that was used in construction of this motor. I prefer it because it is more of a programming language and is geared more toward technical modeling. If you have a little programming knowledge the learning curve is minimal. But the program has many examples and, even with no programming experience, it should be simple to get started. The CAD program can generate a file called .stl, this file is then used by another program to “slice” the code and generate a .gcode file that is then used by the printer. A good slicer program is Cura. Both of these programs are free to use but I suggest making a small donation to assist the programmers.

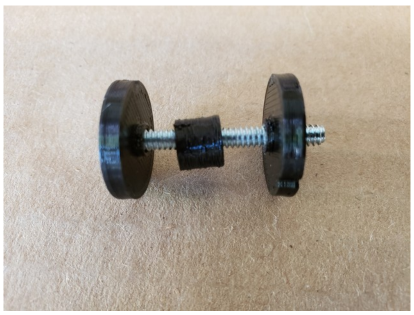
**Parts List:**

The printed parts for the motor consist of the two piece stator, two rotors, two rotor covers, and two side covers. There are also parts needed to build the motor consisting of the three-piece bobbin parts, assorted shims, four angle brackets and a terminal block.



**Coil Build:**

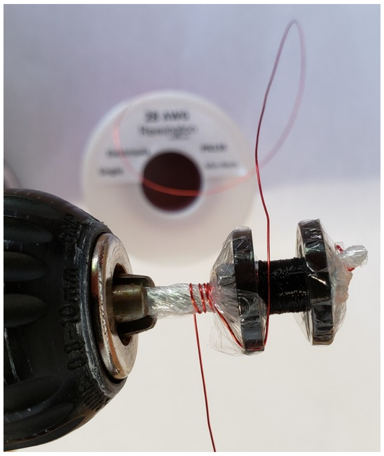
There are three parts to the coil bobbins. Two sides and the sacrificial core. Note that the sides have a lip on them that centers the core piece.



To assemble the bobbin use a 1.25” (one and a quarter inch) 6-32 machine screw and nut. Cut two squares of plastic wrap. Put one side piece on the screw. Punch a small hole in the center of the one of the plastic wrap squares and press it on the screw. Then put the center core on the screw. Put the second piece of plastic wrap on the screw, then the second side. Make sure the lip on the side is facing in. Then put the screw on and snug it up. (Not too tight.)

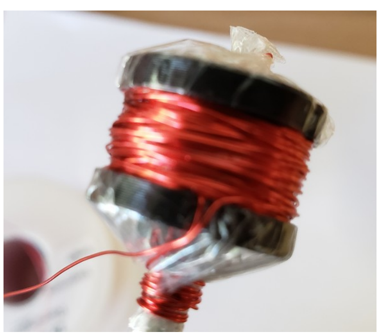
Pull the plastic wrap over each side piece. The side with the screw head can be tied back using a small piece of wire. (I use a piece of enamel wire.) The side with the nut can just be wrapped around the screw and secured in the drill. (Or can be tied if you are winding by hand.)

A length of about 6” should be pulled out for a lead. Place it in the notch on the side piece on the nut side of the bobbin and wrap it around the shaft of the screw.



The wire lead should be wrapped around the screw, by hand instead of using the drill motor, in the opposite direction of the drill rotation.

Start winding the coil very slowly. With care good results can be obtained. (But notice how bad mine are.) After winding two layers on the core piece, apply a few drops of glue. Then wind a few more layers and apply more glue. Continue winding and gluing until the edge of the bobbin is reached.



Do not let the winding exceed the diameter of the diameter of the coil sides. The sides are the exact size of the holes the coil will fit in on the stator.

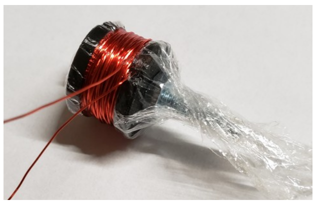
Run the wire though the slot. Measure a 6” lead. Carefully wrap the wire around the screw to secure the winding.

Apply several more drops of glue to the finished coil. You may need to run the drill while holding a piece of paper on it to smooth out the glue.

While the coils are drying the rotor and side covers can be built.

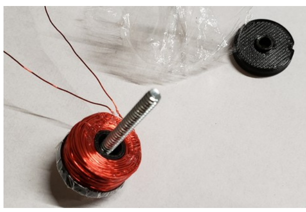
The coil can be removed from the drill and set to dry. Make sure to set the bobbin on the side and not on the windings or contaminates may be glued to the coil. (Like paper or the table...)

More coils can be wound and left to dry as a batch.

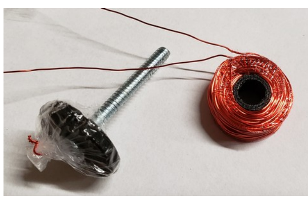


Removing the coils should go smoothly since the plastic wrap will keep the coil from being glued to the side pieces.

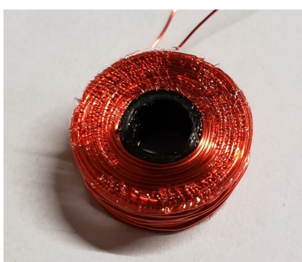
Most cryro glue (super glue) will dry in a few hours good enough to mess with. Carefully unwind the leads. (At this point you will understand what is meant by hand winding the first lead.)



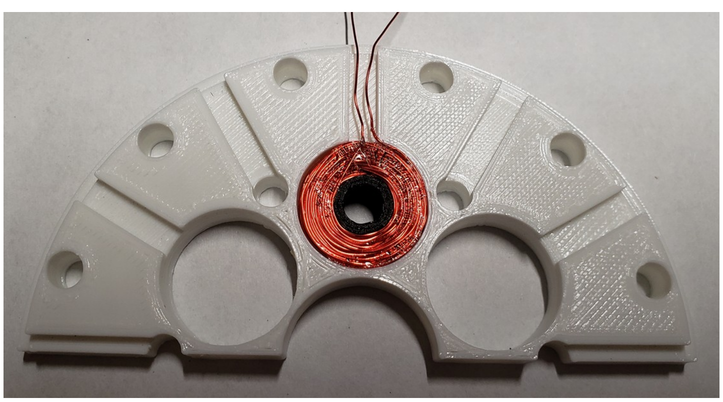
The nut can be removed and the side of the bobbin should be carefully removed.



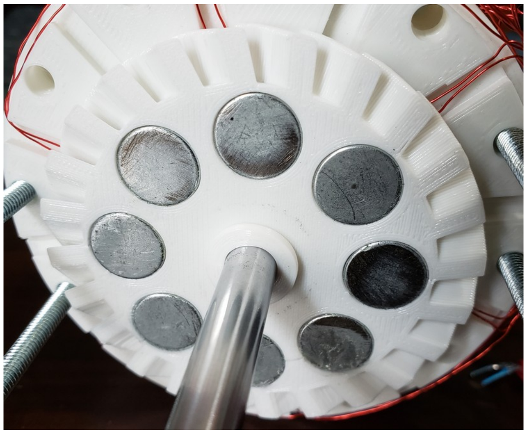
After removing the plastic, the coil should come off relatively easily. And you should be left with a very nice coil.



The coil should fit into the hole in the stator easily or with minimal pressure. If the coil is too tight and will not fit easily, the hole can be enlarged using a round file or carefully with a knife.  It is okay if the coil is a little small as the glue should fill the gaps and hold it in.



**Rotor Build:**



The magnets used in this are ½ x ¼ inch n32.
The shaft is 8mm and cut to 3 inches.

Care must be used when handling the magnets as they are strong and can damage things and pinch fingers quickly.

The magnets need to be laid out so that they have alternating polarity around the axis. Use a spare magnet to verify the polarity before gluing.

It’s easier to put in every other magnets with all poles directed in the same direction. Also, notice how in this photograph the magnets are crooked. It is best to build the rotor on a flat metal surface so the magnets will lay flat.

Make sure to put plastic wrap under the rotor as not to glue the rotor to the surface.

This rotor is on a metal cookie sheet with a piece of plastic wrap underneath it. Also there is a stiff piece of cardboard under the plastic so that after the magnets are glued, it will be easier to remove from the metal surface.

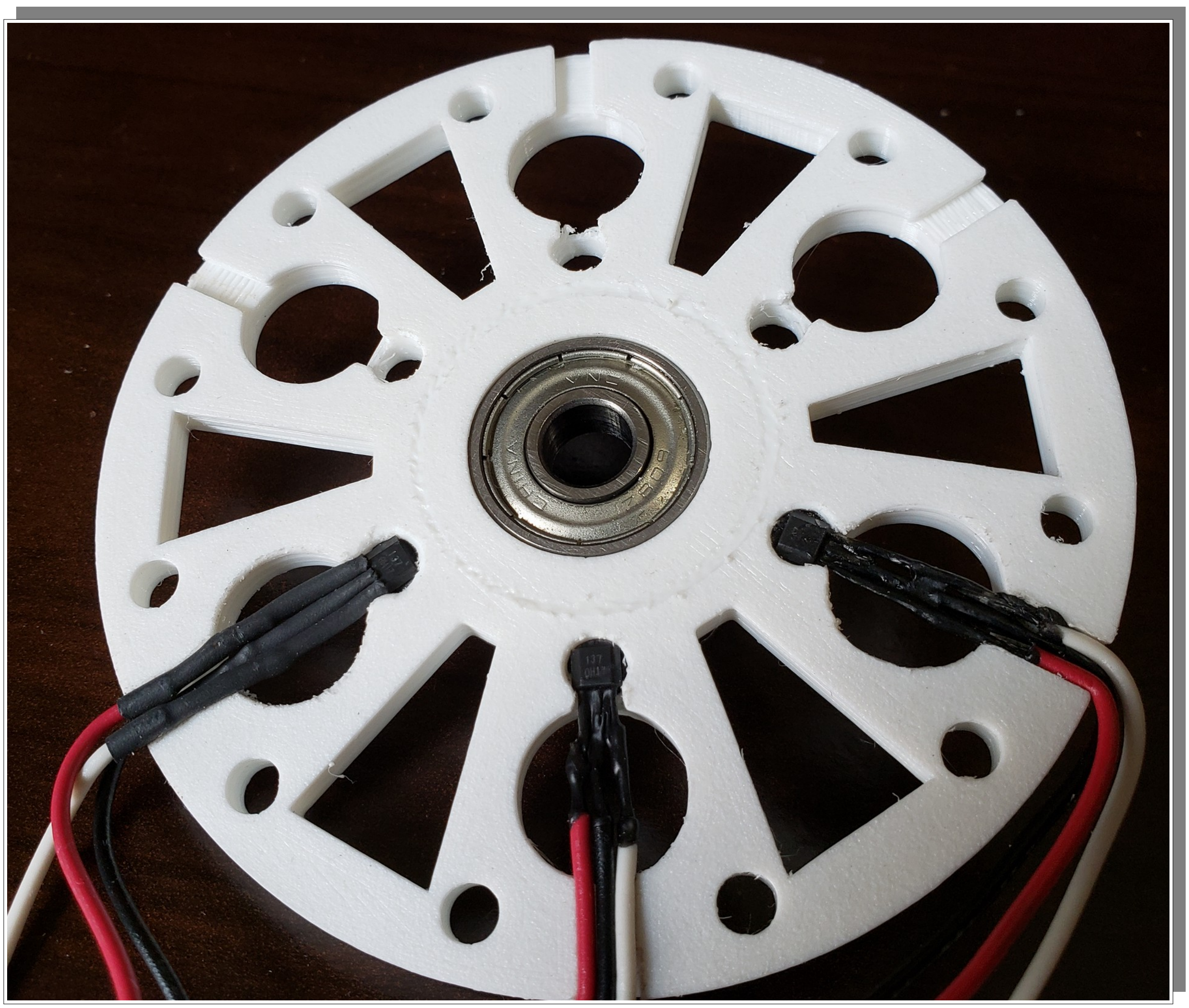
Apply glue around the edges of all the magnets so that it runs in between the magnet and rotor. Let the glue dry 24 hours before removing the rotor for best results.

You may want to place something heavy on top to hold it together tightly. Be sure to put a layer of plastic over the rotor first.

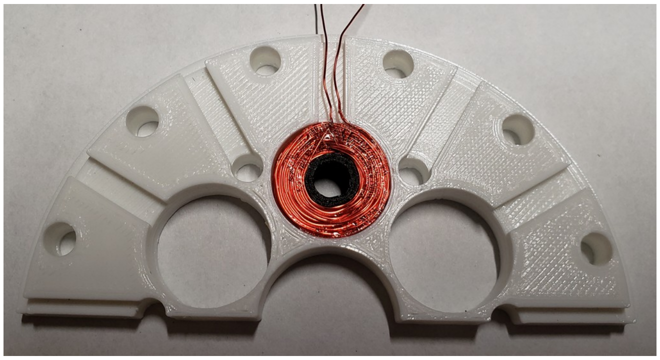
**Side Cover Build:**

The side cover needs to have the bearings pressed into them. The bearing have a 22mm outside diameter.

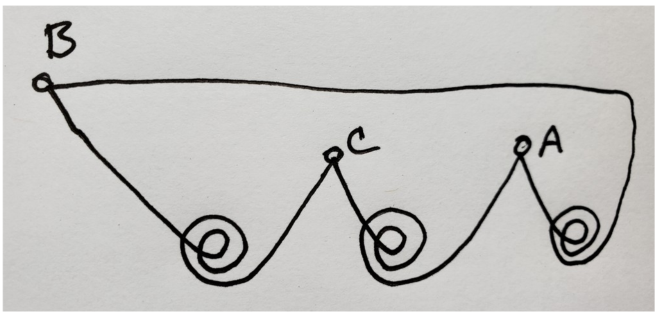
Three halls need to be mounted into one of the sides. Solder leads to the halls before mounting. The halls use little power so thinner wire can be used to make mounting easier. It is important that the halls are flat and all facing the same direction. There is writing on one side of the halls but it does not matter which way they are facing as long as they all have either writing all up or all down. Liquid tape can be used to glue the halls into place and insulate the connections. Color coding makes connecting the halls easier as each has a positive, a negative and an output. The three positive leads will be connected to the 5 volts from the controller, the three grounds will be connected to the ground on the controller and each output lead will connect to the corresponding hall A, B or C. This will be covered in more detail in the section describing connecting the motor to the controller.



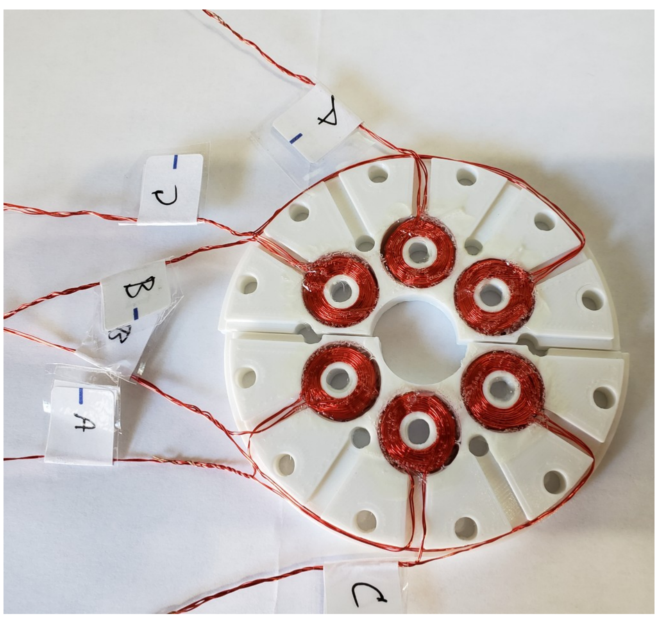
**Stator Build:**



Each coil should be positioned in the stator. Place the stator on plastic wrap and glue the coils in by using super glue dripping it between t edge of the coil and the stator.



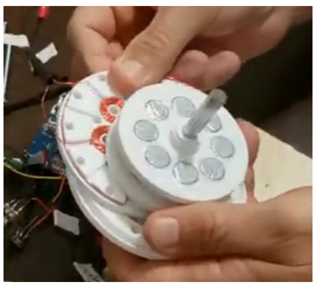

The wires should be connected as shown in the schematic.



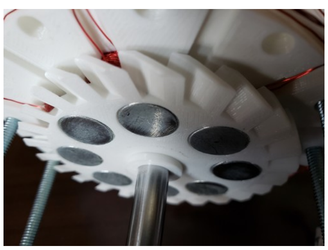
Both parts of the stator should be wired the same. Then the As, Bs and Cs connected together. The stator is split to make it easier to slide between the rotor and over the shaft.

**Motor Assembly:**

Carefully press the rotors on to the 8mm shaft. The shaft itself is about 3 inches long.



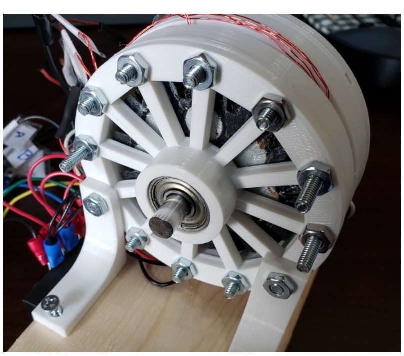
The 2mm shims can be used to make the space for the stator the correct size. Test to make sure the stator fits with about 1 mm on both sides so the magnets do not rub on the coils.

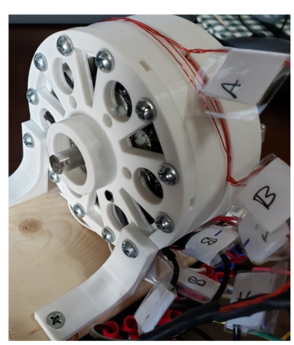


The shims are also used to space the rotor from the sides.

Here is a short quick (high speed) example of assembling and adjusting the motor coils and rotors. This is a duel stator coil so adjustments were a little more difficult than a single stator. I would suggest the first build be a single stator motor.

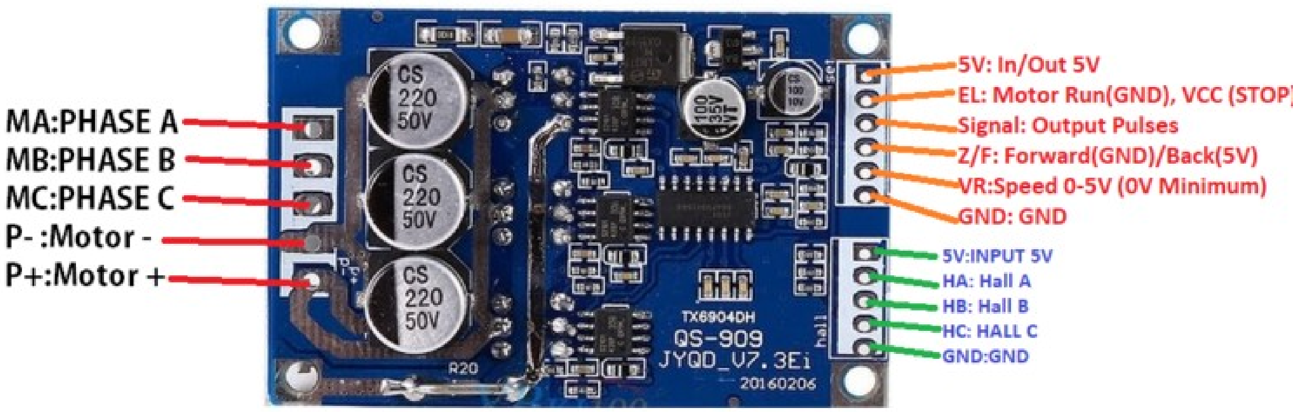
[https://www.youtube.com/watch?v=h7NTWatm6Ec](https://www.youtube.com/watch?v=h7NTWatm6Ec)



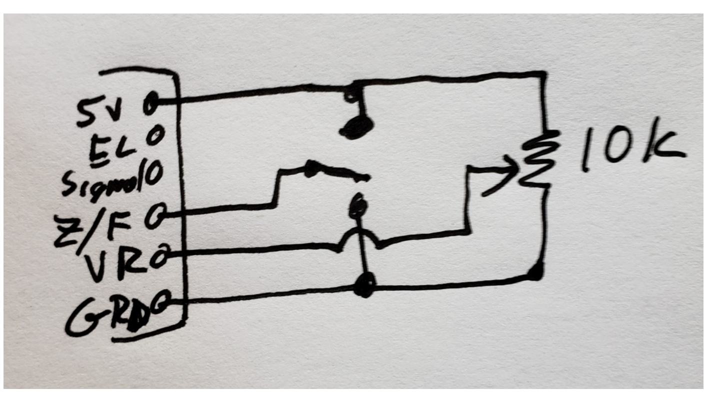


**Connecting to the Controller:**

The controller used in this build a an inexpensive JY01 controller found on ebay or aliexpress. It cost between $10 and $15. Some are rated at 350 watts at 36 volts and some are rated at 500 watts at 36 volts. The input can be 12 to 36 volts. All my test have been done with 12 volt lithium batteries. If you order a cheaper controller then it most likely will not have a heat sink for the MOSFETs and it is advised that if the motor is run over 60 watts that it should have a heat sink. The problem is that three MOSFETs have the input power as source and three have ground as source. This means that the metal tabs on the MOSFETS are not of the same voltage and an insulating material must be used to secure the heatsink. So it may be advisable to order the more expensive controller that has the heat sink mounted if you plan to run the motor at higher power than 60 watts.




P is the input for the power: 12 – 36 volts.
MA, MB, MC are the motor A, B, C connectors.
On the left side bottom are the 5 volt and ground connections for the hall transistors, along with the corresponding HA, HB, HC connections for the hall outputs.
On the top left the 5volts and the ground used for the 10k ohm potentiometer used for speed control and the two way switch used for forward and reverse direction.
The EL and Signal connections are not used in our application. The signal is a series of pulses that correspond to the motor speed and could be used to build a tachometer. The EL would be used for a switch connected to a brake (like on a bicycle) to stop the motor when the brake is applied.
The Z/F is reverse and forward pin that is connected to a switch to switch between ground and 5 volts.
The VR pin is connected to the varying pin on a 10k potentiometer.




This is a schematic of how the connections should be made. The switch can be a small micro switch but any single pole / single throw will work.

**Conclusion:**

There is a lot of information in this document. Unfortunately not everything can be included in this document. The operation of the BLDC motor requires a serious amount of study to get a good understanding of the subject. There are many good YouTube videos covering this.

One of the main reasons I have for building this motor is for learning BLDC controllers. Again there is a lot of information on YouTube showing different methods of building controllers. Most use motors recovered from computer disk drives. There are also many using hobby motors that are sensorless. Though sensorless motors do not use hall transistors, they still do require some feedback circuitry.

The whole point of this document is to make the subject of BLDC motors and controlling the motors more interesting and a lot less daunting. We are entering a new era of motor vehicle motivation methods and the BLDC motor is playing a large role in this. We need more people that can repair and maintain these devices and advance them beyond what they are now.

The motor described in this document has many features that should make it more adaptable and modifiable. First, there are several methods to increase power. In this document I have alluded to duel stators and multiple rotors. These motors can be compounded or stacked to create more power and it does not increase the size of the motor. Most modern motors require two complete motors to accomplish the same thing. Another technique is to replace the stator with a set of coils of higher power. As an example on this motor the coil is wound with 26 feet of 28 gauge wire. If the wire is cut in half and the two wires placed in parallel and wound together on the coil it will actually quadruple the power of the motor. This can be easily verified utilizing the calculations from above.